Lens × Block

World as Construction Kit

by
Jay Silver
B. Electrical Engineering, Georgia Tech (2002)
M. Phil. Internet Technology, Cambridge (2003)
M. Media Tech., M.I.T. (2008)

Submitted to the Program in Media Arts and Sciences
School of Architecture and Planning
In Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

at the

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September 2014

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Abstract

Purpose and meaning of the physical world can be re-assigned and re-made by individuals as they go rather than being pre-fixed by people who came before them. But this mindset is more rare than it should be if we want an empowered population full of creative powerful beings. So can we make special tools that *by design* help people to put into practice the mindset and actionable behavior that: The World is a Construction Kit? We can, and in fact people have already done so with some existing tools which I will present. Then, I will present several new digital construction kits with a focus on two, Drawdio and Makey Makey, that are designed to focus attention on the world *as* the construction kit. Rather than combining kit-parts that come in a box, participants take pieces of the world they live in and re-purpose and re-combine these everyday objects from their life.

I formalize this type of construction kit, explaining how it takes the constructive aspect of a traditional wooden block, and the world-transforming multiplicative aspect of the traditional looking glass lens, to make a block-and-lens-in-one, which I call a Constructive Lens. I consider traditional construction kits like LEGO, or kits that aren't necessarily thought of as "construction kits" per se, like Painting Kits: Brush/Paint/Canvas, and show how to transform these traditional construction kits, which offer their own pre-fixed components, to the realm where the world, that is the everyday objects in one's life, is instead acting as the components of the kit.

The ultimate goal of the thesis is to show how we can we make tools and activities, "*Constructive Lenses*," that, *by design*, catalyze:

re-seeing (lens) ***the everyday world*** as something we can re-make (block)

The thesis approaches this goal through a rich narrative with thick description of design studies and case studies, intended to experientially model the process of motivating, making, and deploying Constructive Lenses to hundreds of thousands of people.

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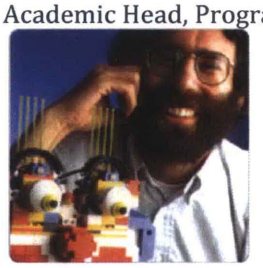

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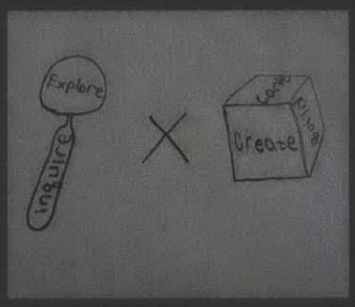
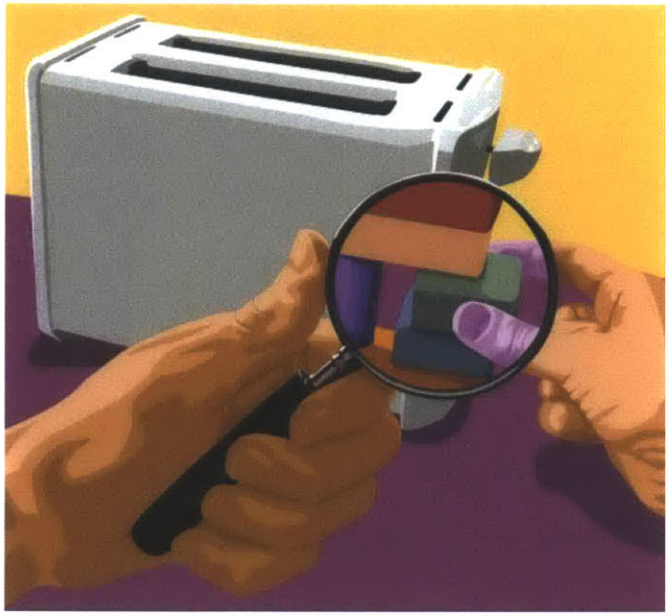
LENS × BLOCK



World as Construction Kit

Lens	*Block*
"By the means of Telescopes, there is nothing so far distant but may be represented to our view; and by the help of Microscopes, there is nothing so small, as to escape our inquiry; hence there is a new visible World **discovered** to the understanding." ~Hooke	"The smooth shapely maple blocks with which to build, the sense of which never afterwards leaves the fingers: so form became feeling. And the box with a mast to set upon it, on which to hang with string the maple cubes and spheres and triangles, revolving them to **discover** subordinate forms." ~Frank Lloyd Wright

Discovery can be defined as the process of **re-seeing the world** we live in as Hooke proposes. Discovery can be considered as **building something** as Wright suggests. What if we do both simultaneously, taking a lens and combining it with a block?



Constructive Lens

Presentation & Online

My gosh is it 2014 already? You can watch this thesis in video form online, and find any rewrites, book versions, or any future updated information at the following web address (if the internetz still exists):

http://1derful.org/phdthesis.php

Outline

The mindset that **the everyday world is malleable and I can take creative action on and with it** is crucial to solving future unknown problems [Louv, 2008, Last Child in the Woods] and to being able to playfully reimagine one's world and oneself [Silver, 2014, This Thesis Just Now Above this Line].

But what type of learning tools can be designed to directly catalyze such a world view**?**

As a teenager I was reading some literature reviews of Thoreau's writing, and someone, maybe it was Walt Whitman, said (paraphrased, as even the internet can't help me find this one): "Thoreau's writing has the quality of a good country western, he rides in on a horse and dust is flying everywhere, the rider shoots bullets in all directions, some hit their target, some miss, and some deflect and hit the rider, but what a show!"

The direction to which I strive in my writing style in this thesis shall be exactly as described. I want to put on a fantastic show, and risk death! Here it goes...

Although the MIT Registrar's office has rejected the concept formally, let it be known here that this thesis was written in collaboration with all beings, and specifically the co-author M. Nature, and for philosophical purposes I share credit and copyright and my PhD degree with M. Nature.

Summary

The Challenge
I am inspired by natives' abilities to see the world they live in as a construction kit: leaves, rocks, plants, are building blocks. What types of tools can we design to catalyze this action in our modern largely human-made environment? Traditional lenses, like magnifying glasses, make it more likely that we can see things we couldn't otherwise easily see. Traditional blocks, like wooden blocks, catalyze us to build structures, like castles, without which we would not as easily build. What is a metaphorical "lens" that helps us to see the pieces of the world we live in, pencils, houseplants, old cans, as if those things were metaphorical "building blocks" ready to be rearranged and remixed into new creations? What hardware or software, set of instructions, or other product or information or ritual, can we offer to human beings, that would catalyze a behavior of repurposing and remixing the everyday objects they live with to give those objects new meaning and new purpose, different from their original meaning and purpose? Just re-seeing is not enough for me, it is re-seeing the world as something that can be re-made that is the goal. This thesis addresses the challenge of:

designing tools that catalyze the direct action of re-making the everyday world

Example: Tatt-Blue
Tools that allow you to see your fingerprints or see the tiny molecules inside of a blueberry are just lenses; cool as those things may be, they don't systematically lead to direct creative action. Tools that result in you discovering your fingerprints and then deciding to dip them in smushed up blueberries and make an artistic image by stamping your finger print out onto your friend's face, are Constructive Lenses: you have seen your fingerprint as a stamping machine, you have seen blueberry as paint, and used them both to make the world a different place. You have taken fingerprints, you have taken blueberries, neither of whose explicit purpose is to create a tattoo-mask for your friend, and you have given them new purpose and made a tattoo-mask on your friend's face.

Example: Trash Tower
To build a tower out of blocks is to take creative action on the construction kit which is included in the box. To build a tower out of soda cans in the recycling bin is to see trash and soda cans in a new way, as if they were building blocks, and to take action on them to make something new.

Constructive Lenses
The soda cans are not pre-designated as a construction kit, they are the everyday world being repurposed to become a construction kit. The blueberries and fingerprints are not a construction kit in a box, they are the everyday world we live in being repurposed to become a construction kit. To create this new type of seeing is to catalyze the seeing of the World as Construction Kit. In doing so, the world starts to look reconfigurable, less fixed, more possibilitized. Purpose becomes internalized and re-determinable, fluid and changeable, not something cast down upon us by some official third party. Locus of control migrates more toward the internal, creative confidence grows with *direct experience* of making the world different, first small, then bigger. This is the goal of the "Constructive Lens" which is the result of crossing the Block with the Lens.

The thesis will go into great detail analyzing the effects of releasing two digital Constructive Lenses that I made into the wild: Drawdio and Makey Makey. By analyzing seven workshops, and looking at some cases of use in the wild, we will see specifically what types of re-making and re-purposing of the everyday world can happen using these two tools. Then I will offer folk wisdom and design guidelines for creating other types of Constructive Lenses with a special analysis of the role of the Sample Project Space.

I. Introduction

1. Motivation

Re-seeing (story about Nature Awareness)

Ten years ago, I went on a nature walk at Kenburn Orchards in Western Massachusetts. It was led by a 19-year-old named Connor. We made fire with sticks. I thought why are we doing this when we already know how to make fire with technology. He showed us some bird calls. He really cared about talking to the birds, and some of them answered back. I did not understand what the big deal was. What's the use in talking to birds? Then when we were walking on the trail he stopped me and pointed to the ground. Jay, you're not getting this Nature awareness thing, I seemed to hear him say subverbally, as he said, "I'll be back in 5 minutes. When I come back, tell me -- what do you see?" I crouched down low and looked at the mud on the ground that he was pointing to. I thought, well, I think it's mud. But there must be something more to it. Maybe he's playing a trick on me and it's actually poop. Or maybe I should look really close 'cause there are some bugs down there. I kept looking and looking and he came back and I felt confused and silly and I blurted out, "Is it mud?"

He put his finger to the ground and traced a shape on the ground... and then... I saw it! It was an animal foot print. A deer hoof he said. I spotted another, and soon another. I started to see lots of deer hooves. And then lots of animal prints of other sorts, birds and other mammals that I couldn't identify. But until he opened my eyes -- the prints were totally invisible.

I started to wonder, "What else am I not seeing that is right in front of me?"

I could stop right here, because this simple question, "What am I not seeing in my everyday life?" Is enough to keep me fascinated forever.

So I left the Nature walk and went back to Boston, but I wanted to learn more about seeing the invisible. I wanted to apply what I had learned in *nature* to the reality of my urban life in Boston.

Re-Making (Story about Staying with Natives)

A year later, I found myself staying with some Ngäbe (known to me at the time as Guaymí) natives in Costa Rica. I watched and worked with them for many days and they seemed to have an ability to see right through things. They saw the waterproof-ness and shape of the leaves and chose them carefully to put together their roofs. They made medicine out of other leaves by smushing them up and combining them with something from the ground, not sure what.

They knew which fibers were in different leaves that they could take out of the leaves and roll into strings and then weave bags. Take this palm frond apart and peel little threads off of it and then she would roll the threads together and make little thicker threads like strings and she would weave the strings together. As the materiality of this exact very bag formed before my eyes over those 3 days, the materiality of the way the world works, of reality, started to unravel in my mind.

Figure 1.1. The author, Jay Silver, holding a Ngäbe made bag which he watched a Ngäbe woman make over 3 days from nothing but naturally occurring materials in her environment. (Image taken by TED videographer)

Because I realized that this bag, and your trampoline, and your clothes, and your pencil sharpener, everything you have is made out of either a tree or a rock or something you dug out of the ground and did some process to, maybe a more complicated one, but still everything was made that way. So I had to start studying who is making these decisions? who is making these things that our world consists of? how do they make them? what stops people from making them?

I realized that they weren't just seeing the invisible, but they were making things out of the invisible. Making changes to the environment based on what they were seeing. They were re-making.

I returned to Boston again, and this time I started to try to see through the concrete in my environment just like the plants in the rain forest. What is inside of the sidewalk? Why do blades of grass grow through some cracks or are they causing the cracks? And, most importantly, how can I re-make my modern urban environment?

I started trying to see the invisible, and to turn it into something constructive. I joined a dumpster diving team. We called dumpsters "Urban Gardens" and we called dumpster diving "Urban harvesting." We would go out and collect the night's harvest, naked juice, bread, almonds, vegetables, etc. in a biodiesel farm truck that ran on reclaimed oil. Back in those days we got the used vegetable oil from a little restaurant called "the middle east" so the joke was that we got our oil from the middle east. We ran a community supported agriculture model of dumpster diving, which means we let people pay $3 for a box before we went out, then we'd split the harvest equally when we returned. We'd bring the food home and each person would get enough food for about one week.

I started to see harvestable food everywhere. I had done it! I had learned to re-see, and not only that, I could re-purpose "trash" to "food" and recreate my world.

Coalescing of Thesis and Research Questions

Starting 8 years ago, I began studying how people re-see the invisible in the modern urban environment and then re-make it. Over that time I introduced several tools into people's hands and watched how it affected their ability to re-see and re-make the world they live in. The rest of the thesis tells the story with my ups and downs, with a narrative that is based primarily around the development of 3 of these technologies:

- Camera for the Invisible
- Drawdio
- MaKey MaKey

The thesis discusses how these 3 tool-based experiences influenced the actions people took and the way people looked at the world. In the next section I'll introduce a name for the type of tool I'm aiming to create; it will be called a *Constructive Lens.* A Constructive Lens, as I'll explain, is designed to help people re-see (lens) and re-make (constructive) the everyday world they live in, both at the same time.

No thesis is a straight path, and many things happened that influenced my thought patterns toward focusing in on this thesis topic. I will now present 3 windows into my thought patterns that are meant to be representative of how I was thinking about
1) re-seeing,
2) re-making, and
3) theories around learning
This will allow the reader to glimpse into various resonant thoughts I had over and over again throughout the last 8 years and understand better where I am coming from and where I am motivated to head towards. This is how the thesis actually evolved in my mind nonlinearly.

Re-Seeing

After learning about the power of Nature Awareness, I started to learn more about the "Beginner's Mind" or how to see as if seeing for the first time. I started watching young and inexperienced people approach things, and I interviewed a number of Nature Awareness experts. Here is my favorite quote from the interviews, this quote comes from Erik Plakanis who is a professional Nature Awareness Guide at "A Walk in the Woods," as well as some photo outtakes from a video of some of my favorite moments in trying to see with a beginner's mind.

"You can read about it, you can see it on TV, you can hear about it, you can be lectured about it. But when you can take a stethoscope in the spring, and put it on the outer bark of a tree, and you can hear the pulse of that sap being pulled up, you know water being pulled up from the ground, that sap pumping up rhythmically up until the branches until the buds unfold."

I would also simply observe beginners of all sorts looking at things for the first time, including adults, but more often babies and children.

Here is my son interacting with snow and then pollen for the first time ever:

It's inspiring to me to both watch his reactions and try to imagine his mindstate: "What is this for? What does it feel like? What can I do with it? What happens when I do this with it? Why does it move and feel like that? What is it made of? Where did it come from? In the mind of a beginner, anything is possible.

Window Into My Thoughts 1.1. An excerpt from an interview I conducted with a Nature Awareness Guide and some photos of my son experiencing various phenomena for the first time ever.

Re-Making

Similarly to the above I would look out in my everyday life for examples of ways I could take re-seeing to a new level and turn it into re-making and re-purposing:

I was inspired by the artist Andy Goldsworthy:

(images reproduced from Andy Goldsworthy)

The image on the left is a photo Andy Goldsworthy took of a bunch of leaves. Of course they didn't just happen that way. Andy goes into nature with nothing but his hands and clothes and a camera and rearranges only what he finds to make some new aesthetic statement. On the left, he sorted the leaves by hue very carefully to give the appearance of a perfect hue fade. That was a photo I took out of one of his books. On the right is a freeze frame from his movie "Rivers and Tides." He comes onto the beach and breaks icicles from the rocks. He finds a stone that is bowl shaped and fills it with sea water. All this before the sun rises. Then he melts an icicle with the warmth of his breath, wets the edge of it with seawater, and then holds it onto his structure so it refreezes into the location he wants to (the air is well under 32 degrees). As he is building it's a race against the clock because when the sun rises the whole sculpture starts to melt. Seen above is his third attempt on the third morning. Each time when he fails he is so disappointed it's beautiful. So on this third attempt he gets the whole icicle sculpture modeling the shape of a river swirling through a stone built just as the sun is coming up. The icicles in this scene are backlit by the sun. He finishes, and then watches happily as the sun melts away the successful sculpture.

I wondered if you could take Andy's ideas and have teens work with it. Can everyone walk into nature and repurpose what they find? I took a group of teens at a camp called "Not Back to School Camp" into the woods by a stream.

I showed them some Andy Goldsworthy art books, and set them off. First I said to take 5 minutes and form some simple geometry out of what you find. Here's what they did:



On the left is an oak leaf shape made out of other oak leaves, a sort of fractal meta-oak-leaf. In the middle is a leaf tied to a stick with a blade of grass. On the right is a triangle in progress being made out of sticks underneath a flowing stream.

Then we launched into full project mode for one hour to make something beautiful. Here's what happened after 1 hour:





On the left is a wavy river-like shape made out of the negative space of some leaves. Top left is a wreath with a hue fade made by sorting leaves. On the top right is some stark contrast provided by birch bark striped across decaying matter. Bottom right is a mushroom with sticks and leaves stuck into it. And bottom left is called "Fire" and is a bunch of sticks and leaves stuck in between two trees. Someone asked "how did you get the sticks to hold up?" The creator answered "I don't know but I can show you after." The reply represents a sort of bodily and material intuition that can't yet be verbalized. To not know is to leave space for possibility. To do things the way you are supposed to is to suppose that other ways are not possible.

I tried in my own life to see if I could find little moments to repurpose my own "modern nature," the stuff of my everyday surroundings from animals and plants all the way to even human-made artifacts and structures.

One day at Whole Foods in Cambridge I was going up an escalator and dropped an M&M:


On the left you can see the M&M it just rolled and rolled against the little forks at the top of the escalator as wave after wave of metallic stair pushed it along but the forks held it back from going over the bump. While this could be viewed as an accident and time to move along, I was thinking "what is this escalator really? Maybe it's an M&M surf board. What else can I put down on this surfboard?" And I threw down what I had in my pockets, and that's why you see the chapstick over on the right, a

beautiful cylindrical body spinning to keep up with the speed of its new chapstick-treadmill.

Out in the yard one day there were some flies and we were running through them. They were the kind that hover in place and when you run through they move out of your way:

My son was screaming and I noticed that the flies were moving whenever he would scream. We all started "voice controlling" the flies. The frame on the right is from a video I took of them responding to my voice. The frame on the left is after I decided this was a moment to see what those flies could be. I took out a portable speaker and played them a Black Eyed Peas song from my phone. The flies moved to the beat and became a form of graphics equaliser display as they would go up with rising pitches, down with lowering pitches and speed up or slow down in proportion to how high or low pitch the sounds were, and of course they would respond through time as the sounds came out.

Window Into My Thoughts 1.2. Examples of experimenting with re-making the world in my everyday life

Theories around Learning

These ideas about re-seeing and re-making were overlaid upon a landscape of reading about learning theorists. The theories of my favorite authors mixed with my own theories led me to have daydreaming sessions about human potential. Here's one of the thought patterns influenced by learning theorist Ivan Illich, one of 8 or more important "learning saints" in my personal cosmology, with more of the "learning saints" listed at the bottom:

Thoughts on Malleability and Modernized Poverty
Is the world malleable? If so, whose hands are bestowed with the magic of forming and reforming the world's parts and their relationships? What process did those people go through in order to have the special power of creative action? How does the perceived malleability of the world affect one's own concept of the malleability of mind, thoughts, and beliefs?

There have always been obstacles to taking creative action (Banaji, Cranmer, & Perrotta, 2010) on the world, reforming it, repurposing it, and bringing meaning and inspiration from inside the mind to manifestation outside. There are problems of skill, confidence, motivation, etc. These are timeless. The same industrialized modern situation that leads to the proliferation of available creation materials is also leading to an even larger proliferation of pre-created solutions, dulling the capacity for everyday innovation.

Ivan Illich has a name for the inability to act creatively in the industrialized world: Modernized Poverty (Illich, 1971, DeSchooling Society). He defines it explicitly

> *Modernized poverty appears when the intensity of market dependence reaches a certain threshold. Subjectively, it is the experience of frustrating affluence which occurs in persons mutilated by their overwhelming reliance on the riches of industrial productivity. Simply, it deprives those affected by it of their freedom and power to act autonomously, to live creatively; it confines them to survival through being plugged into market relations.*

We need a way of simultaneously acting-and-seeing which bypasses our industrialized affluence and renews our sense of self-reliant unadulterated creative capacity.

Here are other Radical Learning Philosophers that have motivated my work:

Window Into My Thoughts 1.3. An example of my underlying motivations fueled by revolutionary learning philosophers. From left to right: Eleanor Duckworth, Rudolf Steiner, Ivan Illich, Maria Montessori, John Taylor Gatto, Paulo Freire, Grace Llewellyn, Larry Harvey.

Research Questions

Based on my 8 years of experimenting and daydreaming, I started asking these questions which are now the central questions posed in this thesis:

a) What are some examples of Constructive Lenses and their applications?

There is currently no wide analysis of Constructive Lenses. I will introduce two well-played out, solid examples of such a tool
- in many different situations
- over a long time
- with many people
- both in the wild and in facilitated workshops

I will discuss not just the technical features of the two tools, but also the historical genesis in thick description [Geertz, In the Interpretation of Cultures 1973, Thick Description: Toward an Interpretive Theory of Culture]. I will also discuss other existing tools, some made by myself and collaborators and some made by others, that could be called Constructive Lenses, and how to change existing tools to become Constructive Lenses.

b) What kind of re-purposing can people do when you put Constructive Lenses in their hands?

How do Constructive Lenses affect the workflow and re-purposing behaviors, as well as the thinking and learning, of people like Beginners? Experts? Academics? Professionals? What do these people do with Constructive Lenses out in the wild and in workshops? I will run and display the results of 9 workshops and show results of use in the wild including interviews and photos.

c) What are the design principles to guide the development of Constructive Lenses?

Are there principles that help tie together the design of all these different tools? What design approaches are the most successful historically at generating tools that are as close as possible to being Constructive Lenses? What intentions are likely to lead to good Constructive Lens designs? If others were to try to design Constructive Lenses, what set of wisdom should they keep in mind? I will offer dozens of tips and generative constructs to help others and my future self form Constructive Lenses. Hopefully the advice is applicable to design in general but especially creative tools and specifically Constructive Lenses.

2. Background

The Success and Failure of Camera for the Invisible

On my quest to learn how other people catalyze and teach re-seeing and re-making the world they live in, I found out about professor Anne Spirn, who was researching the hidden urban nature in modern society with her students. Here is the cover of her book:

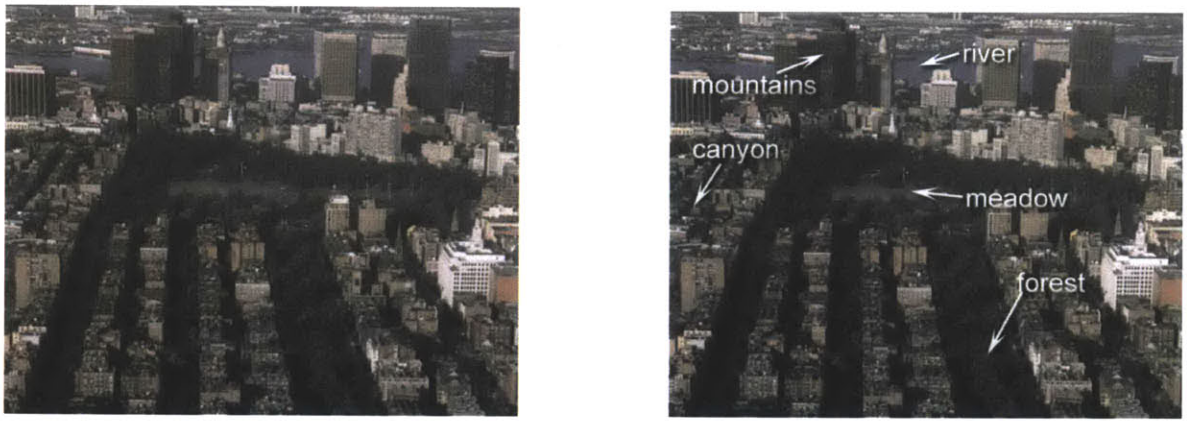


Figure.2.1. Left. Anne Spirn's book cover "Granite Garden." Right. My markup of Anne Spirn's book cover to show one macro perspective on how the city we live in can be thought of as urban nature. (Image reproduced from book cover of Granite Garden by Anne Spirn)

Anne's students' use regular cameras as one of their main tools. I interviewed a number of students.

One of her students had drawn this diagram.

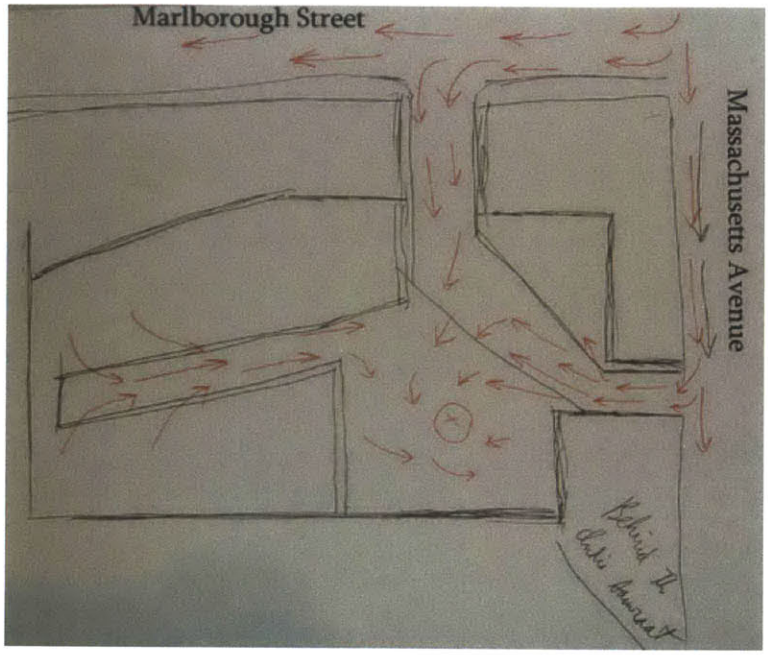


Figure 2.2. Map of wind near the intersection of Mass Ave. and Marlborough St. in Boston. (Image reproduced from project by Anne Sprin's student)

This diagram was made by the student sticking a licked finger in the air and measuring the wind speed and direction at each point on the street intersection and inward into the courtyard. But what was at the circle with the "X" in it? This:

Figure 2.3. Picture of a pile of debris in the courtyard of the intersection in Figure 2.2 at the circle with the "X" in it. (image reproduced from project by Anne Spirn's student)

Ahah! Nothing! And Everything! At the same time. A pile of debris. What a powerful map and photograph. I thought, what if we could take "pictures" of invisible phenomena (like wind) with a special "camera" and

explore the hidden dimensions of the urban natural environment systematically?

I started to wonder how you could build a "camera for the invisible" for taking pictures of these types of invisible situations, to help people re-see.

That same day I did a quick mockup. I built 4 temperature-to-color sensors. These lights show a temperature gradient from hot to cold emanating from the laptop.

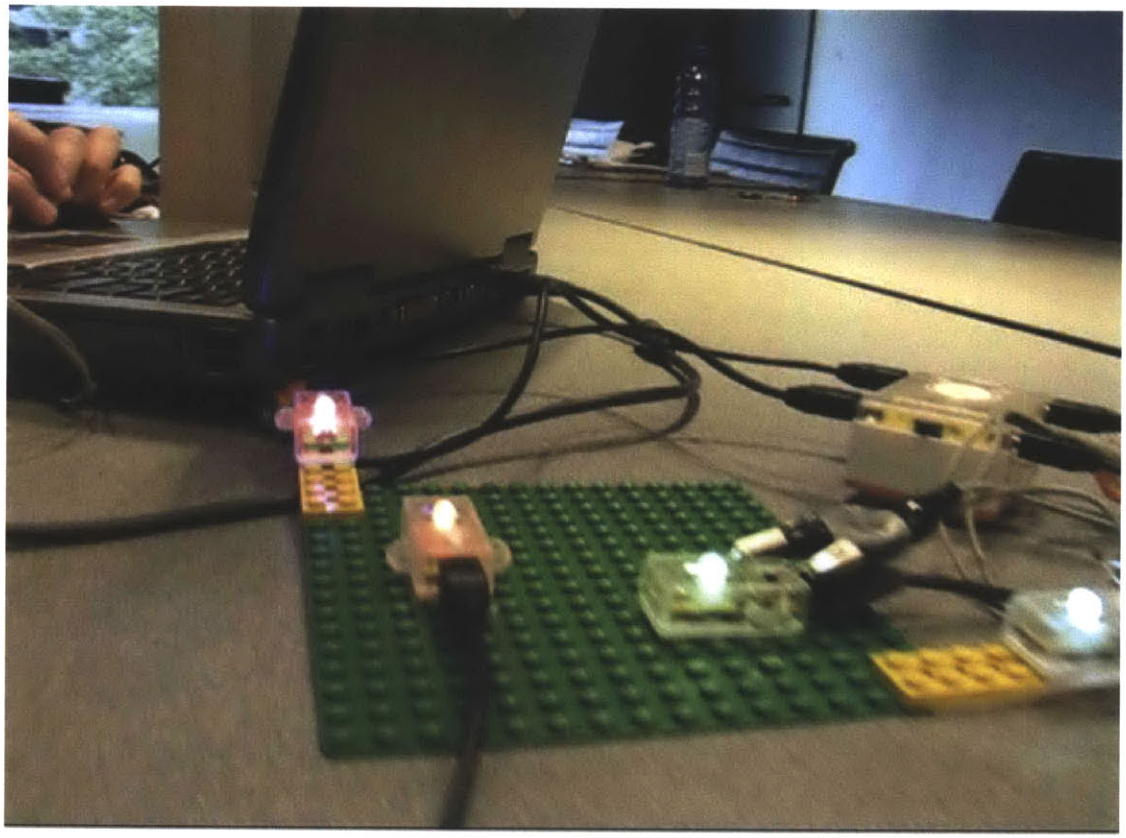


Figure.2.4. Four temperature to color converter modules spread out on a table next to a hot laptop in a cold room. Red represents the hottest temperature and blue the coldest.

Then I started a 6-month project to build a Camera for the Invisible. That is a camera that lets you sense non-visible aspects of the environment with sensors/lenses and transform those non-sensory phenomena into some form of phenomena that can be sensed by a human with actuators/viewfinders.

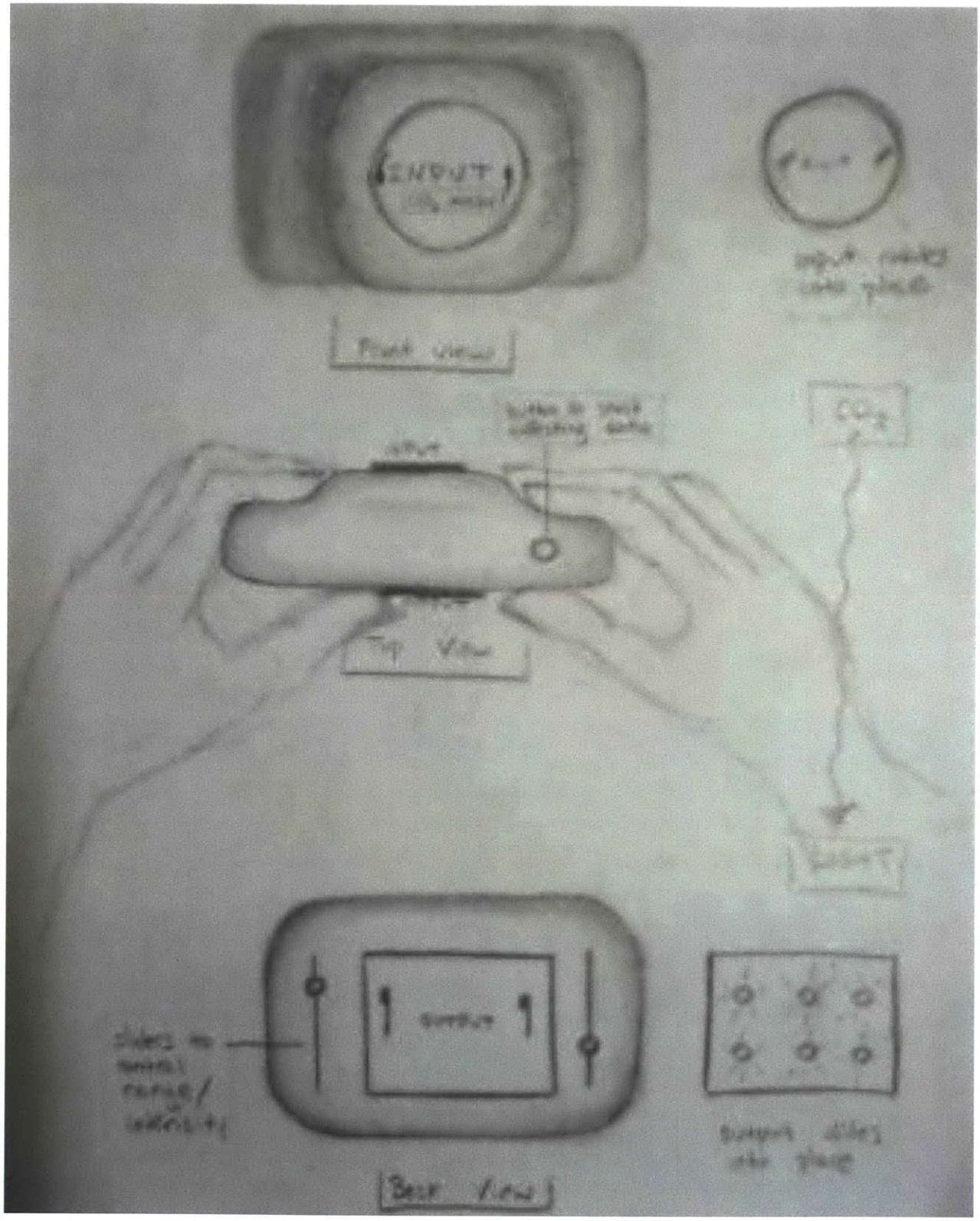


Figure 2.5. A diagram predicting the camera form factor of the Camera for the Invisible.

It let you see carbon dioxide as a color, or listen to temperature as a sound, or feel brightness as a vibration.

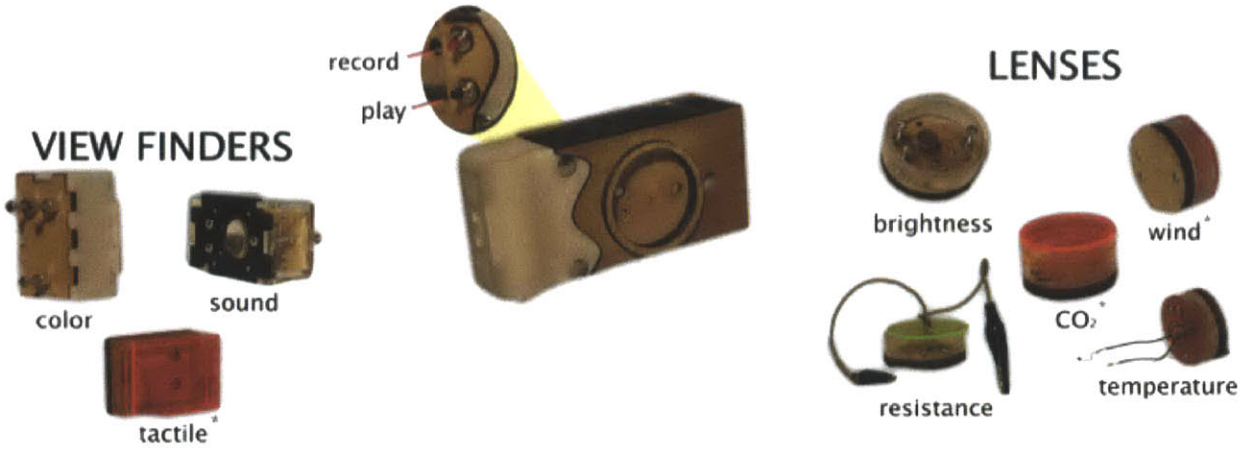


Figure 2.6. Camera for the Invisible prototype laid out with all its lenses and viewfinders, along with a peek to the back interface with two buttons.

Read in detail about the Camera for the Invisible in my Master's Thesis [Silver, 2008, Camera for the Invisible]

The Camera for the Invisible had "lenses" (lens-shaped sensors) and "viewfinders" (viewfinder shaped actuators) that you could mix and match.

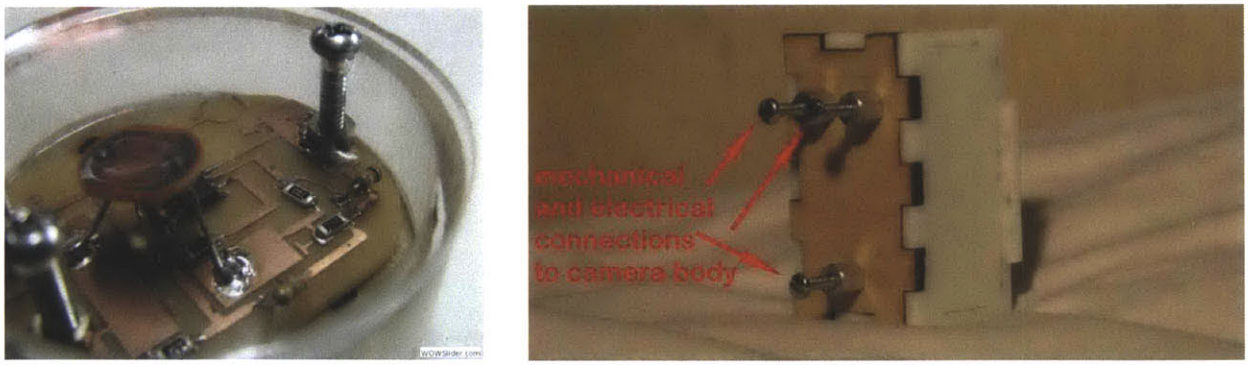


Figure 2.7. A lens (left) and viewfinder (right) example that work with Camera for the Invisible.

For example, you could have a temperature lens (temperature sensor on the input) and a color viewfinder (colored LED on the output) which would give you a temperature-to-color camera setup. Or you could have a carbon dioxide lens, and a sound viewfinder, which would let you hear carbon monoxide. Or an electrical resistance lens and a tactile viewfinder, which lets you feel the resistance of a material as a vibration on your fingers.

Because synesthesia is a condition where stimulation of one sense in a person automatically triggers the stimulation of another sense (for example hearing a sound makes someone think of a color), I sometimes refer to the lens and viewfinder combination as "Synesthetic Pairs."

The camera was made of a natural cherry wood body with holes for routing wires from the hand-soldered motherboard

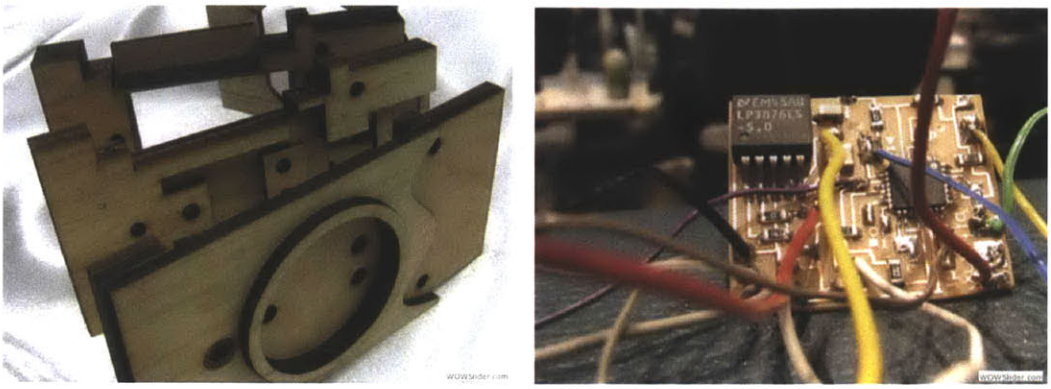


Figure 2.8. Left. Cherry Wood laser cut layers of the camera body splayed out. Design lead was UROP Melodia Kao. Right. The motherboard of the camera hand soldered and CnC milled guided "by hand" on fiber backed copper.

It could be used to explore any urban natural environment to re-see the invisible aspects, such as this sewer cover's temperature in different spots, re-seen as color in the viewfinder.

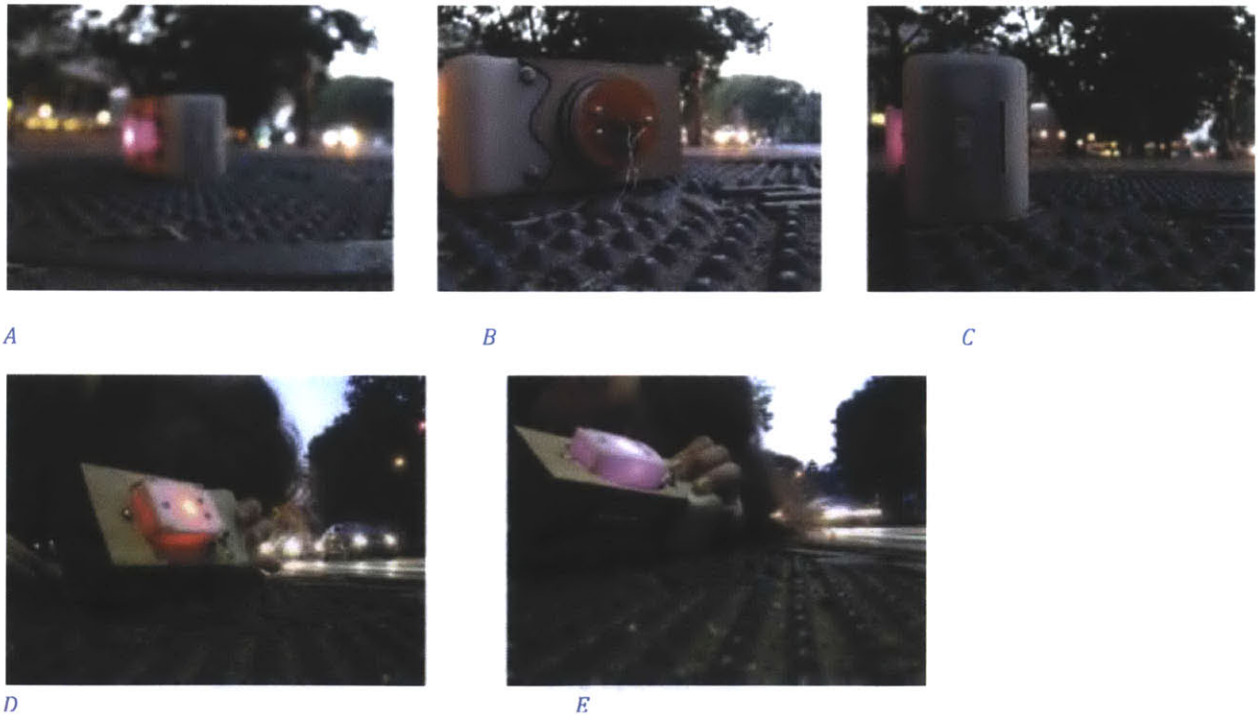


Figure 2.9. Camera for the Invisible with a temperature lens and a color viewfinder used to explore a range of temperatures on a cold day at various parts of the cover of a sewer grating.

I tried it out with several people, one of them a 15-year-old teenager.

Figure 2.10. Site for Camera for the Invisible Study with Teen

She was able to make some discoveries (see master's thesis for details) about shadows and clouds, her fingerprints, and the temperature and electrical conductivity of her body. But when I asked her what she would do with those discoveries in the future she said she didn't know.

That was important. She had investigated electricity indoors, sound and light phenomena outside, resistance and skin-pattern concepts within herself, and noted seeing the world in a new way. *But*, in relation to action after the discovery events, there was no noticeable difference in her willingness to *do* something, to *change* the world, to *make* something new.

So I set out to build a new version of the Camera for the Invisible. A simpler one that encouraged people to look at things anew (*re-see*), AND build something out of what they discovered (*re-purpose* and/or *re-create*).

In fact, when I first started researching the Camera for the Invisible, it had consisted of simpler pairings that were more like blocks and less like a camera. In fact when I had introduced the camera concept above, I skipped some of the story that had come before. Let's work backwards from the camera concept point in the story to see where the camera diverged from.

The camera concept came only after an initial exploration that consisted of simple A to B sensory transformative pairs. The design immediately preceding the camera looked like these "railroad blocks":

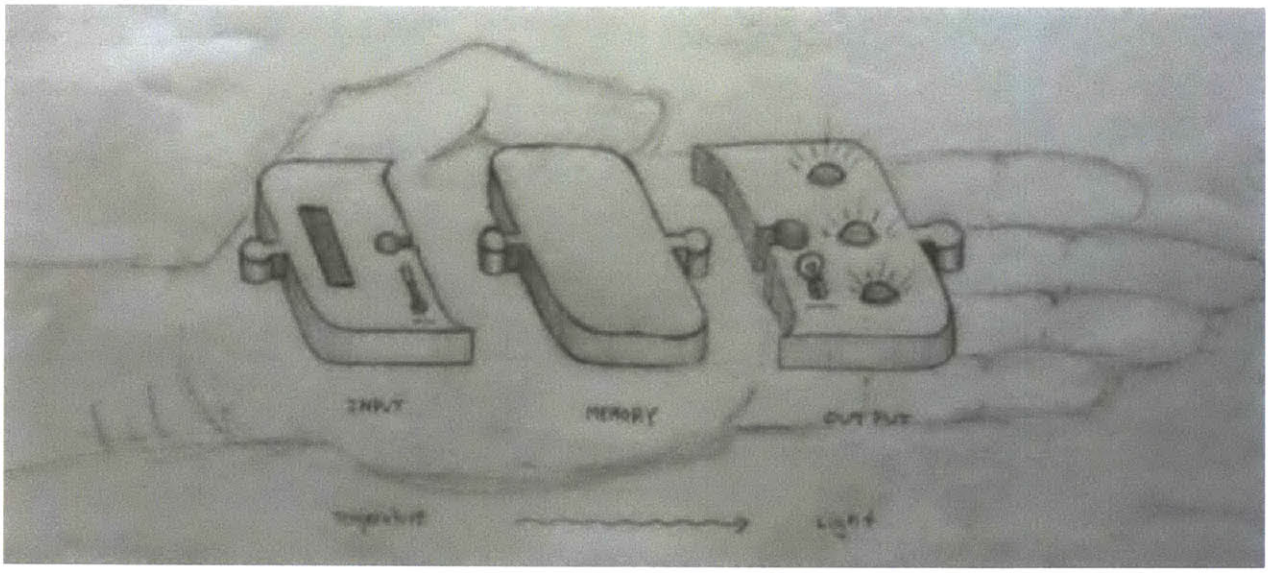


Figure 2.11. An example of input/output pair temperature to light

Working backwards from the blocks simulation, I had a working Scratch software simulation of these sensor pairs (again more like blocks):

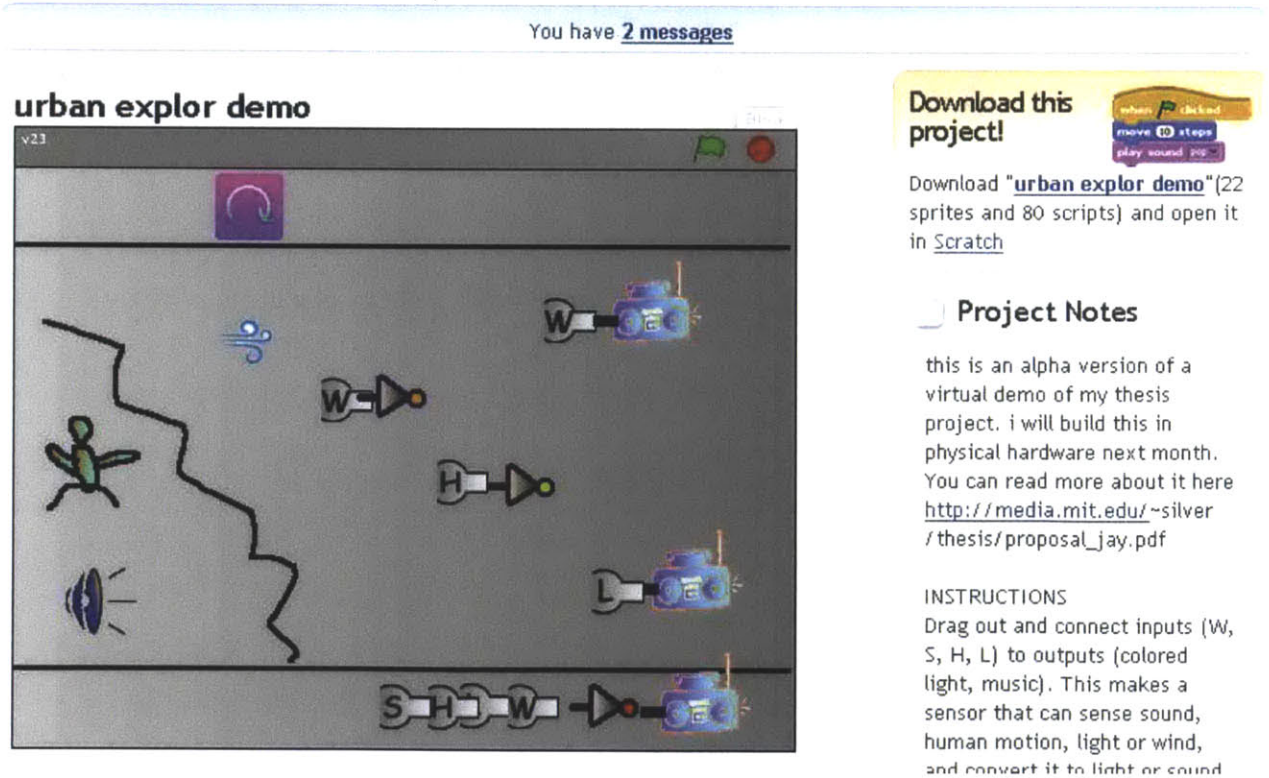


Figure 2.12. Scratch simulation of input output pairs with simulated proximity to various natural phenomena.

Again stepping backwards, this software was based on this abstract diagram, of an input/output pairing system that I drew:

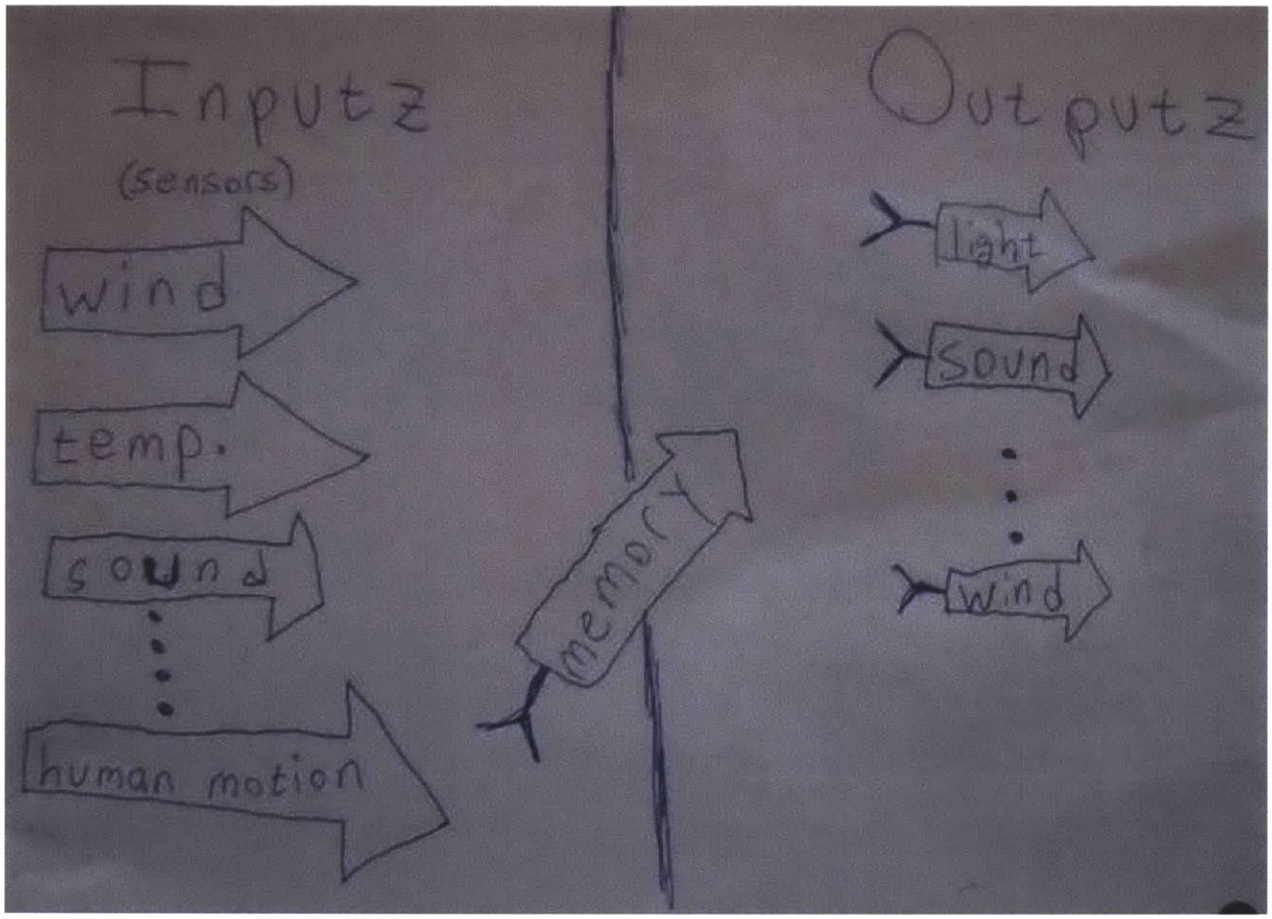


Figure 2.13. Input/Output theoretical diagram

Today a diagram like this is even more familiar in the marketplace of products with examples such as Little Bits in existence:

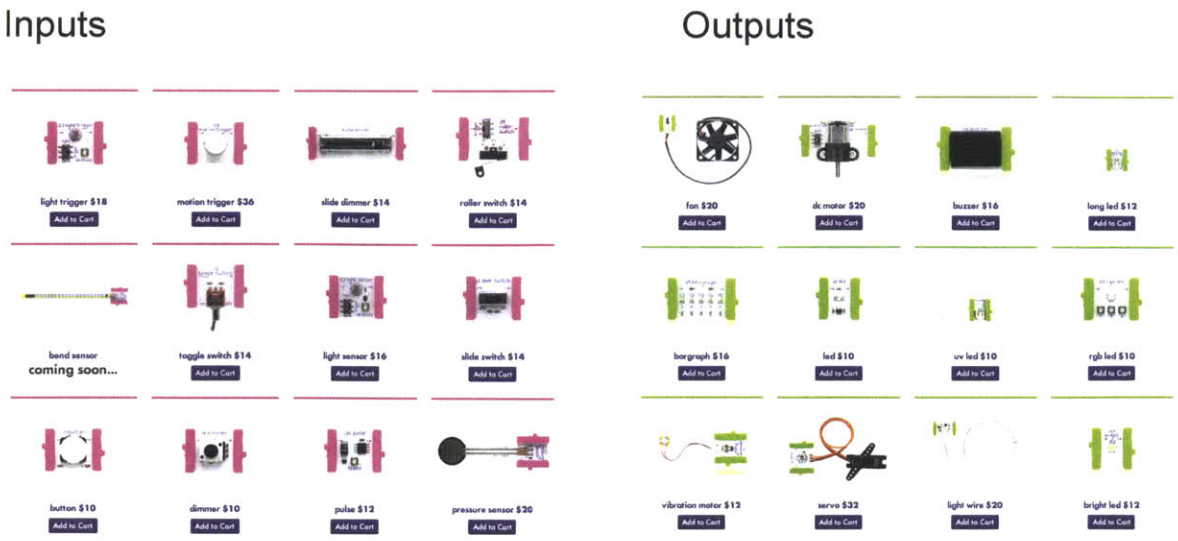


Figure 2.14. Little Bits set of Inputs and outputs. (Images reproduced from littlebits.cc)

Inputs are on the left in pink, outputs are on the right in green, and you can snap the two together with magnetic connectors and have input/output pairs.

Note it is no surprise that around this time there were many input output-sensory transformative kits, and there is also a history of such thinking before this. I was working in the Cube at the Media Lab, which was a repurposed theater space that held Lifelong Kindergarten and a class called How to Make Almost Anything, both of which were hotbeds of kit ideas that had sensors paired with actuators. Lifelong Kindergarten is the group that LEGO Mindstorms and PicoCrickets came out of, both of which were commercially available microcontroller-based kits that let you very easily pair inputs and outputs with computation in between. Flow Blocks was also created here, which allowed you to very easily and magnetically snap computation blocks together and then break them apart. So this was the location where many such input/output easy-access kits were created. Furthermore, the founder of Little Bits was also working in the Cube in a group unrelated to education prior to starting Little Bits, so she would have most likely been peripherally influenced by these types of projects.

What is interesting, however, is the breakthrough I had that was a bit counterintuitive.

Simplify and Constrain the Synesthetic Input/Output Pairs

I veered away from the mix-and-match inputs/outputs model. You see, the results of my study of Camera for the Invisible was that it was great as a *lens* but terrible at spurring creative/constructive *action*. Too much time was spent on the mixing and matching. While plugging blocks and components into each other might be great for "engineering education" we run the risk of using too much valuable energy/attention on the blocks part if the goal is: to focus the participant's attention on the everyday objects and how those can be re-made.

In an attempt to focus and preserve the valuable user attention and cognition, I decided it was necessary to simplify the mode of interaction to the point where the tool itself is boring unless multiplied on the environment/world. This simultaneously also simplifies the cognitive load of understanding the tool so more time can be spent in flow with objects the user already has a long history with in the physical world.

My final categorization scheme of tools, as inspired by Camera for the Invisible, was a scheme that positioned Instruments, People, and Environments relative to each other in typical use cases. In this analysis the camera was positioned like this:

Figure 2.15. Model showing physical relationship of a scientific instrument when a person uses it to study and interact with the environment

Thus making it a "PIE" use scenario, with the instrument coming right in between the environment and the person. I then went on to consider a dozen or so other configurations, and I proposed that for putting people into direct contact with the environment the best configuration would look more like this:

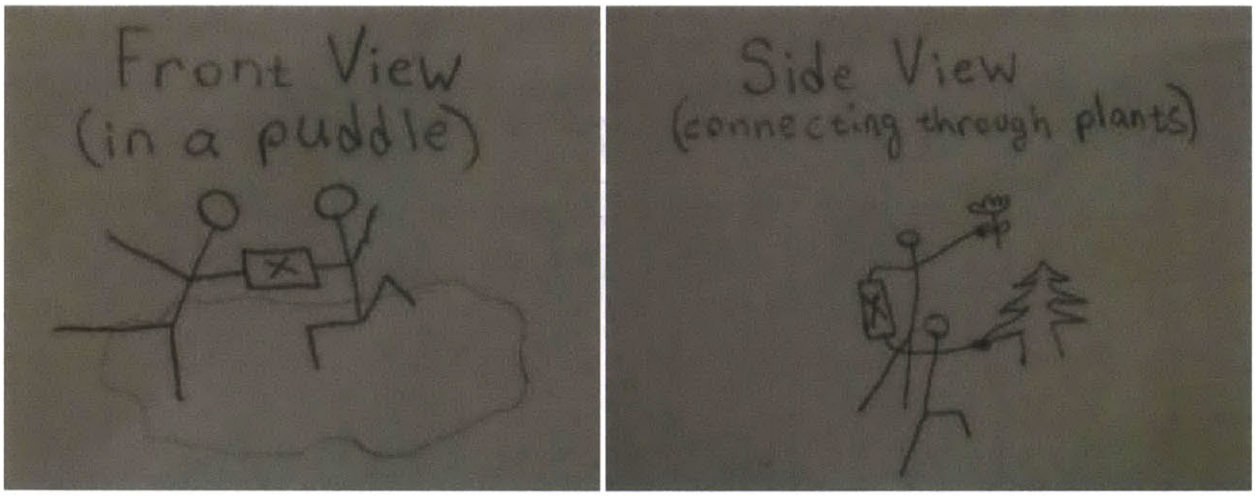


Figure 2.16. The instrument in this diagram is represented by a box with an "x" on it. Left: Dubbed "Puddle Jumper" this is an instrument which reacts when two people go jump in a puddle while holding the instrument. Right: Dubbed "Flower Petter", this instrument reacts when two people touch elements of nature while holding the instrument.

In this configuration the instrument (represented in the above drawings by a box with an "x" inside) puts the person directly into contact with the environment by nature of its use. In the figure on the left, to use the instrument the feet must jump into and come into contact directly with the water in the puddle. In the figure on the right, the people must touch the plants in their environment with the skin on their fingers as a forcing function of the instrument. This makes the instrument in this case in a configuration of "Instrument, Person, Environment" or "IPE"

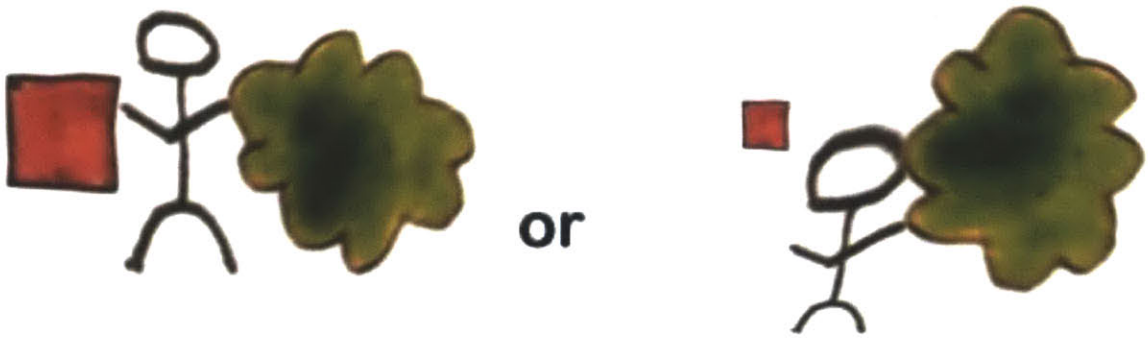


Figure 2.17. Diagram of person coming into contact with the environment with the instrument out of the way

Thus bringing the person into direct contact as much as possible with the environment, and the instrument is placed more out of the way. This was one step closer to the stated goal of my master's thesis of instrument transcendance.

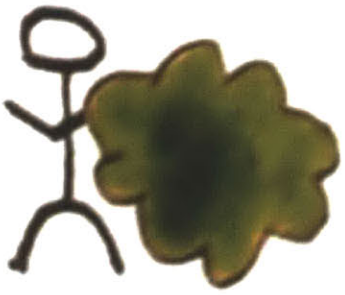


Figure 2.18. Diagram of instrument transcendance

In this diagram, the person is in direct contact with the world they live in without the need for the instrument.

The IPE configuration, which puts the person in direct contact with the environment, was the model that came before the idea that people should directly reconfigure the world they live in. That is to say, coming into contact with the environment was just one step before making changes with the environment in my mind as a designer. As explained earlier and to be explained more in Chapter 3, the Constructive Lens is the name I am giving to a tool that helps someone to see the world as something they can and want to reconfigure. The title of the thesis, "LENS X BLOCK," is the first half of a formula:

LENS X BLOCK = Constructive Lens

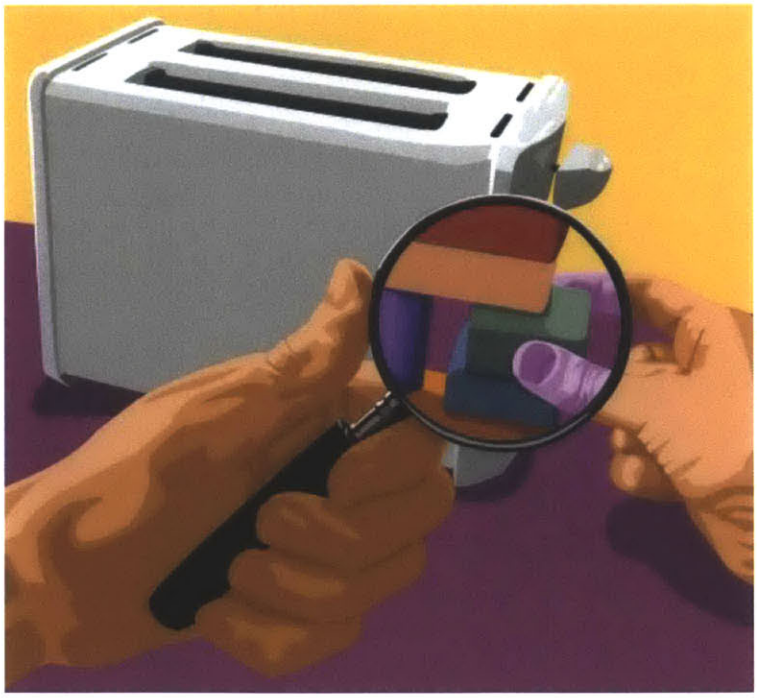


Figure 2.19. An illustrative but fictional depiction of a "Constructive Lens" that makes any everyday object look like it's made of blocks that can be rearranged. In reality, a Constructive Lens must also motivate you to build something interesting not just turn objects into blocks, but visually this image is meant to impart the idea that, "When a Constructive Lens is in your hands, the world

you live in starts to look like something that is ready to be re-seen and re-made, as if it were made of wooden blocks." (Image created by Sophie Diehl under guidance of Jay Silver)

The instrument transcendance depicted above, with the person directly reconfiguring and reconstructing the world they live in, could be seen as the ultimate goal of the tools evangelized in this thesis. When this viewpoint, that the world is something that can and should be reconfigured, is held over long periods of time, creative action becomes a mindset and a way of seeing. When a mindset of creative action becomes dominant, the world is seen as a construction kit, as depicted and spelled out in the subtitle of this thesis "World as Construction Kit"

Figure 2.20. World as Construction Kit depicted in a drawing. An adventurer overlooks a landscape after climbing the most recent peak. In her backpack are some tools, perhaps Constructive Lenses. She looks out and sees music notes in the tree bark, wires in the roads, paint in the plants, lenses in the lamp posts, wooden blocks in the houses, dice and keyboard keys in the rocks, pianos in the river, and electrical circuit components in village. (Image created by Sophie Diehl under guidance of Jay Silver)

Thus the question becomes: what is an example of an instrument (better named "tool" in this case), and more broadly what are the characteristics of tools in general, that by their nature directly catalyze constructive action on the world one lives in? This is effectively the topic of this thesis, and tools with such properties shall be named and explored in the following chapter.

Intellectual Traditions Drawn On and "World as Palette" Extension

At this point I was starting to merge many fields of study:

a) Inquiry-Based Learning

> "Humans are born inquirers. You can see it from the moment of birth: Babies use all of their senses to make connections with their environment."
> ~[National Science Foundation, 2000, FOUNDATIONS A monograph for professionals in science, mathematics, and technology education]

Inquiry-based learning is learning through asking questions. Exploring and questioning gives rise to knowledge through experiential interaction with the environment. Inquiry is often affiliated with a constructivist way of learning, and is often used in the context of science learning to gain a deeper scientific understanding. In "The Having of Wonderful Ideas" [Duckworth, 1996, The Having of Wonderful Ideas], Eleanor Duckworth describes watching the moon nightly while keeping a journal to start to piece together the moon's patterns. This delightful activity is a good example of inquiry, and yet even the title of Eleanor's book gives away the fact that inquiry is more on the side of "having" ideas and less on the side of "enacting" ideas in the physical world. Like a lens, inquiry lends itself to developing new ways of seeing the world. But also like a lens, there is not a direct call for creative action.

b) Constructionism

Learning Through Design Process
Constructionism [Papert +, 1991, Situating Constructionism], is in many ways an extension of constructivism [Piaget, 1967, Biologie et Connaissance], the idea that people learn by building their own knowledge when their current ideas interact with their experiences. Constructionism takes constructivism for granted as a way that people learn, and says that this happens especially effectively when people are involved in the process of construction in the context of a project that they find personally meaningful.

Like the "Block," constructionism advocates learning through creative action. But it doesn't focus on exploring the world or everyday objects in order to repurpose them as an explicit part of the creative action. Take the Logo programming language [Papert, Logo] for example. Logo focused on many powerful ideas, such as recursion, and recursion does exist in the everyday world. However, Logo provides no specific scaffolding for repurposing things from your everyday experience in general. Rather, all of the activity takes place "in the box" (within the sandbox, albeit an expansive sandbox, that is Logo) even though the thinking is in many ways outside of the box. Papert said that Logo was supposed to help people think about their own thinking, and in that way the learner starts to apply what they are doing in the kit to matters outside of the kit.

But there were some constructionist threads, such as the Beyond Black Boxes project [Eisenberg +,

Journal of Learning Sciences 2000, Beyond Black Boxes: Bringing Transparency and Aesthetics Back to Scientific Investigation], that came closer to trying to explore the world outside of the kit. The projects Metacricket [Martin +, IBM Systems Journal 2000, MetaCricket: a designer's kit for making computational devices), the Playful Invention and Exploration Network [Petrich +, Proposal to the U.S. National Science Foudnation 2000, The PIE Network: Promoting science inquiry and engineering through playful invention and exploration with new digital technologies], and Sensory Design [Mikhak +, 1998, Sensory Design], took traditional constructionism in a more sense-oriented and environment-oriented direction. I pick up where these projects left off, pushing even further in the direction of *less computation focus* and *more nature-based design and instant-feedback sensory-action*.

c) Bricolage

The term "bricolage" is borrowed from the French verb "bricoler," the core meaning in French being:

> "fiddle, tinker" and, by extension, "to make creative and resourceful use of whatever materials are at hand (regardless of their original purpose)."

A person who is engaged in bricolage is called a bricoleur. A bricoleur is often known to curate a junk pile so that many interesting items are on hand, and some expert bricoleurs carefully investigate the properties of the items in the junk pile so that they have a mental catalog of the uses of the various items.

In any case, in order to make use of everyday objects one must both investigate the properties of those items and also fiddle and tinker with them in order to create a vision. This process engages both inquiry and constructionism, both investigation and creative action, nearly at the same time.

Take for example the genre of Earth Art, and specifically the work of Andy Goldsworthy [Goldsworthy, 2001, Rivers and Tides: Andy Goldsworthy Working with Time]. Goldsworthy arrives at a place in nature, and using only what he finds, creates a work of art: an ice sculpture made of found icicles, or a hue fade made by sorting Fall leaves and sticking them together with thorns and mud. Another more digital example is I/O Brush [Ryokai +, Computer Human Interaction 2004, I/O Brush: Drawing with Everyday Objects as Ink]. With I/O Brush, a bricoleur paints on the screen with swatches instantaneously photographed from all types of objects found in the real world. This is very similar to the practice of collage, except digitized so that the swatches can be smeared, replicated, and animated.

I/O Brush and "World as Palette" by Kimiko Ryokai

I/O Brush is the object of Kimiko Ryokai's thesis, which is named "World as Palette: Painting with Attributes of the Environment"

Figure 2.21. Left: I/O Brush takes a "Photo" of a plate of M&M's. Middle: I/O Brush smears the photo of the M&Ms across the screen to make a snake-like drawing with the texture and color of M&Ms. Right: a "Snail" is drawn from photos taken with I/O brush of the eyes of a girl, the peel of an orange and an apple, and the colorful stripes of a handbag. (Note: All photos are stills taken from the I/O Brush video made by Kimiko Ryokai).

The way I/O Brush works is that it allows you to take a "sample" consisting of a circular photo of any object by pressing the brush up against the object. The color and texture from that object now becomes like "digital paint" which you can smear on the screen. This is where the thesis title "World as Palette" comes from: each object in the world is a veritable swatch of digital paint just waiting to be used by I/O Brush. This simple theme captured my imagination during my time at Media Lab and subtly inspired many of my projects leading to this thesis: World as Construction Kit.

World as Construction Kit could be viewed as a direct extension of World as Palette. In the chapter on Constructive Lenses, I will introduce how Palette will be just one component of a construction kit, which can have the world take its place. In this way, this thesis can almost be seen as an attempt to generalize the idea of the World as a Palette.

Looking Ahead (Drawdio and MaKey MaKey)

In trying to manifest an instrument that would be similar to the puddle jumper or the flower petter referenced above, two tools which will be highlighted in this thesis were ultimately discovered, (as tools are) by a combination of accident and intention through a series of life events. They will be explained in more detail in the chapter "Drawdio and Makey Makey." But as an overview let's consider them in introductory form here.

Drawdio is a simple device that measures electrical conductivity (the inverse of electrical resistance) between two wire leads, and makes a pitched sound as a result of the measurement: high conductance leads to high pitch like a high soprano note, and low conductance leads to low pitch like a low bass note.

In light of the framework behind Camera for the Invisible, Drawdio could be considered as an input/output synesthetic pair with the input being electrical resistance and the output being pitched sound. The important difference is that there is no swappable input lens or swappable output viewfinder. You might call this a dumbed-down less flexible Camera for the Invisible. But what it inspired ended up being much more important. Another way to say "less flexible" is "more focused". Additionally, due to the lack of complexity, the bar for understanding and using the tool was significantly lowered.

Once I had one of these in my hands, it was possible to explore with it just like a "lens" or "camera". But it was also a catalyst for inventions because when it was hooked to certain devices those devices became musical instruments or user interfaces

- musical pencils
- musical paintbrushes
- kitchen sink theremins
- tree bass guitar
- macaroni slide whistle
- nose bump beeper
- etc.

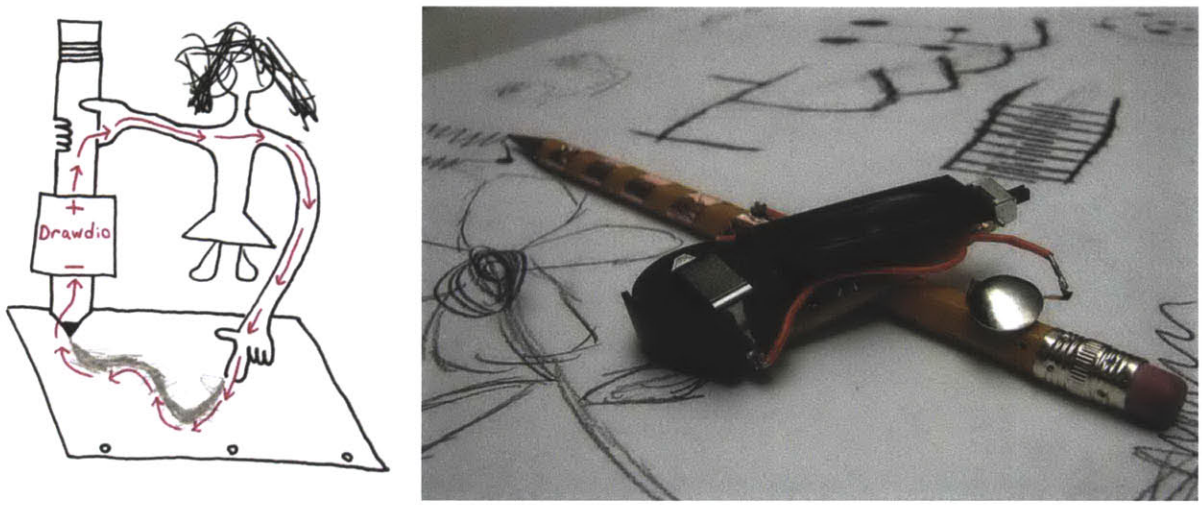


Figure 2.22. Left: A cartoon depicting the flow of electricity when using a Drawdio Pencil: out one side of the circuit, across the outside of the skin of the body, through the graphite on the paper, into the pencil's graphite core, and back into the other side of the circuit. RIght: A Drawdio circuit thumb-tacked onto a regular wooden pencil along with example of musical instruments drawn on the paper.

Although technically the camera could have performed the same result, the form factor (big and camera shaped) and the support materials (suggested usage as displayed in videos and instruction) prevented it from doing so despite its more advanced feature set. The forcing function of Drawdio is to connect things in the world together (it ships with 2 alligator clips), which is inherently an interrogative-action-based process by which in order to simply "see" the next thing, you have to change the way the world is connected up.

Throughout the years of working with Drawdio, the question arose, what if we could hook everyday objects up to a computer instead of just to a speaker that makes pitched sounds? This question eventually led to the creation of a circuit called Makey Makey which allows the connection of up to 18 objects to a computer. Each object, upon being touched, can trigger an action on the computer through an HID keyboard press, or through a mouse action such as a left-click. Note that in order to do this the circuit board "pretends" from the computer's point of view to just be a keyboard and mouse, sending keyboard and mouse commands to the keyboard just as a USB Keyboard or USB Mouse would. However instead of sending these commands when a user pushes a key on the keyboard or clicks on the mouse, instead it sends these commands to the computer when two things (for example, a person and a banana)

that are hooked up to the circuit by alligator clips, each come into contact with the other, thus closing a circuit. See the diagram for two such examples:

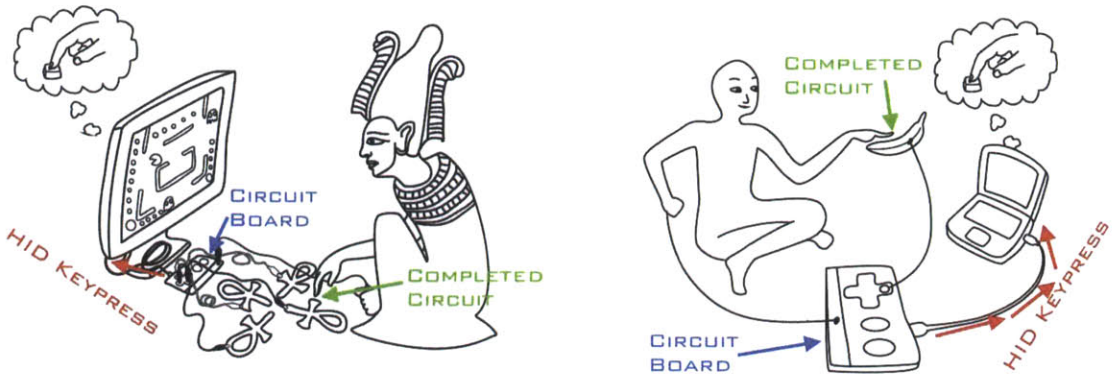


Figure 2.23.

Left: A person and four metallic pieces of jewelry are connected by alligator clips to a circuit board. When the person touches one of the pieces of jewelry a circuit is completed and the microcontroller (small computer on the circuit board) detects this event. It then sends a keypress command to the computer to make the video game character turn around.

Right: A person and a banana are each connected to a circuit board. When the person touches the banana, a circuit is completed. The microcontroller (small computer on the circuit board) then sends a keypress command to the computer. The computer just thinks a key was pressed on a regular keyboard and responds in just that same way, by either putting a "space bar" character into a word processor, or playing a sound on a digital piano, whichever app is currently in focus on the computer screen.

The Makey Makey can then be used to make:

- Banana Piano - Google for "web piano" and bring up a web app that plays piano noises when you push the keyboard keys. Then hook up a banana to each of the Makey Makey ports which corresponds to the key on the web app that triggers a piano noise. Now when touching the banana the piano noise corresponding to the key *that* banana is hooked up to is triggered. All the bananas make a different sound.

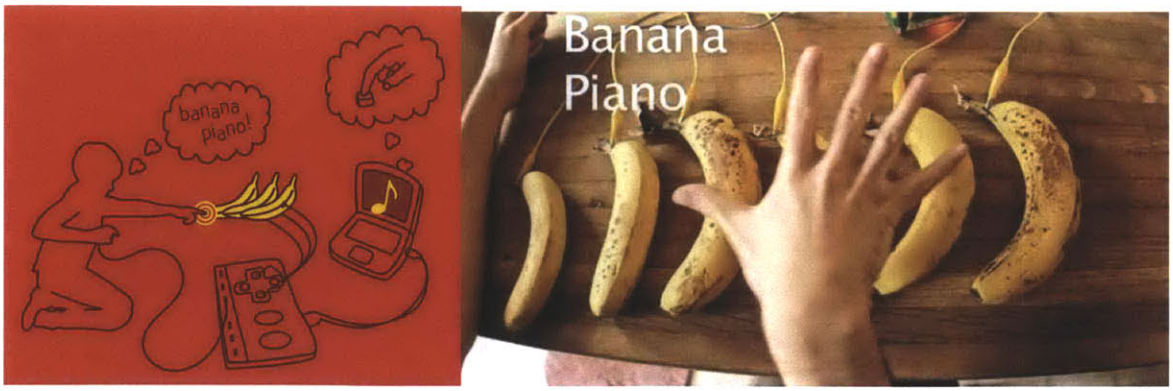


Figure 2.24. Banana Piano diagram (left) and photo of it in action (right)

- Play dough Video Game Controller - Google for your favorite video game, such as Super Mario. Load the web app and start playing the video game with the computer keyboard. Now hook up Makey Makey to

some pieces of play dough corresponding to the keyboard keys that trigger your character, perhaps Mario, to run and jump. Now form the play dough into custom shapes, perhaps buttons or arrows, and orient them in a layout that is conducive to that particular game's style.

Figure 2.25. Play dough Game Controller Photo-Diagram (left) and in action (right)

- Cat Selfie Cam - Google for a an online camera. Load up the app and give it permission to access your webcam. Then hover the mouse of the "take a picture" button on the app. Connect an alligator clip to the "click" part of the Makey Makey, then connect the other side to a cat bowl full of water. Ground a piece of aluminum foil next to the cat bowl. Then when the cat stands on the aluminum foil and licks the water in the bowl the cat closes the circuit and triggers a "mouse click" event. The computer then takes a picture of the cat drinking water.

Figure 2.26. Diagram of Cat Bowl Selfie (Left), and photo of it in action before cat arrives (middle), after cat arrives (right)

These three examples cover three of the main types of Makey Makey inventions: Musical instrument, Game interface, and "general invention". Of course all 3 are inventions of sorts, but the instruments and game controllers are especially conducive and popular.

Whether making a musical pencil with Drawdio, or a cat selfie cam with Makey Makey, these tools allow you to explore and re-see the resistance of everyday objects, while repurposing them to do new things.

Re-seeing and Re-purposing a pencil

People don't normally see a pencil as an object with a "conductive wire" of graphite running down the middle. Nor do they see the graphite markings a pencil makes on paper as little wires that could carry an electrical current. The wood in the pencil is an insulator that protects the conductive wire that runs down the middle from leaking current to objects that come into contact with the pencil. The body of the pencil is an electrical connection point for human hands to plug into the Drawdio circuit. Finally, a musical pencil is made, which is not the original intended purpose of the maker of the pencil, so new meaning and new

function is given to the everyday world we live in.

Re-seeing and Re-purposing a cat water bowl

People don't normally see a cat water bowl as a button for taking a photo. The bowl is an insulator which holds a conductive liquid-form "button" in the form of water. The cat is insulated by its fur, but the cat tongue is conductive. We wouldn't normally look at the body of a cat as a jumper wire to close a circuit between a sheet of aluminum foil and a cat bowl. The cat's pads on its feet are also conductive (as is the ears and nose, but not most other parts of its body). The cat is re-purposed as a photographer or at the very least a trigger for a photograph, and a jumper wire of sorts. The household kitchen material of aluminum foil is used as a grounding plate, and the cat water bowl as both an attractor of the cat, which is a typical use, as well as a button to trigger the camera.

This is the special feature of the Constructive Lens, it allows us to re-see and re-make the world we live in. It catalyzes new vision and new action.

3. Contributions

In part 1 of this section I will talk about the virtues of lenses and blocks, neither of which has the virtues of the other. In the second section I will talk about combining the virtues of both into a single object. Finally, I will provide one method for thinking about and improving existing Construction Kits so that they have the dual lens-block advantage. I'll go into detailed specifics with the example of a painting kit. I will also define Constructive Lens.

Lenses and Blocks

Lenses, take magnifying glasses for example, are an amazing tool for inquiry. The entire visible world becomes something worthy of inspection, maybe even investigation, to a curious individual augmented with the use of a magnifying glass. Of course the whole world was already "willing" to be investigated, but the addition of the particular tool, by design, enhances the possibility of the particular action of investigation.

Blocks on the other hand, take wooden blocks for example, are an interesting tool for architectural creation, tinkering, reconfiguring a known set of parts. A person augmented with the power of wooden blocks is a person who is highly likely to create towers, maybe even towns, etc. Wooden blocks are great for rearranging. Wooden blocks invite anyone from 1 month to 100 years old to put their hands into the action and start creating and destroying in cycles.

But blocks are not a very good "lens" onto all the parts of the world. That is to say, playing with wooden blocks rarely teaches about ladybugs (or fingerprints or table salt). What about magnifying glasses? How likely are they to lead to experience with creation, experience with repurposing? How often do lenses lead to a reordering of the physical world? It doesn't happen by design, though it may happen by accident. So, when thought of as a tool for education, a wooden block is, by design, made to teach about creative action, and a magnifying glass is, by design, made to encourage investigation of the world. What if we put them both together?

Constructive Lenses

Many educators would agree that both lenses and blocks are great ways of learning. And so they are often employed... separately. But what is it that happens when you combine the two into a tightly coupled pair?

I call this a Constructive Lens. What does a "Constructive Lens" do? One interpretation is that when you tightly couple the acts of creation and exploration (wooden blocks and magnifying glasses) you get people investigating the properties of the everyday world (like a magnifying glass) and you get people reconfiguring and tinkering (like wooden blocks), and that when you do them at the same time, you might get people engaged in the process of re-investigating and reconfiguring the everyday world in tightly

coupled iterations.

This "Constructive Lens" is 2 things at once. It is a lens, because it is a world view. At the same time it is a way of acting because the world view enables an activity of appropriation and designation of meaning. The Constructive Lens inherently diminishes the strength of the idea that there is only one existing order in the world simply by bringing to light the possible existence of infinitely many possible orders.

While a high bar indeed, creating a situation in which people take objects from the everyday world, analyze the objects' properties so as to re-see their workings, and then synthesize something new by combining the objects together or casting newly designated purpose on their use, is an exciting prospect. This means that people are re-seeing the world as repurposable, thinking of it as malleable, and acting in accordance. Another way to say this is that the Constructive Lens will encourage the process of repurposing the world, thus creating the space for the thought that the world is malleable, and seeing the world in accordance. The two statements are one in the same.

If there is a Constructive Lens that works this way, one might even say the actions taken by the person using it bestow a confidence and sense of agency, create a fertile ground for expression, and even a sense of empowerment.

World as Construction Kit

There are many modern Construction Kits, such as: paint sets or electronics kits. Modern Construction Kits often come in a box with everything you need so that you can get started right away creating. There are many genres and subgenres of Construction Kits within various fixed media. For any expressive medium (gardening, sculpting, 3d printing, computer programming) one can imagine the design of several kits to support the activity.

For a given kit, is there a way to open up the box a bit so that the kit leads not only to creative action within the confines of the kit parts, but so that the kit also becomes a sort of lens onto the world as potential creative pieces or as a potential creative space?

Let's define Construction Kit, not for the purposes of an absolute taxonomy, but for the purposes of scaffolding the generative process of turning kits inside out so that they become lenses onto the world (while still being kits for creative action).

Let's say that Construction Kits have 3 components:
1) Parts (especially loose parts)
2) Tools (for combining and reconfiguring loose parts)
3) Stage (a substrate or place where the creative action is situated and may live on)
(note: not all kits will have all 3 parts, and not all kits have to fit nicely into this framework)

A strategy for turning a "regular" Construction Kit into a "World as Construction Kit" situation might be to choose one component of the kit and remove it from the kit. Instead the creator must look to the everyday environment to find that component. Assuming the construction kit is expressive enough, then the user is motivated to make something with the kit, but by removing one of the components of the kit, some of that

motivation to express is directed toward the everyday world as the user now goes on a sort of hunt for what they can use. In this way, the user is directed toward the everyday world and begins looking around with an eye for "how can I use this item for such and such a purpose" as they scan the environment looking from thing to thing.

Take a painting kit for example. It might consist of:
1) Paint (loose part)
2) Brush (tool)
3) Canvas (stage)

> But what if there is no paint? Perhaps the creator can be encouraged to scavenge paint from crushed berries, or from objects (like rainbow sprinkles or small pebbles) mixed with glue.

In this scenario, if the creators eye scans across a berry (or a balloon, or some cheerios, or a blade of grass, etc.), the creator asks herself, "How could I see this berry (or cheerios etc.) as if it were paint?" Then, having had experience with berries (or cheerios etc.) the idea of using it as paint either snaps into place or doesn't or somewhere in between. The creator is catalyzed to reconsider the usages of their everyday world in particularly constrained ways, like "How could this be used as paint?" In doing so, the creator has to strip out the normal meaning of what they think they know, "This is a berry, berries are for eating," then hold that berry, now stripped of its supposed "known" purpose, in a new light, a light of paintability. (Cheerios, by the way make a great, albeit chunky style, paint when combined with glue).

> What if there is no brush? Perhaps the idea could arise to boil spaghetti and paint with it, or grab a toy race car and use its four wheels as brushes while driving the car around the canvas, or stamp leaf patterns.

In this scenario, the creator once again has her attention directed toward the everyday world to reconsider what she thinks she knows about common objects. As she scans her couch pillows, her cat's tail, a light bulb, and a gallon of milk, each is considered as if it were a paintbrush, and what it would mean to think of each object as a paintbrush. This is the "Constructive Lens" effect: to look at what we already know and consider it for new uses, consider its properties and affordances, and how those affordances might be beneficial, interesting, or surprising in a new context, different from the originally designated or generally agreed upon purpose.

> What if there is no canvas? This seems to point to the field of graffiti or sand dollar art. Buildings or sea creatures become the canvas.

In this scenario, the creator gets to reconsider objects as a medium that carries a painted picture or holds paint as a substrate. What does it mean to paint a picture on a car vs. a building vs. painting directly on water? Is that even possible? How? What would happen next? Can you paint on air? On rain? Can you paint on a rainbow? What about the head of a pin? What about on human skin or bones or a flower or a porcupine? While these types of questions could be asked and practiced as an exercise in and of themselves, it is so much more powerful and meaningful to engage with them in the context of an expressive project in which these questions are an inherent part.

The point is not to prove that any of these art genres are particularly new, though I think it's rare that

people try to paint pictures on porcupines, but rather to evoke the idea that perhaps this framework is a generative way to think of new media art and even new types of Construction Kits that are Constructive Lenses onto the world:

> *A kit that catalyzes querying everyday objects for their paint-properties and then using those objects as paint to create an expression, is a kind of Constructive Lens for "World as Paint."*

Let's reconsider the same paint kit, but in the additional light of *digital* tools:

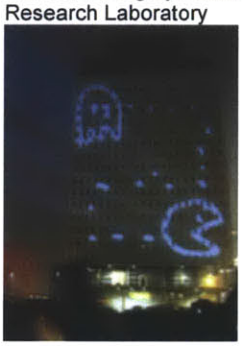
Construction Kit Components	*Loose Parts*	*Tool*	*Stage*
Paint Kit Components	Paint	Brush	Canvas
World as Paint Kit Components (Non-digital examples)	World as Paint: Collect objects and make paint like berries	World as Brush: Find objects and use as brush like spaghetti	World as Canvas: Paint on any object in the world like a rock
World as Paint Kit Components (Media Art Examples)	World as Paint: I/O Brush I/O Brush lets you paint with photographic swatches 	World as Brush: Light Drawing Anything that emits or reflects light can be a "Paint Brush" 	World as Canvas: Projector Graffiti Here is a Drawing projected onto a building by Graffiti Research Laboratory 

Table 3.1. Construction Kit Components Concretized Through a Particular Painting Kit Example

As described earlier, I/O Brush [Ryokai +, Computer Human Interaction 2004, I/O Brush: Drawing with Everyday Objects as Ink]. is a digital brush system in which paint is sampled from the everyday world around you. When using I/O brush, you can't even start until you take a picture of something with the brush ("sampling a digital paint swatch from the world"). There is no color picker in the program. You simply have to look to the world and touch the brush to something to get the texture and color of an object in your environment so you can begin painting. Not only do you "have to" do this, but it is quite exciting and expressive to take the texture of an eyeball and begin to make a drawing out of it. Once that desire is created, the desire to look around and see the texture and color of everyday objects as useful or not useful for the painting you wish to create, then in the human mind a sort of "lens" forms when looking around at things. The lens is not literal, but instead is a way of seeing. Specifically it's a way of seeing the world for its component parts, in this case color and texture, and how those component parts could be used to make something, in this case a painting. This is a specific type of inquiry that is not inquiry into the working of machinery, but specifically inquiry into what can be created out of the everyday world. A sort of creative inquiry. The person starts to see the *World as Paint* or more generically *World as Loose*

Part, which is a form of *World as Construction Kit.*

Glowdoodle (Rosenbaum, Creativity and Cognition 2009, Glowdoodle: A Medium for Expressive Inquiry) is one example of a light-drawing system in which everyday objects can be used as paintbrushes. It allows you to wave objects in front of the webcam and trails of those objects appear on the screen if they reflect or emit light or color. The creator thinks, "What kind of a resulting brush stroke will this LED toy (or this smartphone screen, or this sunflower) have when waived across the scene?" The creator imagines each item, or perhaps tries without imagining too much, depending on the person, as a digital brush. In doing so the person starts to break down the world into types of object reflectance and light emission, even if not explicitly thought of with that vocabulary, to evaluate the usefulness of each T-Shirt, paper airplane, and Starburst wrapper *as digital paint brushes.* The person starts to see the *world as paintbrush* (or more generically, *world as tool*).

The L.A.S.E.R. Tag project [Graffiti Research Lab, 2006, L.A.S.E.R. Tag] is a digital graffiti system that encourages you to look around the world and consider any solid object as a potential canvas for drawing on digitally. What if I laser graffiti on the moon? What about a foggy night? What about my body as a canvas for laser graffiti? The lens of digital graffiti, like the lens of old fashioned graffiti, is a lens in the mind of the creator that makes the creator look to the environment with an eye for "How would it be meaningful to transform this item by painting on it?" "How will this item take to the digital 'paint' based on its properties?" "What is this tube of toothpaste as a canvas for laser graffiti? What about this waterfall?" The person begins to see the *World as Canvas* (or more generically, *world as substrate* or *world as container*).

Whether of the form new media art or traditional crafting, separating a construction kit out into its component parts and then systematically removing a component and asking "what if we direct the user's attention to scavenging that component from the world?" can be a way to generate new "World as Construction Kits."

Ultimately, "World as Construction Kit" is a state of mind that represents a world view.

II. Design

4. Constructive Lenses in the World

This section will start by taking a traditional kit, and "opening" it to explore the specific differences between a Constructive Lens and a traditional construction kit. Then we will try to define what is different specifically and give terms to those differences. Finally, we'll take a look at Constructive Lenses that already exist in the world.

Open LEGO -- Opening a Traditional Construction Kit

What if some traditional LEGO kits came with a special set of LEGO bricks that were made just for attaching to other objects around them? Ideally there would be a few LEGO bricks that could attach to each type of material in both the man-made and natural environments. Imagine the following "Open LEGO" scenarios:

- Suction LEGO -- Some LEGO bricks with a suction cup for attaching to very smooth surfaces like glass or polished materials

  "When I was done making the birdhouse I suction cupped it to the outside of my window, and a real family of birds moved in"
- Eyelet LEGO -- Some LEGO bricks with an eyelet so that it can have string looped through it to be tied to things

  "I made a beautiful flower bud, and when I was done I looped it through my necklace chain and wore it as a pendant. Afterwards, I started a tradition of decorating the tree in the front yard with my LEGO creations"
- Floatation LEGO -- Some LEGO bricks with floatation built in so that objects can be built on liquid surfaces

  "I built a mini rowboat and put a ladybug inside it to pretend she was lost out at sea. We attached the row boat to a LEGO floatation platform and pushed it into the pond, and we elaborated sagas of the misadventures when the wind would blow it this way or that..."
- Snap-In LEGO -- Some LEGO bricks with velcro, button holes, or snaps so that they could attach to other objects that have those receivers

  "I've been playing hacky sack for a while, and I thought that it would be great to have a little 'scooper' on the top of my velcro shoes, so I built one and attached it with the velcro LEGO piece. I've been modifying my design each day after hacky sacking."
- Sticky LEGO -- Some LEGO bricks with very sticky tape for attaching to somewhat smooth surfaces like weathered wood or rusting metal, or leaves

  "I am making a little teepee out of sticks and leaves, and I wanted to add some windows, so I used the tapable LEGO to help hold my windows in place and bind it to the sticks."
- Magnet LEGO -- Some LEGO bricks with magnets to attach to fridges or other toys that contain magnets

"I like to make marble machines out of LEGO bricks, and I stick the machines to my fridge with magnets which makes them easy to move around and reposition. The 'marbles' are metal ball bearings, so I can also use the magnet pieces to alter the course of the ball bearing. When I play in the bathtub, my marble machine becomes a water machine, because I noticed that bathtubs are magnetic too. Sometimes I build with my LEGO set and my magnet kit at the same time because they are inter-operable."

- Other Kit LEGO -- Some LEGO bricks that have little attachments for Tinker Toys, compatible K'nex hookups, and 3 sizes of holes to press-fit twigs.

  "Today I gathered up some fallen branches, and I made a dome on my tree fort with a hybrid of K'nex, LEGO bricks, and twigs."
- Visual Media LEGO -- Some LEGO bricks with a clear plastic pouch that can hold a printed or drawn image on one side and can be drawn on with markers or pencil on the other side.

  "I made a mask in the shape of a gator and then drew teeth and scales on with a pencil."

and on and on like this.....

LEGO bricks as they are now can and always have been repurposed and combined in all kinds of situations, but it has been *despite*, not *because of*, their design. In this example the traditional LEGO construction kit is composed of different colored loose parts called LEGO bricks. Because the LEGO bricks are press fit (the fasteners are built into the top and bottom of each LEGO), there is no tool other than the human hands that are needed to perform the basic construction operation. LEGO kits often but not always come with a substrate in the form of a big LEGO sheet to attach your creation, and the design of this sheet is not generic or implicationless: it implies that the creation should sit on top of something flat, like on a floor, shelf, or table. In the example, we opened the loose parts of the construction kit with the "Other Kit LEGO" brick. We opened the substrate with the "Flotation LEGO" brick. In doing so we turn the LEGO kit into a lens onto the everyday world for considering how the LEGO kit might interact with and be co-constructed with the everyday world.

Open Construction Kits

What is *Open*?

What do I mean by open? To open a construction kit is:
To redesign a construction kit so that one of its components (parts, tools, or substrate) is left unspecified in a way that suggests it should be drawn from the world around you.

I mean to operationalize the idea of "World as a _____." For example, one way to "open the painting kit" is to "invite the artist to appropriate the properties of everyday objects as the paint" (as in I/O brush).

A closed construction kit is one where the loose parts, tools, and substrate are fixed and unchangeable, at least by design (anything is changeable if you try hard enough). But something doesn't sit right about that definition. Take a basic painting kit for example. It seems quite open ended, as we can paint pictures

of anything even if it's always with the same paint, brush, and canvas. There is one more piece to the puzzle of open activities using open construction kits. Take for example a typical construction process. There are some people who came to construct something: where did they come from and who compelled them to do so (Prologue)? There is some situation or theme, or goal in which the construction is carried out (Beginning). Then the materials are gathered and acted upon with tools (Middle), a final project is converged upon (End), and then that final project is placed somewhere (Epilogue).

1) Prologue - People: Recruitment mechanism, Theme, Setting
2) Beginning - Loose Materials
3) MIddle - Tools
4) End - Final Project crystalised
5) Epilogue - Placement or Afterlife of Project

This is very rough because it ignores all the iterative loops and complex processes involved with creative action and activity conception. But it serves our purposes. The reason a normal painting kit seems so open-ended is because it is exactly that. The end product is completely open (unless there are instructions guiding otherwise). It's only the loose parts (the beginning) and materials (the middle) and the substrate (the epilogue) that are closed. That is to say that traditional painting is open-ended (step number 4), close-beginninged (step 2), close-middled (step number 3), and close-epilogued (step number 5). That is, unless you are in a class where everyone is to paint the same subject, which it would be close-ended. Now in this case, of course, everyone's painting will turn out a bit different, but this is not called open-ended. But the interesting thing is: what does it mean for a project to be open in a way other than open-ended?

Let's take painting as an example. If a painting project is open epilogued but closed elsewhere else, then one example would be:

Everyone will start in the same room with a bowl of fruit on the table. Everyone will get a brush and a set of paint colors and a piece of paper with glue that is meant to be affixed to something in the world when completed. Everyone will paint the bowl of fruit on their canvas. Then when they are done they will go out into the world or into their house or onto their bodies and affix their painting somewhere. You might think of that project as open-ended as it is indeed a project with different outcomes. And that would be accurate. But the project idea was generated via thinking of it as open-epilogued, and that is the power of the technique of opening a component of a construction kit. Note again that open-epilogued painting projects often end up feeling like graffiti (or tattoo projects if affixed to a person's body). Banksy, the most famous modern graffiti artist, does his graffiti in just that way: first create the art, then roll it out on to building street or facade. But tattoo is definitely distinct from graffiti in my mind.

Importing and Exporting

Many now accept that facts and knowledge alone are not a satisfactory outcome of an excellent learning process, and that we must "learn how to learn" or learn to "be creative." To make creative space, many activities (including standard/basic LEGO construction in their older original form) are open ended. That is to say, at the end of playing with a basic LEGO set, each person will have a different finished product, if they have a product at all. (This isn't always true of LEGO kits, as the majority of modern LEGO kits have prescribed building patterns, like a particular Star Wars spaceship). This "Open Endedness" is a form of open, and is much more likely to connect to something that the creator finds personally meaningful than if the end product is prescribed. What you see in the Open LEGO example above is a case for LEGO

projects to be -- by design -- open-beginninged, open-middled, and open-epilogued.

Importing (or "open-beginninged" and "open-middled")

To the LEGO Company's credit they have a nice concept of System and Play, which refers to the LEGO Company's policy of making parts that mix and match among themselves using a standard protocol for connection. For LEGO sets to be open-middled, they need to be able to mix, match, and connect with the material world outside of the LEGO system, like in the Other Kit LEGO example. This type of combinability that provides an openness to the beginning or middle of the building process could be referred to as *importing*. Importing happens when the material world can be brought into the kit world to act on or be combined with the kit's loose parts. Most modern art software applications allow the creator to import existing images into their work to remix, collage, or mashup.

Exporting (or "open-epilogued")

Floatation LEGO says to creators, "When you're done building something, maybe you should take the final product and put it in some water." Like importing, there is a certain connection that is being made to the creator's everyday life. Another, perhaps more powerful, type of exporting is to share the finished product with friends. Since the advent of YouTube, the average video has had a much more vibrant epilogue to its creation story. The final video project can be uploaded to YouTube, which is probably already part of the creator's everyday life, and then many types of social interactions can begin around the video. (Note: The document you're reading was created with a word processing toolkit that allows for exporting to PDF for easier sharing).

Importing and exporting is really just another way of talking about whether a given toolkit is interoperable with various parts of the world. There are formats, languages, protocols, and other ways of aligning with standards so that a toolkit can incorporate or be incorporated into different parts of everyday life. In the software world this is called "API" and is one of the most important aspects of a modern webified application. Beyond interchangeability, instructions and positioning have a big effect on whether something is exportable or importable. Permission changes the mindset.

Some Existing Constructive Lenses

Non-Digital Constructive Lenses Already in Existence Out in the World

MakeDo

MakeDo is a set of tools

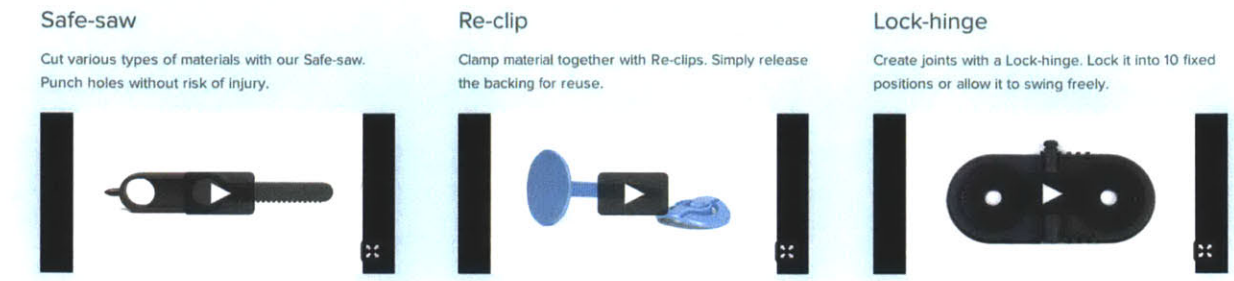


Figure 4.1. MakeDo's Overview of Parts. (Images reproduced from mymakedo.com)

Parent Hacks says

> *"Makedo hits the jackpot with early independence and open ended play."*

And it is true that it is open-ended, and it also happens to be open beginninged in that the materials which you use are not specified. Further it's not completely open beginninged in that it has some suggestions and most of its examples focus on cardboard. However even cardboard comes from many sources and in many forms. Here is an example of how MakeDo would be used:

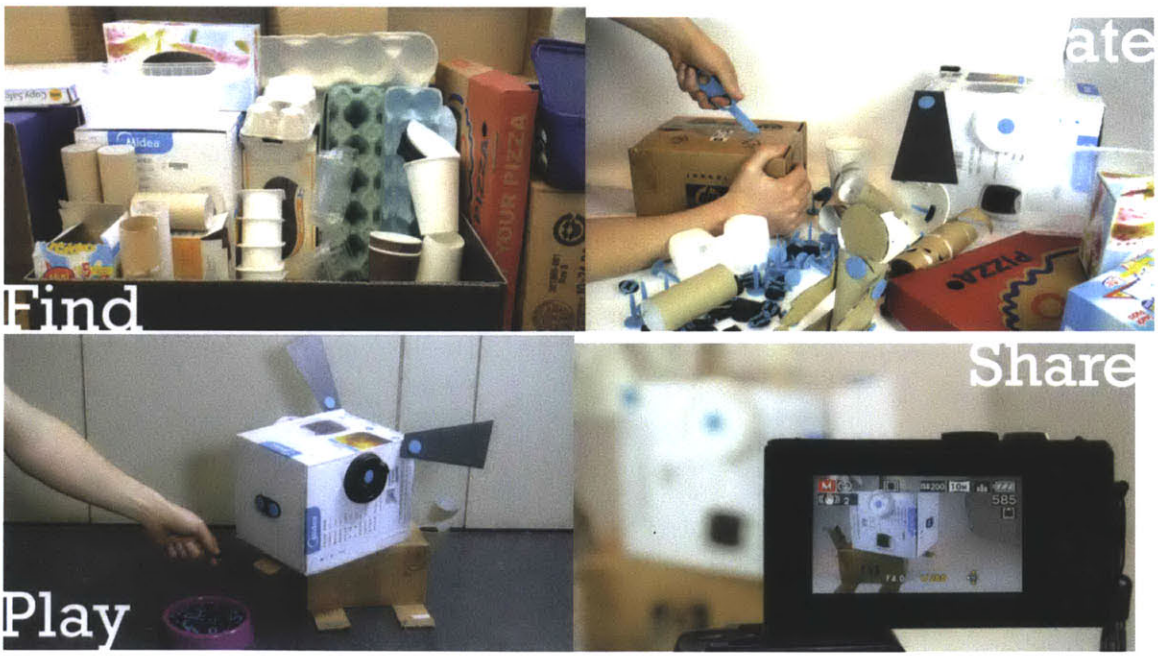


Figure 4.2. MakeDo's four steps: Find, Create, Play, Share. (Images reproduced from www.mymakedo.com)

Notice the attention to the beginning with an explicit attempt to encourage the bricolage and open beginninged-ness by showing what appears to be a random collection of junk all of which can be operated on using MakeDo. These instructional materials are key to support the open beginninged-ness and "World as Construction Kit-ness" of MakeDo. If the kit shipped with cardboard and didn't encourage

bricolage in the support materials and instructions, then despite its potential as an open construction kit, it may not realize its potential as such.

Notice the attention to epilogue in the "Share" step. Though I wouldn't say they have gone the extra step to encourage sharing in multiple substrates, I would say they stopped short of making the kit explicitly open epilogued.

Note the language around "Play" and "Create". While these are communicative and typical linguistic usages, they point to an important mistake in thinking about play patterns. The "create" step is extremely playful and just as an important part of true play as the "play" step. In unhindered child play patterns children will make, bend, and break the rules of the game and the physical components of the game all as part of the game play. This type of game play in fact develops the same part of the brain that is used in adult civic and family life for

- Setting agendas
- Stepping back and focusing in on project goals and ways of engaging with a project
- Structuring relationships in group dynamics
- Negotiating and deciding on goals and norms
- Determining the very experiences that life will make up

Edible Seed Bomb Kit

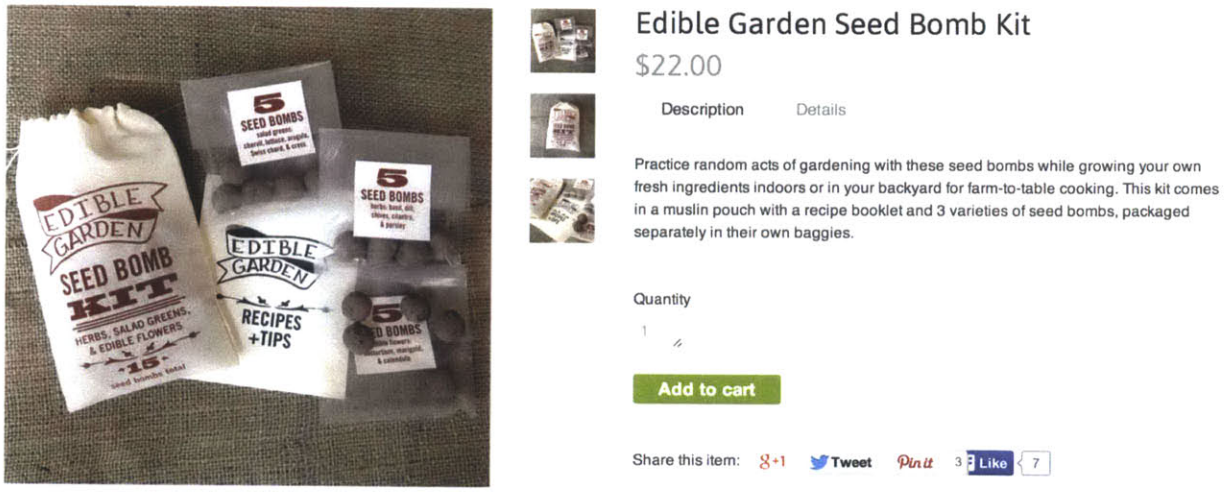


Figure 4.3. Edible Seed Bomb Kit Screenshot. Image reproduced from visualingual.com

This seed-bombing kit is closed-beginninged with the seeds already provided to you. The form factor is explicitly open-epilogued as it is a throwable ball with proteins for the seeds and the seeds inside the ball. The seeds are chosen just so that they will likely grow in a variety of climates and soil conditions thus making them explicitly useful for growing in multiple substrates, which makes their epilogue or "garden canvas" open. They are missing an opportunity to have been open-middled. Since they don't provide any tools for launching the seed bombs into the world, they could have provided instructions that people should make or find tools or mechanisms by which to launch their seed bombs using strings, slingshots, ramps, cars and bikes, secret holes in pockets of pants, etc. While this kit has the potential to be open-middled, it missed the chance to operationalize that potential with some simple instructions or examples,

making it less likely to happen, or at the very least making it implicit instead of an explicit design parameter.

Interestingly, note that the epilogue could be considered split: open in the first half of the epilogue as to the substrate of where the garden grows, and then closed again in the second half where the kit suggests picking the edible plants and cooking them according to a recipe book. Using the "open construction kits" framework, the makers of this tool could consider whether their recipes could involve mixing in other ingredients that aren't explicitly listed, or they could consider under what circumstances the dinners made with the recipes could be served, thus giving new chances for openness and creativity. The closedness of the second half of the epilogue of this kit is not problematic, it is good to have open and closed components of the kit. And it is good to be aware of these choices, as we live in a world that has lost balance with open parts of play.

Digital Constructive Lenses co-created by Myself and Eric Rosenbaum

- Twinkle [Silver & Rosenbaum, Tangible Embedded Interaction 2010, Twinkle: Programming with Color] Video at: TwinkleVid.notlong.com

  Compose 2D musical compositions with colored objects or colored markers. Then play them back by tracing them with a color sensor wand. Twinkle allows people to think of the world (objects with colors) as a musical composition, and rearrange that world to compose one's own compositions.

- Singing Fingers [Rosenbaum & Silver, Interaction Design with Children 2010, Singing Fingers: Fingerpainting with Sound] Video at: SingingFingers.com

  A way of finger painting with sound, and then tracing the painting to get the sound back out as if scratching on a record. Singing Fingers uses a touch screen interface to convert sound into color and then back into sound again. Singing Fingers catalyzes people to think of the world (the sounds objects and voices can make) as paint and as components of a musical drawing.

- Color Code [Silver & Rosenbaum, Tangible Embedded Interaction 2010, Twinkle: Programming with Color] Video at: ColorCodeVid.notlong.com

  Color Code is a platformization of the concepts in Twinkle in that instead of producing sounds from colors, any computer action can be taken based on the color of an everyday object. In this way, everyday objects can be viewed as musical compositions, game controllers, or even computer instructions. Color Code catalyzes people to think of the world (the hues and shapes of objects) as components to interactive video games and interactive scenes.

- Drawdio [Silver, Creativity and Cognition 2009, Nature as interface: MacGyver'ing and Martha-Stewart'ing interactivity with trees, pencils, grandpa, even the kitchen sink] Video at: Drawdio.com

  A circuit that lets people hook up everyday objects to turn them into musical instruments. A simple 555 timer converts electrical resistance to audible sounds. (Note: There are several Drawdio products on the market, so when I say "Drawdio" in this thesis I am

referring to what is commercially referred to as "Drawdio Fun Pack" which is a pre-soldered circuit with 2 alligator clips that is ready for the creator to start using to repurpose objects as soon as it comes out of the box.) Drawdio catalyzes people to think of the world (the analog electrical conductivity of an object between certain attachment points and the actuation of that conductivity by moving the objects through space) as a musical instrument.

- Makey Makey [Silver & Rosenbaum, Tangible Embedded Interaction 2012, Makey Makey: Improvising Tangible and Nature-Based User Interfaces] Video at: MakeyMakey.com
  Makey Makey is a digital-computation-platformization of the concepts in Drawdio in that instead of producing sounds from electrical resistance, any computer action can be taken based on the electrical resistance of an everyday object. Makey Makey lets you hook up everyday objects as if they were a keyboard or mouse to control software on your PC running in the OS or on the web. Makey Makey catalyzes people to think of the world (the digital conductive or insulative on/off connectedness of objects) as a user interface to a modern computer.

For the purposes of going deep and making a clear point, the thesis will focus in particular on two tools, Drawdio and Makey Makey. These two tools will be covered in more depth in the next section since they are the focus of this thesis.

5. Drawdio Genesis

This chapter and the next chapter approach the understanding of the Constructive Lens through a design exploration of two new Constructive Lenses. I (along with Eric Rosenbaum) have developed several tools which fit the pattern of what I have been calling a Constructive Lens, as mentioned in the last chapter. How did these come into being and what were the circumstances and influences? I will explore Drawdio in this chapter and Makey Makey in the next chapter as examples.

Nature Sensing Adventure

As mentioned previously in Background, I had been working with the concepts of sensor inputs and actuator outputs and had decided to try to simplify the combinations to something less flexible to look for some more creative action. I was sent on a mission to Drishya, a slum school in India headed by Geetha Narayanan. Geetha had agreed with us that the goal for the visit would be nature sensing, which fit right in with my interests at the time.

I stopped in Paris to join up with Evelyn Eastmond, another member of the team, and there I spent some crucial time with Jean Baptiste LaBrune, who would later become a postdoc in the Media Lab. Jean Baptiste, also known as J.B., Evelyn, and I toured around Paris for a couple days thinking about nature and sensing. We visited some museums with green walls growing on the side of the building: a vertical living garden built into a building wall. We visited some hacker spaces and set up some sensor experiments there with PicoCrickets, Scratch, and the sensing of leaves and water. J.B. showed me two very interesting incarnations of a sensor-actuator pair which only 5 years later would I realize were influential. The pair was a solar panel and a piezo. If you hook a solar panel to a piezo, you can see the piezo vibrate and hear it buzz when enough light, especially direct sunlight, falls on the solar panel. J.B. incidentally showed me two things he has made with this combo:
1) A "robot" or "little figurine" with a solar panel on the chest and piezos incorporated in such a way that when light fell on the solar panel the little figurine would begin to move by vibrating and slowly "walking" ala vibrobot. Thus when placed near a window, as the sun traced out a patch of light on the ground throughout the day, the "robot" would walk out of the way of the sun patch because upon the sun patch falling on it, it would begin to move until no longer illuminated.
2) A stick the size of a broom handle with 5 solar panel / piezo pairs glued to it in a straight line. They all buzz intermittently depending on whether strong light is falling on each solar panel at that moment. And, if you twirl it around, especially near a window, the ambient light falls on different parts of the stick in different amounts in changing ways over time and interesting sound patterns emerge.

I don't know how much J.B. connects those two incarnations, or whether he knows they influenced my design in the future. I only recently become consciously aware of the connection when writing this thesis.

I want to point out the importance of the experience in Paris with Evelyn and J.B. Evelyn played a very supportive artistic role of accepting my ideas unconditionally and riffing with me off them. J.B. played a role of expanding my ideas and making me think anything was possible as well as showing me around various environments and materials to make me think. This type of adventure-research and co-stoked-ness is important to making breakthroughs as it creates a safe and stimulated space to think big thoughts.

Figure 5.1. Study of plants as part of urban nature in Paris. Images in Figures 5.1 through 5.8 were taken interchangeably by myself and Jean-Baptiste Labrune.

The left and middle show two sides of the same scene, a study of plants with a macro lens at a museum. On the right I am pondering a vertical green wall at a museum. The greenery behind me is actually the side of a building permeated completely with plants by an artist.

Figure 5.2. Left: Closeup study of the texture and composition of the non-living parts in various places sidewalk in Paris. Right: Study and consideration of a set of plants encaging a generator, then a set of metal bars encaging the plants, then that nested set of encagements forming a "C" shape with me inside partially encaged.

During our study of the city's cracks and crevices, and urban nature, we were intrigued to find plants in a cage, which upon investigation seemed to have been used to hide a generator, then the cage used to protect people from getting into the generator.

Next, at a hacker space in Paris, using several sensor boards, we began to study some of the plant and nature samples

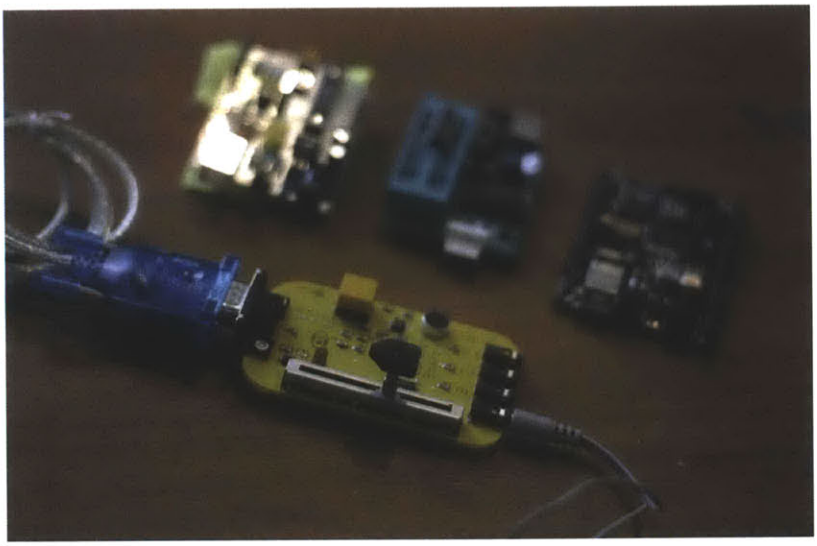


Figure 5.3. A Scratch Sensor board plugged in up front, with 3 other sensor boards behind it.

Figure 5.4. Scratch board with leaf measuring resistance; note early presence of bananas which later became important in Makey Makey.

Figure 5.5. The setup at the hackerspace. Lots of sensors, lots of crafts, and a room, with J.B., Evelyn, and myself.

Figure 5.6. The Scratch sensor board readout on a laptop.

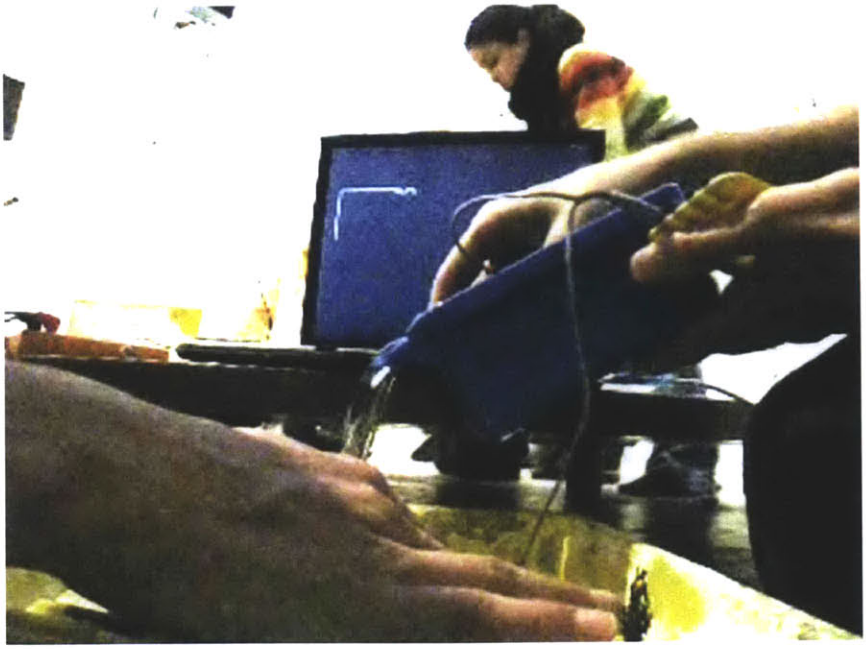


Figure 5.7. Pouring water from one bin to another while measuring electrical resistance as a graph over time as shown on the screen in the background.

Figure 5.8. Evelyn Eastmond playfully working, working playfully.

In these images above you can see Evelyn Eastmond, a previous grad student in Lifelong Kindergarten working on the sensors with us (right) being playful with the sensors (middle) and what happens when she finds a stage prop lobster claw in the middle of hacking (left). The reason I include the picture of the lobster claw attack is to show the mood during this phase of the exploration which was explosive and playful, like kids on an adventure.

With these ideas fresh in my mind off we went to India (Evelyn and I).

I, along with various collaborators on Geetha's team, and members of Lifelong Kindergarten, were running Scratch workshops at a slum school in India called Drishya. Specifically we were focusing on nature sensors (water, plants, wind, sun, etc.) + Scratch.

We showed the Drishya faculty and students some of the experiments we had done with the Scratch board and sensors that could measure nature.

Figure 5.9. Testing out the measurement of "nature" with Drishya facilitators using the Scratch sensor board

I was teaching myself how to solder and how to hack analog electronics. One day we were playing with PicoCrickets and had them hooked up to convert electrical resistance to sound. This was not the first time someone had hooked something up this way. But something was starting to emerge in watching the way these particular curious children reacted to "listening" to resistance, and here was a certain creative space opened up by my previous experiences with Camera for the Invisible plus the recent trip to Paris where we had worked with nature and sensors and urban exploration.

Later that day we played with the PicoCricket as a resistance-to-sound input/output pair:

Figure 5.10. Left. Listening to the sound of the resistance of an apple with a PicoCricket. Right. PicoCricket resistance-to-sound measuring dirt.

Figure 5.11. Pico Cricket resistance-to-sound measuring rubber or plastic bicycle grip

Figure 5.12. PicoCricket resistance-to-sound measuring skin on head

Electronics Hacking in India

That afternoon we went to Sadar Patrappa Road (S.P. Road) where all the electronics parts supplies stores are located. I bought a full electronics kit from 3 different stores including a hack saw, solderless and solder breadboards, resistor capacitor and potentiometer packs, LEDs, batteries, connectors and

wires, and anything else you need to do basic electronics. Then we went to Om Electronics, shown on the map below:

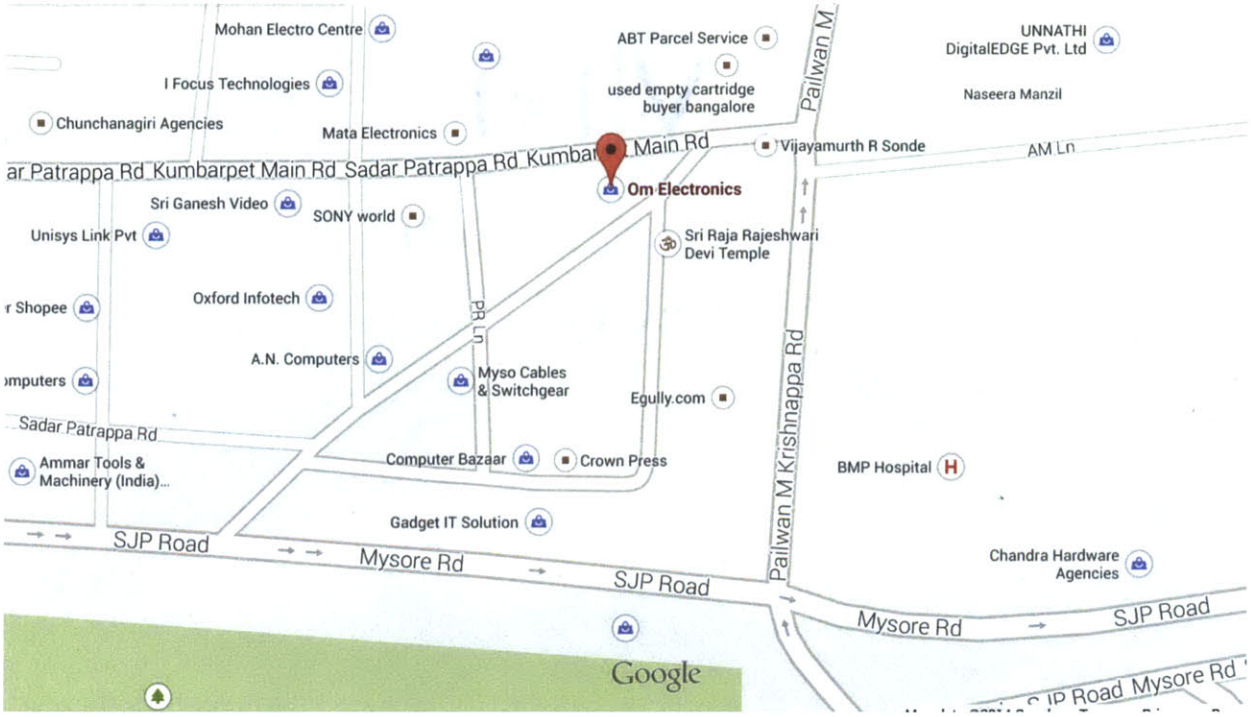


Figure 5.13. Where I bought the harmonium circuit is marked by a pin and the area around is where you can buy all sorts of electronics.

Here they had several "kits" to follow instructions and build certain projects. I bought a heartbeat detector and a "Harmonium Circuit", which was a piano circuit (harmonium is a more prominent version of a piano in India, although it is reed based).

Back at home I started soldering. I worked into the night until about 3am. I had a stack of metal bowls as the mother of the family downstairs would bring me vegetarian meals in metallic bowls that stack on top of each other as is common in India. I didn't have good lighting and I have bad eyes, but I did manage to get the harmonium circuit soldered and working (figure below). The circuit worked by connecting a metal wand from "ground" to any of a number of points along a resistor ladder. The higher in the ladder the more resistance was measured and thus the lower the pitch the harmonium circuit would make through its speaker. Each point in the resistor ladder was connected to a metallic pad that the wand could land on and connect the circuit.

At one point I spilled the stack of metallic bowls on the kitchen table where I was soldering (note to future people: solder is toxic with lead, don't solder on the kitchen table; I didn't know this). Some dahl spilled out of one of the bowls and onto the circuit. Oh no! It started to make sounds and as I cleaned off the dahl the sounds changed. At first this seemed very curious, especially at 2am (with my roommate Evelyn sleeping in the room nearby too). Then I realized the sounds were being made by the dahl on the resistor ladder connecting the 555 timer to ground. As I wiped up the lentils, the resistance changed.

Through some experimenting, I found out I could hold the metal wand in one hand and touch the pads with my other hand instead of touching the wand to the pads. Then I found out I could put the wand into

the lentils and touch the lentils with my hand and touch the pads with my other hand and complete the circuit. I had an idea. I dumped out a water puddle on the table. I put the wand in it and connected to the pad and the puddle with a finger on each hand. As I moved my finger in the puddle I could hear the resistance in the circuit loop changing. I didn't know what it all meant but it felt so fun and magical. I packed up the circuit into a ziplock bag I had been using to keep socks in from my suitcase. I put googly eyes on the bag to personify the circuit, and I soldered on two stripped solid core wires: one where the ground plane was and one coming off of one of the harmonium pads, and I poked them out from the bag so they were like two antennas for measuring resistance as sound (like a resistance input / pitched sound output pair). Yes, the PicoCrickets kit comes with pipe cleaners and googly eyes. I packed the mangled harmonium circuit into my backpack for the next day at summer camp / school.

Figure 5.14. Harmonium Circuit in a plastic ziplock bag with wires poking out and googly eyes for personification. This is the best picture I have access to of the circuit in the ziplock bag. The 9V battery is in the bottom right corner. The speaker is touching it. The green rectangular circuit can mostly be seen partially obstructed by a Drishya student's arm. The pads are silver rectangles.

We took the circuit and poked the "antennae" into all sorts of things

Figure 5.15. Listening to the electrical resistance between two separate clay plant pots

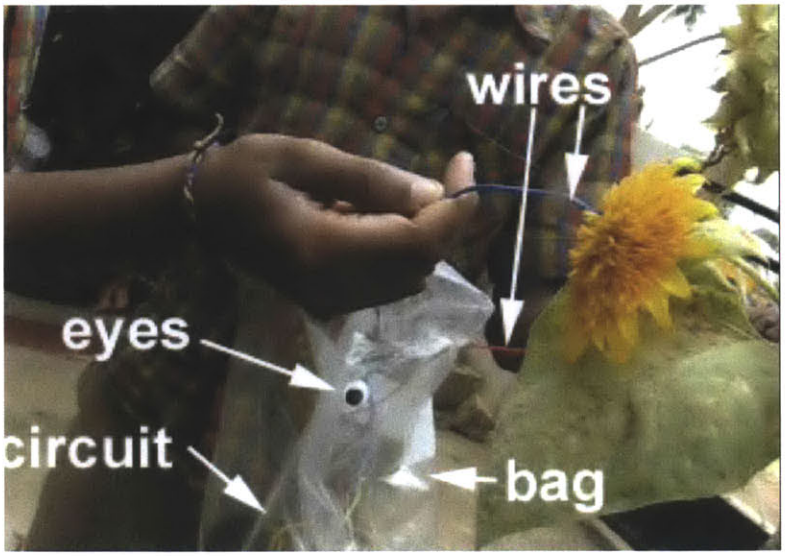


Figure 5.16. Listening to the electrical resistance between two flower buds

Figure 5.17.Trying the circuit in a bag in all sorts of scenarios explained below.

On the top you see two boys working together to listen to the resistance of a plant stem on the right, and to listen to the electrical connection between two separate pots of soil on the left. It was surprising to us that two separate pots would have an electrical path of conductance to each other. After experimenting with what became "Drawdio" over the next several years I learned that unpainted clay pots and concrete are water permeable and therefore conductive if some amount of moisture is present (unlike plastic pots and asphalt which are not).

In the second row, you can see the kids testing different metallic objects: tea kettles, tea cups, and door handles. Touching the circuit wires to metal resulted in a very high pitched sound (due to the very low electrical resistance of metal) which was almost painful, as it wasn't until later that I added some tuning to make a maximum frequency to avoid extreme audio annoyance.

In the third row, the kids went into the kitchen where the cooks were preparing lunch for the school. They listened to the hot metal pot as the cooks warned them to be careful and not get burned. They then asked if they could listen to some food and the cooks curiously engaged offering food scraps and listening in.

The fourth, fifth and sixth rows show people playing with their bodies as part of the circuit. In the fourth row, on the left a student touches the wires to my forehead then in the middle picture to his own forehead. In the fifth row, they touch the wires to their faces and on the right play hand clap games in a circle. In the sixth row of images, the student touches the wire to his face and either due to a capaciting charging effect or because he was adding more pressure to the wires with time the pitch of the sound went slowly up and up and up and he felt that he was being charged up or transformed into another being. So he started dancing in a Michael Jackson style perhaps it was the Thriller dance as if he was a monster. He can be seen howling in the picture on the left.

In the seventh row, the Drishya school facilitators took an interest in what we were doing and began to explore the electrical resistance of the edible garden.

Compared with the PicoCricket version of this resistance-to-sound conversion circuit, this circuit was so much louder (bigger speaker, bigger voltage), with such instantaneous feedback (analog .1ms delay instead of digital 100ms delay), and measured over so much of a wide range of resistance (10K to 100M instead of 10K to 1M) that it instantly caught everyone's intrigue: from me, to the Drishya students, to the Drishya mentors, and the graduate design school students and teachers at Srishti where we ran workshops on replicating the circuit:

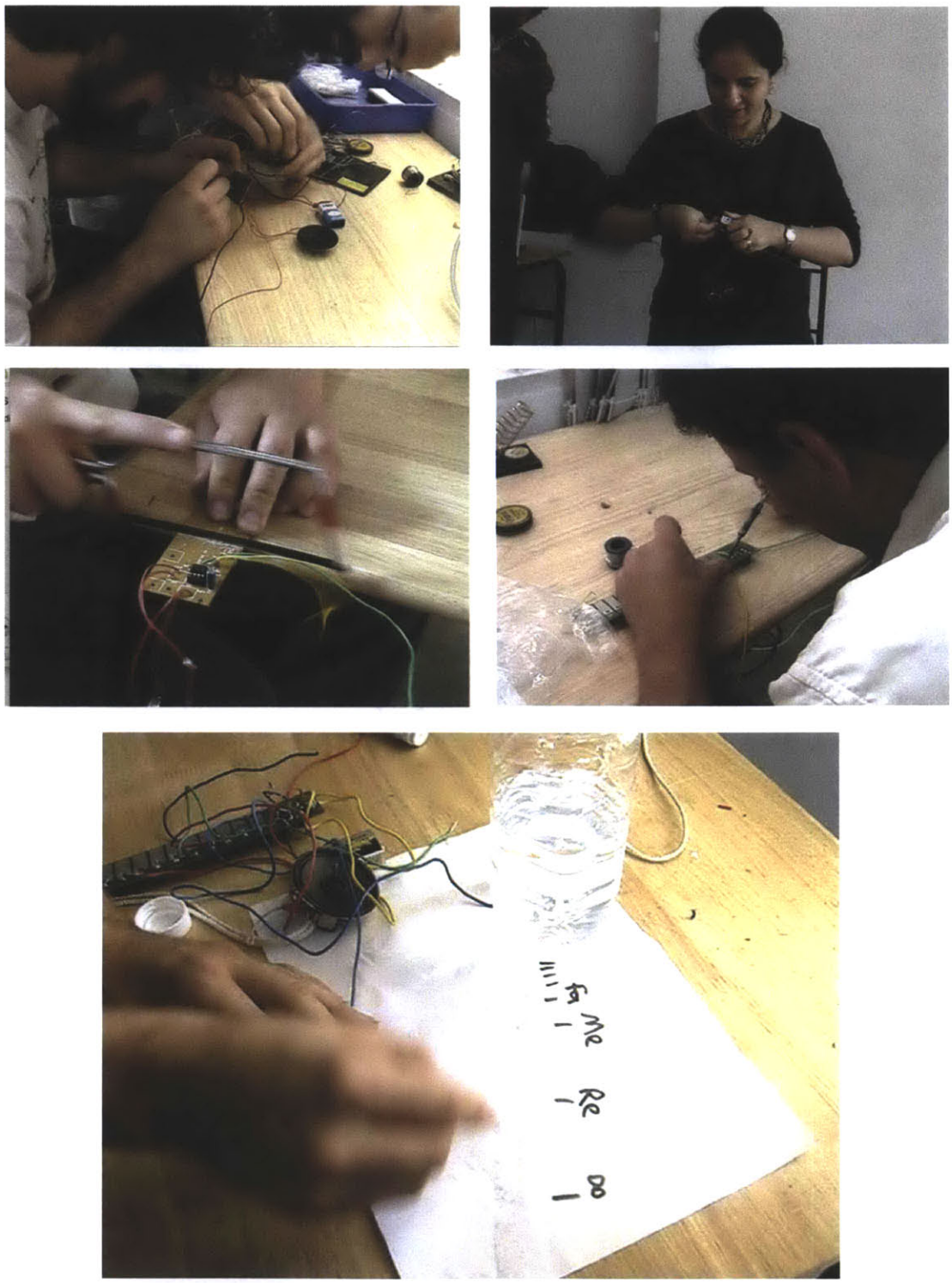


Figure 5.18. Top Left: Zack Denfeld, a professor at Srishti, assembles his circuit as I look over. Top Right: Teacher from K-12 school and a collaborator of ours from the Media Lab assembles her circuit. Bottom Left: Hacksawing the circuit apart to remove the "piano" part so that the world can become the piano. Bottom Right: Gabriel Harp solders his circuit together in the "World as Musical Instrument" workshop. Bottom: I pour water on a piece of paper after the "World as Musical Instrument" workshop and for the first time ever experience the joys of playing water as a musical instrument. I start to label the different points at which pitches on the major scale can be heard. Note at this point I am still touching two wires to the paper, not using my body yet. Bottom image is a still frame taken from a video by Dipti Sonawane.

In what was basically an amazing coincidence I walked into Zack Denfeld's classroom as he was teaching design grad students about circuit hacking. I showed the simple sound-making circuit in the ziplock bag and we played with water globbed up on a table. When you put water on a waterproof surface, it tends to glob up and stick to itself due to its own hydrogen bonding through what is termed water cohesion. But when you touch water with an object or your finger, the water also tends to stick to the object, termed adhesion. Through this cohesion and adhesion, simply playing with water on a waterproof surface is really interesting. But when you add a sound dimension to listen to the shape and connections of the water as they move around on the table, it was mesmerizing for the group as well as for myself. We decided to hold a workshop the next day for people to make their own circuits. I made a special run back to S.P. Road (Figure 5.13) to get the electronics ready for the workshop. Note that every driving excursion involves a driver who drives the car for you and what could almost be called a fight or perhaps on a good day a dance with the other cars, the heat, etc. The next day we all made our own sound-making circuits as depicted above in Figure 5.18.

The next night I made a "Curious Caterpillar" out of the hacked harmonium circuit by copying a page in the Bangalore kids' playbook and repurposing a plastic bottle, adding a switch into the nose and sparkly pipe cleaners onto the antennae wires. I added a neckstrap reusing my lanyard to help with hands-free operation.

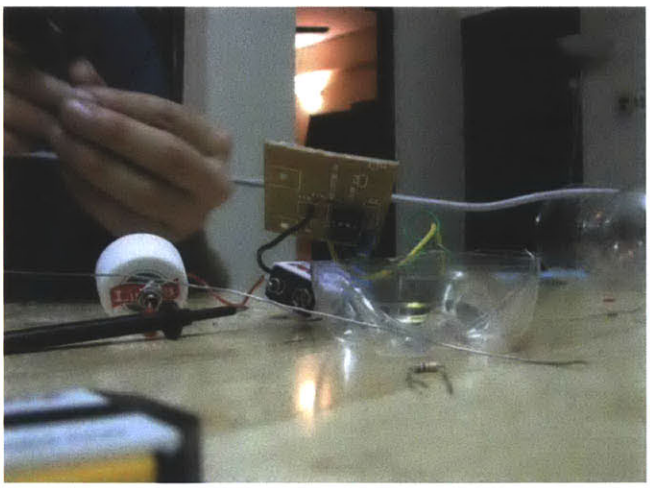


Figure 5.19. Me soldering on the kitchen table

This was all the most advanced "product design" I had ever done at this point with circuit and casing integration.

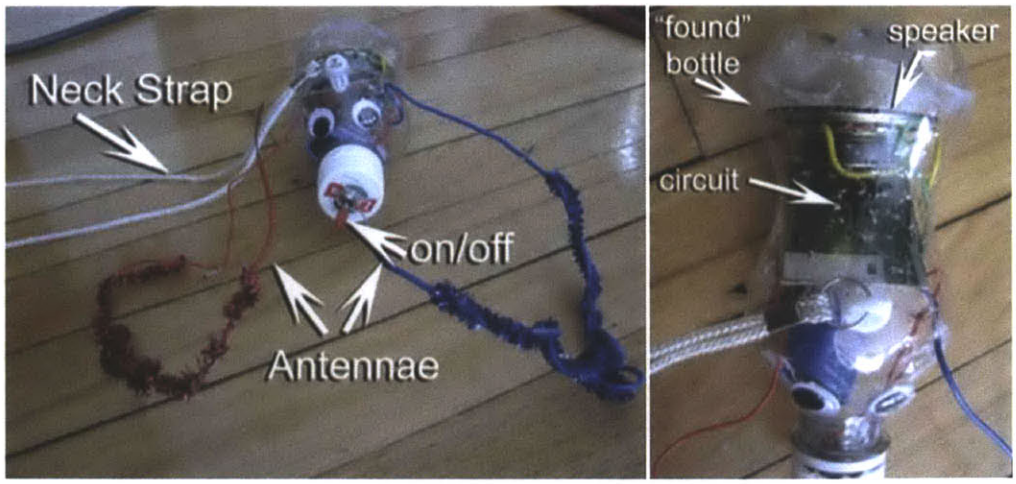


Figure 5.20. A repurposed plastic bottle containing the "Harmonium Circuit." A lanyard is attached for hands-free operation. The nose is a switch. The googly eyes are added just for personification. And the two wires to explore the world are positioned as if they are the bug's antennae.

Figure 5.21. The Drishya facilitator made his own circuit as well the following night. The picture on the bottom is while the electricity was out. The man on the right is the cook, the man on the left is a Drishya facilitator and on the left in the bottom picture is a Drishya student.

Now the facilitators were interested in getting in on making their own circuits. One of them stayed late

after classes, which was a significant sacrifice, and we worked with intermittent electricity and ungrounded electricity as I learned by getting my first A/C high voltage shock. They all laughed at me (in good humor). The cook also stayed and one of the students soldering with us into the night and having a great time.

The experience was an adventure, and the enthusiasm for exploring electrical resistance in the world as a sound was surprisingly high, though no one knew where it would lead.

The Making of an Invention Kit at MIT

Returning home to Boston, I showed this circuit to everyone both in my research group and to friends and collaborators. In discussing with Jeff Lieberman, he showed me that you can draw with a pencil on a piece of paper and that is conductive. We pressed the two antennae against the graphite "circuit trace" on the page and moved them closer together and farther apart to listen to the changing sound. That was interesting.

Crayola was coming for a visit to the lab as a sponsor, and the night before, as I sat meditating, I realized that the circuit should not be separate from the pencil, it should be connected to the pencil as a backpack. I got some perf board and soldered together the most compact version of the circuit that I could, copying the layout from a classic 555 astable timer circuit diagram freely available many places online.

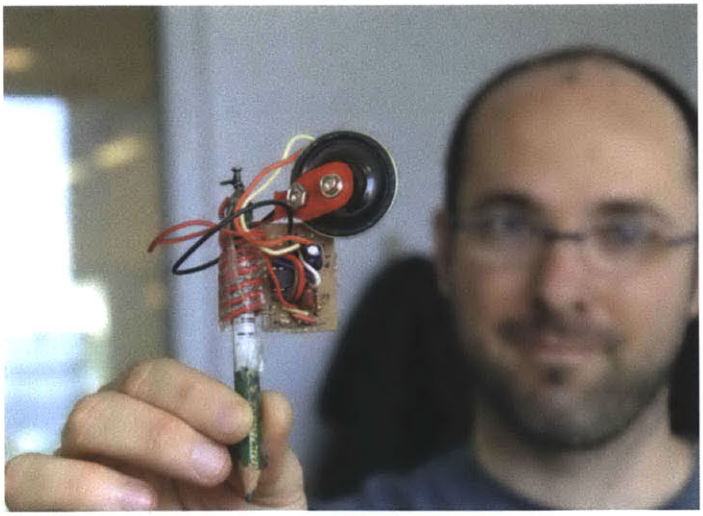


Figure 5.22. Me holding the original Drawdio pencil with a small screw jacked into the graphite at the top

This model (depicted in Figure 5.22) still required a wire to wrap around and touch the page, but when we presented it to Crayola I also presented a second model that allowed you to use your body as the wire so you could just touch the page with your finger. It wasn't until later that that circuit was fine tuned and worked well with the human body.

At this point I sketched out a circuit to etch on the Modela milling machine on foam backed copper (FR4)

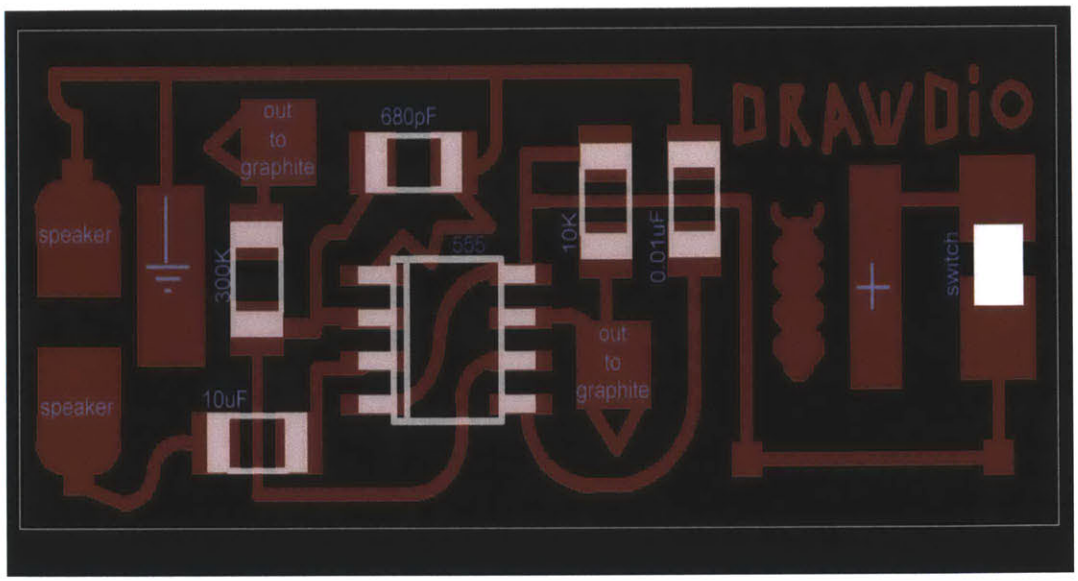


Figure 5.23. Eagle Board file showing the traces for the first custom-milled Drawdio circuit. You can see the caterpillar drawing left over from before the board got the name Drawdio.

The name of the circuit evolved slowly from Curious Caterpillar, named after the bottle form factor with the antennae, to Drawdio, named after "Draw + Audio" in the pencil form factor.

I started to iterate on designs

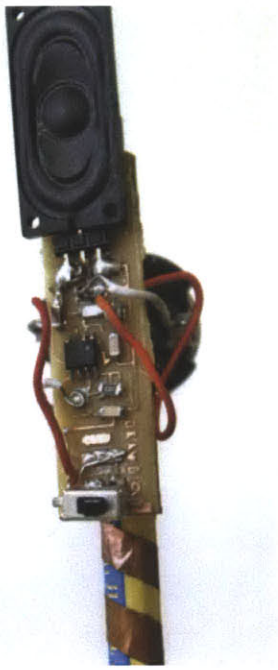


Figure 5.24. Mechanical pencil with Modela-milled Drawdio circuit attached. The mechanical pencil had the attachment to the metal tip of the pencil which came into contact with the graphite as opposed to the screw into the top of the pencil.

I took this mechanical pencil to my first ever Maker Faire in Austin (the second year Maker Faire had existed). I let many people try it out

Figure 5.25. Youth trying mechanical pencil Drawdio at Austin Maker Faire

At this point Maker Faire was relatively unknown around Media Lab and several in my group were indifferent to me mentioning I would attend. (Thanks to Amon Millner for taking me).

There was so much enthusiasm for Making in general at Maker Faire, as well as that expressed for the Drawdio pencil. I met up with Limor Fried who I knew briefly from MIT who now runs Adafruit, an electronic kit making company. She said Drawdio would make a good kit.

Back at MIT Media Lab I continued to invent using the guts in the circuit of Drawdio.

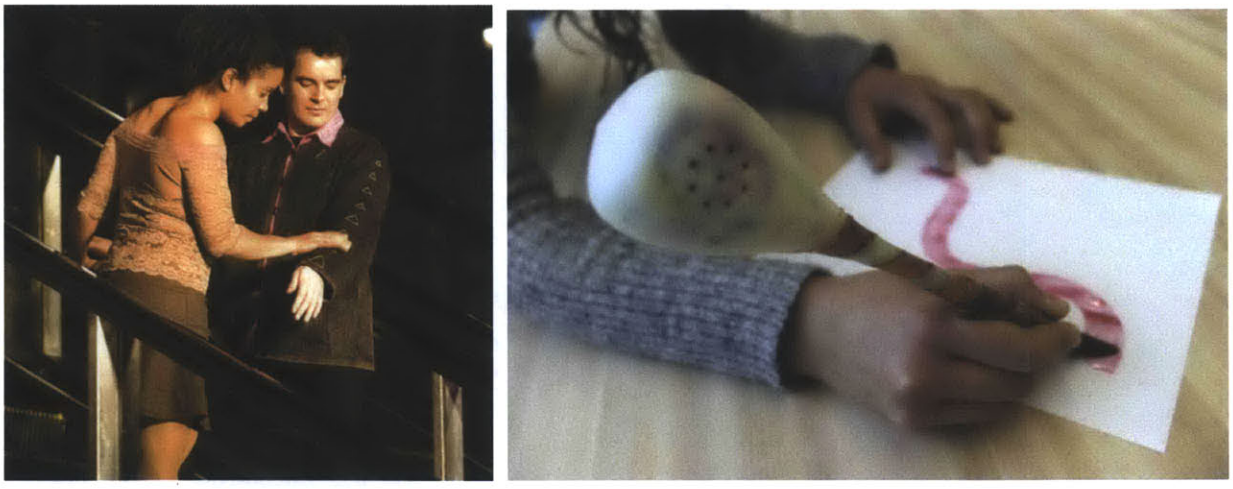


Figure 5.26. Left: a musical jacket with the Drawdio circuit inside "Ok2Touch". Right: a musical paintbrush with the Drawdio circuit inside exhibited in museums

I then got back in touch with Limor Fried and Phillip Torrone, the two people in charge, at Adafruit and we agreed to make a Drawdio Kit together. This would be a solder-it-together type kit and then attach it to a pencil to make a Drawdio. At this point I started to realize that I was inventing all kinds of fun stuff with this circuit and that the real product here wasn't the pencil, but the ability for people to invent all kinds of things, just like I had been doing, they could do it themselves. I suddenly saw that this was where the real value was. Not a huge surprise since I was in a group, Lifelong Kindergarten, that studied creative

platforms, but I had veered off into a separate exploration as a media artist, and now I brought the Drawdio back to the point of an invention kit. I released the kit with Adafruit and this gave me a steady supply of Drawdios to workshop with people en masse. I began to workshop the Drawdio (more on that in Chapter 7).

I also created the "Sample Space" video which showed the Drawdio being used in 26 different scenarios within 1 minute and 44 seconds which garnered 630,000 views on YouTube. More on that video in a future chapter. The sample space video was probably inspired by Hiroshi Ishii's students' videos, such as Hayes Raffle's Topobo video and in particular Kimiko Ryokai's I/O Brush video.

The original Adafruit Drawdio kit shipped with a pencil and a thumb tack and was intended to be made into a musical pencil. Note the innovation which came from Limor to jack into the graphite with a thumbtack through the side of the pencil instead of the screw through the back of the pencil.

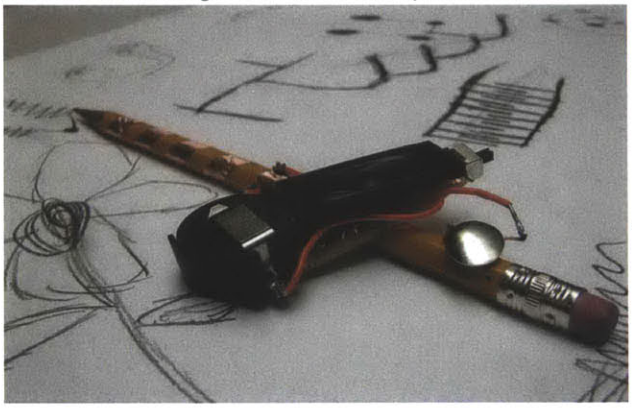


Figure 5.27. a Drawdio circuit thumb tacked onto a regular wooden pencil along with example of musical instruments drawn on the paper.

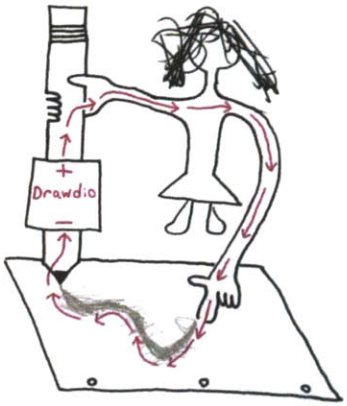


Figure 5.28. a cartoon depicting the flow of electricity when using a Drawdio Pencil: out one side of the circuit, across the outside of the skin of the body, through the graphite on the paper, into the pencil's graphite core, and back into the other side of the circuit.

This iconic project exemplifies one of the core principles of Drawdio usage: you can take an object designated for one purpose and reassign its intended use. Graphite can be a wire, drawings can be musical instruments, your body can be part of the circuit.

Since then, people have invented hundreds of interactive objects using Drawdio as an invention platform.

Furthermore, because the circuit is so simple, tens of thousands of kids have now learned to solder using their own Drawdio circuit boards from a kit.

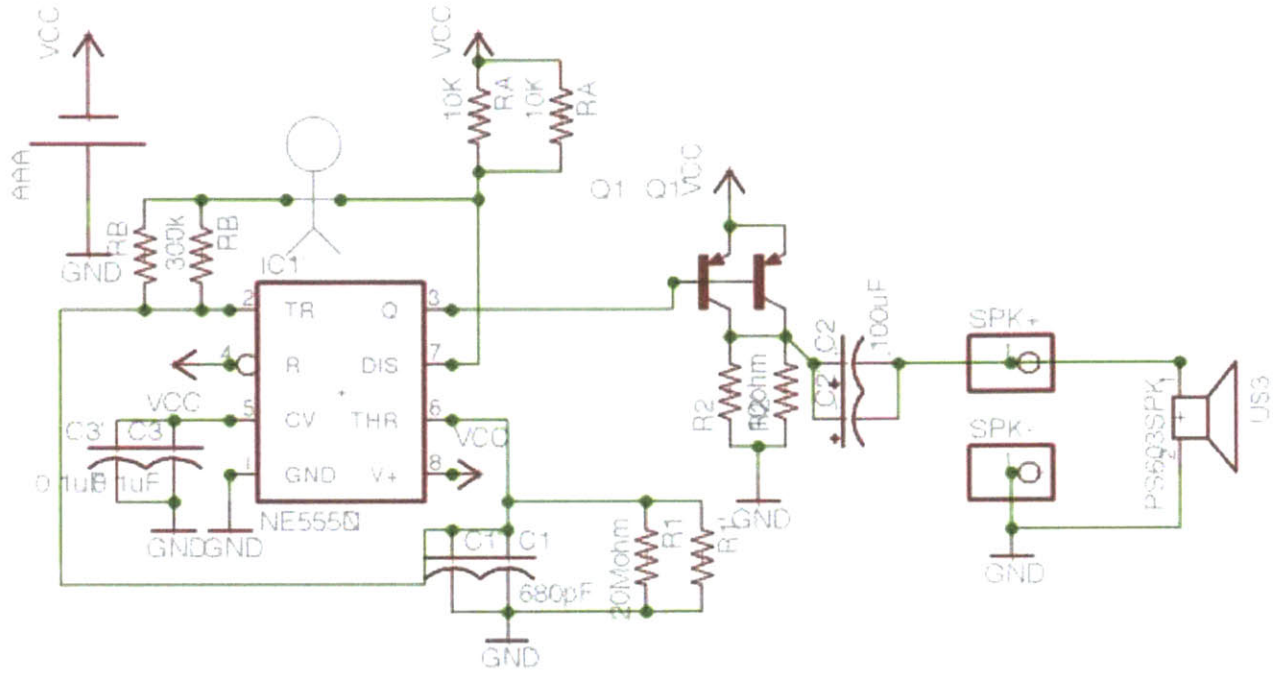


Figure 5.29. A modern version of the Drawdio Circuit, which consists primarily of a class of timers commonly called 555 Timers along with some peripherals such as a battery and speaker. The main difference between this 555-class Timer circuit and a typical one is that one of the resistors is left open "to the world." This is represented in the diagram by a stick figure. This is the version of the circuit that is currently distributed as a kit. This circuit design was led by Limor Fried with me giving feedback along the way. This circuit diagram drawn by Limor Fried.

Because of the new insight that Drawdio is truly an invention platform, Adafruit and I released a second kit called Drawdio Fun Pack, which comes pre-soldered and ready to be used for invention:

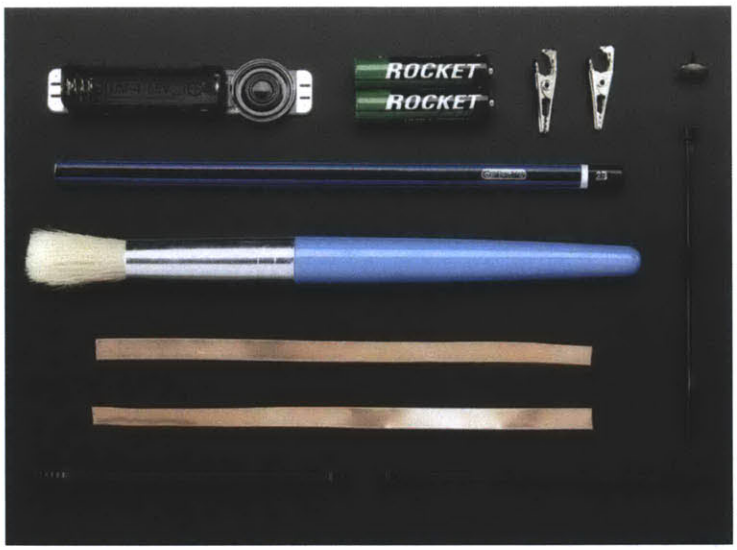


Figure 5.30. Drawdio Fun Pack comes with

- *Assembled & tested Drawdio - no soldering required!*
- *Large brush*
- *Soft lead pencil + thumbtack*
- *2 x Alligator clips*
- *4 x Wire ties (the photo shows 2, but the kit has 4)*
- *12" of copper tape*
- *2 AAA batteries included!*

This Image reproduced from adafruit.com. Thanks to Limor Fried for leading the design of this kit.

This is the Drawdio that was used for all the workshops, and is the Drawdio referred to whenever "Drawdio" is referred to abstractly in the case studies below.

Along with the kit there was also a Drawdio video which showed example projects that you might make with the Drawdio. This is critical to the activity. The original Drawdio actually isn't that much different from a 40-year-old 555-timer circuit, just a couple alligator clips and circuit tweaks. But what is new and makes the product feel like so much more is possible is the Sample Project Space video.

Figure 5.31. Introductory Portion of Drawdio Sample Space Video available for viewing at Drawdio.com

Most workshops were run in conjunction with this video so it is important to show it since without it one might think "what do I do with this Drawdio thing?" This is the first half of the video where the viewer is oriented to what the Drawdio is. The first substantial scene is the Drawdio getting thumbtacked into the pencil as shown in the top row on the left. The pencil is considered the iconic example and also a great example of what you can do with a Drawdio. It's also named for this example. Then the simplest thing is shown, a line is drawn and the finger touches the line and the pitch goes up and down corresponding to the finger sliding closer and further from the pencil tip. Then top row right a spiral piano is drawn and discrete notes are played by touching the pads with the pencil on the spiral piano, playing a tune.

The circuit is then unhooked from the pencil and attached to an ordinary paintbrush, middle row left. Again a line of water is drawn, middle row center, and the finger plays the water as before. Finally a tune is played on a leather couch arm.

The circuit is then unhooked from the paintbrush and attached to a kitchen sink, and again an up and down slide is played, and then a tune is played (in this case "The Itsy Bitsy Spider Went up the Water Spout").

In each of these three examples the circuit is built in front of the person and some orientation time is given followed by examples. This is the "slow" half of the video although it takes only a minute to go

through these.

Figure 5.32. Second half of Drawdio Sample Space Video available for viewing at Drawdio.com.

The video then speeds up and starts showing one example after the next in just a few seconds each. Top row is an indoor tree, a musical jacket, and a group holding hands. MIddle row is food: mac 'n cheese, Gatorade, and a banana. Bottom row is outdoors, a tree, a metallic rock-like sculpture, and a bike wheel. At first they are about five seconds each, but they start to dip into the three and two seconds each range crescendoing until punk rock music plays and lots of images flash and spin. See the video at drawdio.com.

The intention is to first orient the viewer, and show the full buildup of the project to make the viewer feel at ease that it is easy to do. Then to show a small jump from the first example, a pencil, to a more complex example, a paintbrush. Then a bigger jump, a kitchen sink. Then just jumping all over exploring various things as fast as possible, giving the sense of the range of possibilities.

Ideally, the participant in the workshop who watches this feels informed and inspired, but still feels like there's lots of creative space, in face more than before watching the video, in all the space inbetween the examples shown, or with re-exploring examples that are shown or variations thereof.

6. MaKey MaKey Genesis

In this chapter I'll tell the stories of how I came to think of computers as crafts, and apps as something worth remixing just like popsicle sticks are glued together. These stories will form the soup in which you will perhaps be able to imagine how Makey Makey could have come about. Then I will tell all about the evolution of Makey Makey with special attention to the design of the user interface, ending with the launch of the project.

Computer Crafting

Computer Crafting is the name I have given to using computers just as if they were any other craft material: tape, play dough, paper clips. This is to treat the modern advanced machine of our day as just another piece in our prototypes or crafts.

In summer of 2009 I found myself back in India running some more Scratch workshops, this time on mobile devices (keep in mind this is just barely pre-iphone still) supported by the work of John Maloney and the Scratch Team. The workshop I designed was based on an idea called Awareness Mapping, a theme co-developed with Karen Brennan (my groupmate), and executed with support from Zack Denfeld and Geetha Narayanan's Drishya team and worked like this:

We went out and took pictures of urban nature in the slums the children lived in.

Figure 6.1. Students at Drishya, a slum school, "taking photos of nature" in their community however they choose to interpret that instruction.

We drew a map on a big sheet of paper of the entire village. Each youth then picked their favorite example of nature, and we acted out what that piece of nature actually does with live role-playing theater.

We then talked about how maps are static and flat, but actually the world is 3D, dynamic, and moving around. We drew a chalk diagram of parts of the map and added in arrows to represent the motion and dynamic nature of their village. Then we made 3D paper models to overlay on top of the map.

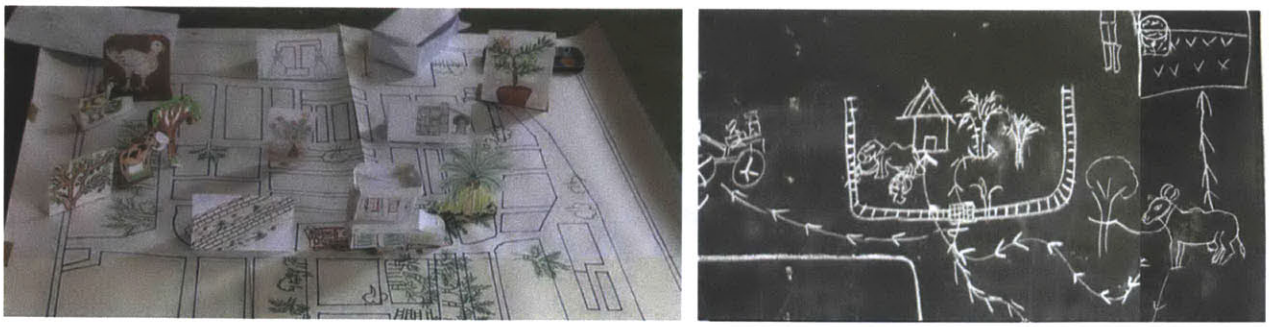


Figure. 6.2. Left. The map of the village with 3D popup models of each child's favorite aspect of nature in their community overlayed. Right. A chalk drawing of one part of the village's dynamic motion. The arrows show how the milk trade carries out each day.

At that point it was time to make the map dynamic using computers as if they were just another craft material. At each part in the map where the children felt they wanted to represent an important part of nature to them, they cut a hole the size of the mobile device, in this case it was a Nokia 810. Then in Scratch the photos they took were used to create interactive projects that responded to taps, sounds, etc., and made some animations or noises as a result that represented the nature in that location. The resulting map had a dozen or so interactive mobile devices embedded in the paper that ran simultaneously.

Figure 6.3. Left. Computer crafting example closeup, screen worked into paper crafting. Right. Map with holes cut in it for mobile devices to be inserted. In the picture are myself, collaborator Zack Denfeld, and the Drishya students.

The picture on the left is one of those 11x17 sheets of paper. It is a good example of computer crafting. The screen is embedded into the middle of regular paper. The bricks on the screen are contiguous with the bricks drawn on the paper, as is the water in the ditch (blue on the paper, blue on the screen, although color in the photograph appears mismatched due to screen brightness). A mosquito flies around in the ditch between the bricks. These mosquitoes can carry malaria and are a problem in this ditch in this slum village, which is why the student chose to focus on the corresponding picture he had taken in Figure 6.1 on the left. When you "clap" the screen sends the mosquito away but it comes back.

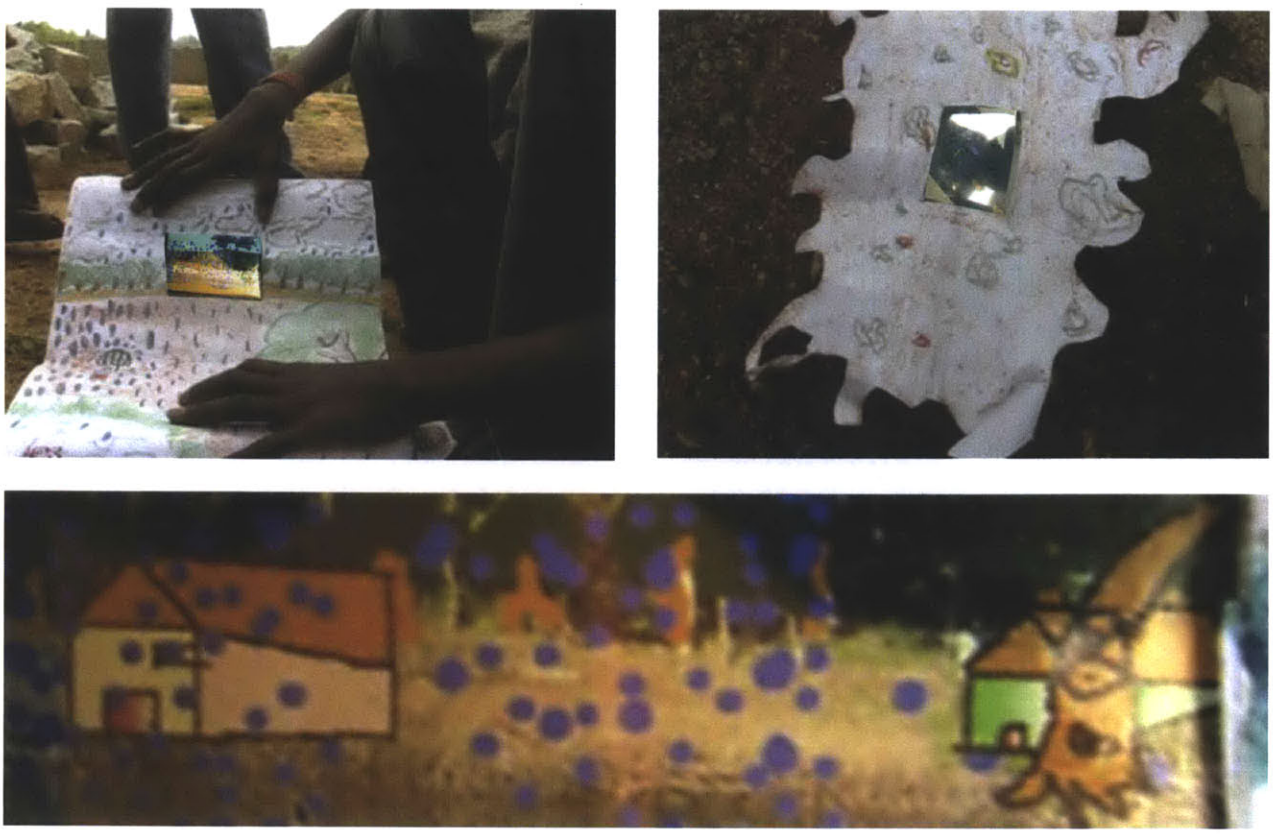


Figure 6.4. Top. Two examples of interactive map pieces being installed on site of the places in the map which they represent with computation and paper crafting merged. Left. A monsoon that ruined what used to be this student's home. Right. A problematic bathroom/trash area. Bottom. A closeup on the screen of the monsoon rendering the student's home unlivable (one of several frames of an interactive animation. In this frame the rain is the front layer that moves across the background layer of the houses and trees).

After showing the map to the other students in the school, we also made individual installations for each location from the map, like little breakout interactive maps bits, and took them to the locations which the mini map represented. On the left we see an installation on the site of the student's home which had previously been ruined due to a very heavy monsoon. On the right we see an installation on bathroom and garbage heap, where the paper itself has been made to blend in with the dirt and trash around it, as has the screen been made to blend into the paper. At each of these temporary installations the families of the children and some neighbors naturally gathered around the installation site as the children told their story of how they interpreted the interactive map and how the situation affected them.

That Fall I continued my work on Computer Crafting using the Nokia 810's in a Not Back to School Camp workshop where unschooled teens were explicitly encouraged to craft the mobile devices running an interactive Scratch project directly into their environments

Figure 6.5. Interactive Fashion - Scratch running on Nokia 810 duct taped into teen's hat, at Not Back to School Camp computer crafting workshop

At this point I was so excited about the idea of crafting on the fly with computers the same way we craft on the fly with material (paper, popsicle sticks, and everything else), I decided to try out computer crafting for Halloween. I dressed up like a doctor, and I cut a hole in my blue scrub shirt near where my heart would be. I downloaded an animated GIF of a beating heart, and I loaded it into Scratch. I then made the speed of the rotating images be proportional to the amount of noise around me, so that the louder the environment the faster my heart appeared to beat, or if you yelled at me my heart would beat really fast. Then I inserted the laptop under my shirt. It was an IBM Thinkpad, which was able to open up to 180 degrees, so the trackpad was held tight under my belt while the screen was sticking way up to my chest over my heart where the hole in the shirt was. The keyboard sat hidden covered by my shirt, in between the hole in the shirt and my belt. All that was visible was the part of the screen showing the life-size heart beating, cropped by the circle cut in my shirt. I added a little fake blood to the T-Shirt around the hole, and carried around a knife with me that night saying I was doing my own open heart surgery.

Figure 6.6. A Halloween I made costume using a laptop inside of my shirt, a technique I call computer crafting.

App Dumpster Diving

I knew computer crafting was going to be big, but I also knew that it had to be more accessible. Up until now, all the examples I have shown used custom software built (in Scratch) for that specific computer crafting scenario. It would be nice if apps could be grabbed and reused, with the customization being a later step. LEGO has one damn rule: you push blocks together to make them stick. That's the kind of computer crafting we needed if we wanted a low bar to entry. Over the next several years I would try desperately to make something as complex as a computer controllable by something as commonplace as a pencil. Or as my advisor says in his paper, Computer as Paintbrush: "Which of these things doesn't belong? Television. Computer. Paintbrush." He goes on to say it's the television that doesn't belong. But when does a computer feel like a paintbrush? When does a computer feel like mud? I wanted to make that jump from drawing sounds with a Drawdio to "drawing" or "painting" computation with a computer. But how? I didn't know. But I had lots of ideas.

In this section I will tell about several prototypes that were never even named or documented, that took a day each, or a week in the case of Gesture Base Scripting. These ideas and prototypes are meant to show the space I was searching around in, which lead to a sort of area which I was steeped in when Eric and I first invented Makey Makey.

Pencil Volume Control

At first I got together with my undergraduate researcher, Tyler Williams, and tried using my trusty Scratch sensor board, hacked slightly to read higher resistance levels to make it more in line with measuring real

world items. I hooked up a pencil to a Scratch Sensor Board, by jacking into the graphite running down the middle of the pencil using a thumbtack. I set up a program in Scratch to let the resistance of the sensor be linked to the volume of the music playing inside the Scratch program. In this way, I was able to draw on paper to change the volume of the music, and it was fun because I could draw different shapes and patterns that would control the volume in interesting ways:

- stripes that made the volume oscillate quickly between on and off over and over again as I slid the pencil across the stripes perpendicularly
- a simple line that slowly faded the volume up and down as I traced over it with the pencil
- Pencil sketched icons of a party, a restaurant, and a person sleeping, each of which would turn the volume to the appropriate loudness: max, middle, silent, when touched with the pencil (the amount of resistance, and thus the volume, was "programmed" by how dark the lines I drew to the icons were).

This definitely felt right, but only being able to control volume just didn't feel explosively expansive or empowering with wide scope. I experimented with controlling the mouse-x and mouse-y with the pencil and this was interesting as you could draw a mousepad of various shapes, so I explored mousepads some more next.

Anything Mouse Pad

I had an idea to make a mouse pad out of a dish of water. I wrote a Scratch program to triangulate the 2D position of an object based on three distance measurements from the object each to a known separate point. I ran upstairs and grabbed Jamie Zigelbaum, a Media Lab student and collaborator, because prototyping alone just isn't the same. We took a small plastic tub, actually coincidentally it's the same one pictured in Figure 5.7 Left, and attached three wires to the corners of the tub on the inside with tape. We connected each of the wires to the resistance input sensors of the Scratch Board (hacked with 100M Ohm resistors so that it could sense the higher resistance of water accurately). We then grounded a fourth wire, and moved the fourth wire through the water in the tub. We used the Scratch program I had written earlier to transform the three resistance measurements into a location of the fourth wire, so that we could then move the mouse cursor on the Screen to wherever the fourth wire was in the water dish. Within 2 hours, after a lot of calibrating, everything seemed to be working, so we used the Scratch "pen down" feature to try to draw a line on the screen by drawing a line in the water. Then line ended up being jagged and a bit curved, but it did work! Momentary excitement faded into the big question:

How can this be an empowering toolkit or platform that many people can create with?

The idea of making a "mouse pad out of anything" was pretty interesting: mud, cereal, a still-wet painted picture, and to this day I wonder if there is something latent in this project waiting to be developed. But I was searching for something bigger. Something without:

- A long or potentially confusing calibration stage
- The need to use with special software
- More diverse outputs than different types of mice

Gesture Based Scripting

Nintendo Wii controllers (WiiMotes), which are basically bluetooth-enabled accelerometers for the purposes I'm using them here, had just become easy to hack with the release of some new open source software. Tyler Williams and I repurposed a Hidden Markov Model Gesture engine and combined it with a WiiMote and a scripting language that let you make your computer complete certain tasks (called scripts) upon receiving a particular gestural input from the WiiMote. Further we let you define your own gestures. So what we ended up with was a situation where you could define a script by recording it on your computer: press record, do an action with the mouse and keyboard, press stop. Then that action could be repeated when you perform a certain gesture. To define the gesture, hit record, move the WiiMote in a certain pattern, then hit stop. In this way you could make actions happen, discrete actions like pushing a button to initiate a sequence of events rather than tight feedback of each motion of the hand mapping to subtle shifts in sound or mouse motion. In this way you could make:

- A video play when you take a sip from a cup (WiiMote taped to cup)
- A sound play when you dance a certain dance move (WiiMote tucked in gym sock)
- An email send "someone is here" when someone opens your door
- Make a character in a game jump when you jump

For the first time I felt the power of being able to control every webpage and every computer program on your computer. The scripting language worked just like the mouse and keyboard, so anything the mouse and keyboard could do the scripting language could do. This was so powerful because nearly every piece of software ever made can be controlled by mouse and keyboard.

However, configuration was still very time consuming, the gesture recognition could be frustrating, and didn't always work. In addition, scripting languages are complicated and only execute correctly if you set up all the right conditions.

With enough work, this has a chance at being a powerful platform, but I left it as I felt its fruit was not low hanging enough from an implementability standpoint, and something felt a little bit too Artificial Intelligence about it instead of Human Intelligence. In other words there was a feeling of wiz bang about what the computer was doing, when that type of feeling should really be felt by the person for what they have created. In any case I still believe it has a chance of going somewhere someday.

Application Dumpster Diving

This would allow a new form of digital repurposing, or what I sometimes like to call digital dumpster diving. By allowing people to scrounge around the web for photos and sounds, many visual and sound artists are greatly empowered with the entire digital world's worth of billions of images and sounds to pull from. Photoshop and Audacity are examples of image and sound editing programs that let you chop up images and sounds that you find and remix them in new ways. Currently, only the coding elite, people who have a mastery of programming, can mix and match pieces of applications (typically in the form of code) to make new uses out of the applications. How close can we get to giving the non-expert-coder the opportunity to grab apps and use them in new ways, to dumpster dive through a pile of interactive webpages, and make new meaning out of what they find, just like an artist who pulls items from a dumpster and makes a sculpture? Probably not as close a coding will get us, but by giving people the

ability to control and use applications in a new way, that is a step closer with a lower bar. What if we could extend applications to the list of things that can be found and reused on the computer and on the internet?

Prototypes

Magic Seth first introduced me to a new type of workshop [Cottam, Defcon 2013, Sketchtools: Prototyping Physical Interfaces] and hacking activity where people take keyboards, pop the plastic keys off and solder wires to the two leads underneath the button, which would normally be connected via a person pushing the keyboard button. Now the two leads could be extended to two wires which could be taken out to the world and hooked up to any ordinary button or switch, or one can make a custom switch by which two pieces of metal come together through any action, thus connecting the keyboard button circuit. This idea was powerful and reminded me of the scripting I had done in the gesture-based scripting section and of the mouse input I had done in Anything Mouse Pad section.

Eric Rosenbaum started using this technique to trigger the pieces of software he had written using big buttons rather than using the laptop on which he had written the software. You see, a big secret of prototyping is that the fastest way to prototype anything is almost always on a laptop (in other words, on a personal computer) because that's where coders have the most freedom with multiple powerful languages and powerful processors all available in the same place. But unless your software is meant to be distributed on a computer, then you quickly want to embed that computer into your creation so it becomes more experiential and less like the experience of using a computer, or you want to migrate it to a new embedded platform that is ready to talk to sensors. Here Eric and I were, literally stuffing an interactive music project Eric had made on a laptop into a box. This meant stuffing the entire laptop into a wooden box, and then popping off a mouse click button (analogous to how the people would pop off the keyboard keys in the workshop mentioned above), and soldering wires to the mouse click internal leads to hook up a big red button on the outside of the box which would help control the interactive sound installation. If this is not computer crafting then I don't know what is, but it requires a somewhat high level of hacking skills to write the custom code, and solder to the mouse guts.

At this point a new idea was fertile and ready to emerge. We needed to give people access to push any keyboard key or control any mouse function, just like the hackers in the workshop, but on the fly in a matter of seconds. This could be the secret "duct tape" that could join any computer app with any everyday object.

Inspired by computer crafting, and app dumpster diving, and still interested in "how to make Drawdio talk to computers," Eric Rosenbaum and I built a prototype of what yet had no name, and would have interim names like Project Q and The Mousinator, but would become Makey Makey. Eric carried out the first prototype building with some technical hardware input from me for a workshop stint at the Exploratorium. This first prototype looked like this.

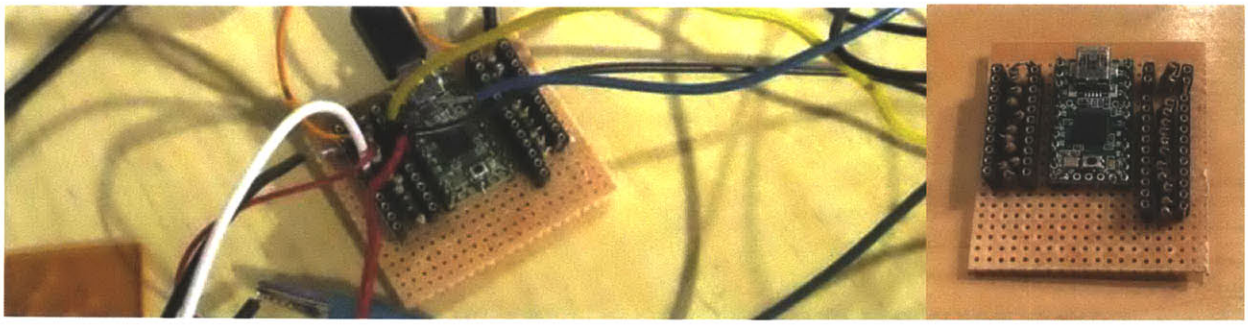


Figure 6.7. First Makey Makey prototype on perf board with a Teensy and some female header and 10 Mohm resistors for the resistance sensing. (Photos by Eric Rosenbaum)

It was built on a Teensy (a type of microcontroller platform). The teensy is the green circuit in the middle of the prototype. It is stuck into perfboard (brown), which is like a free form grid of holes to stick circuit pins through and then solder and connect the pins as you like on the opposite side. Then going outward from the teensy are two sets of 2 rows of female header pin, which wires can stick into (and are doing so in the photograph). The inner row of female header are all ground or "earth" pins. The outer rows are keyboard and mouse triggers: ASDFGHJKL, and the mouse sensors at this point worked by measuring the amount of resistance and mapping the mouse x and mouse y to that amount on the screen (low resistance, mouse x would move the mouse to the left, high resistance move mouse x to the right). Each keyboard key could be triggered upon connecting the ground to that keyboard key through an object, so long as the object was less than 10Mohms.

It showed some promise and in Eric's workshop the creative people in the Tinkering Studio at the Exploratorium were able to get examples up and running such as aluminum foil pads for Dance Dance Revolution, an interactive foil user interface where you blow on the foil to make art on the Screen using Scratch, and drums embedded in to jean pants.

After the workshop, the momentum for the project lulled and it sat still for 1 year. At that point I was in the summer lull in between interning and coming back to school, a beautiful moment in time with no responsibilities. I had been interning at Intel in Silicon Valley. The entrepreneurial spirit of Silicon Valley is somewhat contagious, and I found myself thinking about what would make a good second product to follow Drawdio. I did not have the foresight to know that the Mousinator/Makey Makey would be the one. Instead I turned all my loose ends around in my head, projects mentioned previously in this chapter, and others unmentioned. In daydreaming like this, I realized that the mouse motion for Makey Makey did not have to be an analog sensor that moved the mouse to the point corresponding to the resistance. It could just be a button like all the other keyboard keys, which when pushed would continuously move the mouse in a direction (up down left or right) until the button was no longer pushed. While not as beautiful in some senses as analog input can be, this would provide a single uniform rule, like LEGO has, of how to use the device, and yet the device could control your entire keyboard and mouse. Everything would simply be a button input, on or off, purely digital, connected or not connected. This seemed like the type of breakthrough elegance needed to let anyone understand how to use the device. There would be only one rule:

> Make two objects touch each other to trigger an action on the computer

And this single rule would let a person hook any object in the world up to any program or any web page or app on their computer.

I was excited about Santa Cruz, where we had been living, and Silicon Valley. We (my family and I) decided to drop out of MIT and move to an Ashram called Yogaville in Virginia for 6 months, followed by a move to Santa Cruz. It was during the time at Yogaville that the hardcore development of what would become the Makey Makey really happened. I would collaborate with Eric, still at MIT, first by landline, until I was able to get Internet set up in the remote foothills of the Blue Ridge Mountains (I literally ran an ethernet cable 600 ft through the woods to share 1 MBit/s internet with my nearest neighbor).

We had narrowed down the Makey Makey from a board with dozens of inputs, even considering at one point the idea that we could have one input for each and every keyboard key on a computer, down to a board with just 6 inputs: up arrow, down arrow, left arrow, right arrow, and space bar, and mouse left click. We arranged those six buttons to look like a game pad controller with "Earth" along the bottom.

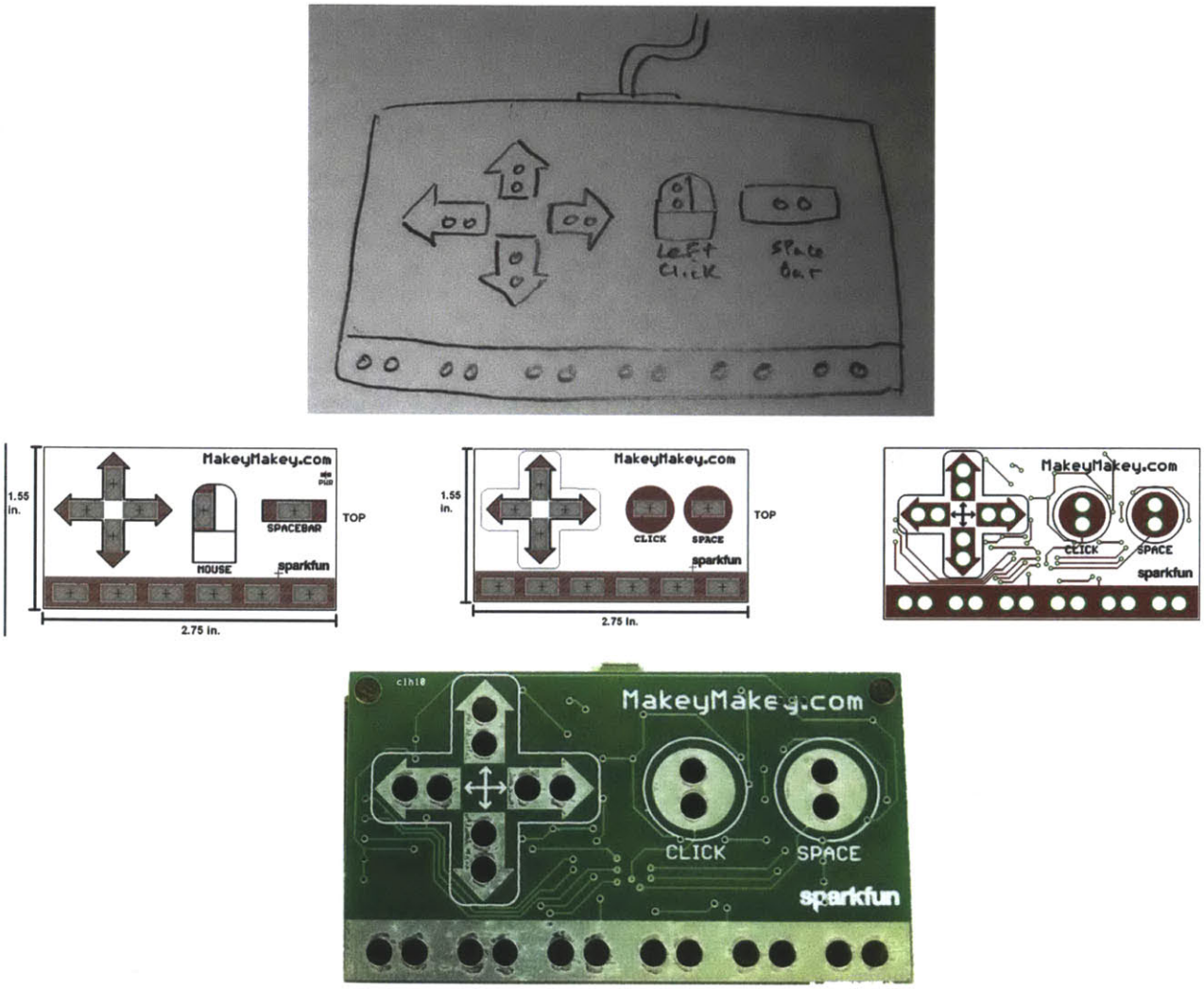


Figure. 6.8. The first sketch of the modern Makey Makey interface and iterations from there to the second functional prototype that we used to do user testing and make an example projects video

We started collaborating with an engineer, Jim Lindblom, at SparkFun to draw up the board. We gave him the drawing on the top. He gave us the drawing on the left in the middle row. We Photoshopped that and gave him the drawing in the middle to make the mouse and spacebar look like buttons, round, and to put

an outline around the arrows. He implemented the changes and gave us back the drawing on the right. We approved it for the second prototype (the first one made by SparkFun), and he sent us actual circuit boards like the green one you see on the bottom. The firmware was a collaboration between Jim, myself, and Eric.

Once we had the circuit board in hand we were ready to make a sample-project-space video. The sample-project-space video is extremely important to helping people understand what your tool or platform does. Your tool is a terrible representation of what it does. Think of a hammer. Looking at a hammer you would never know it could help you build houses if you didn't already have experience. So since we are inventing new technologies, to show what that technology is, is to show the types of things that it can do. Here the example projects shown in the video we made:

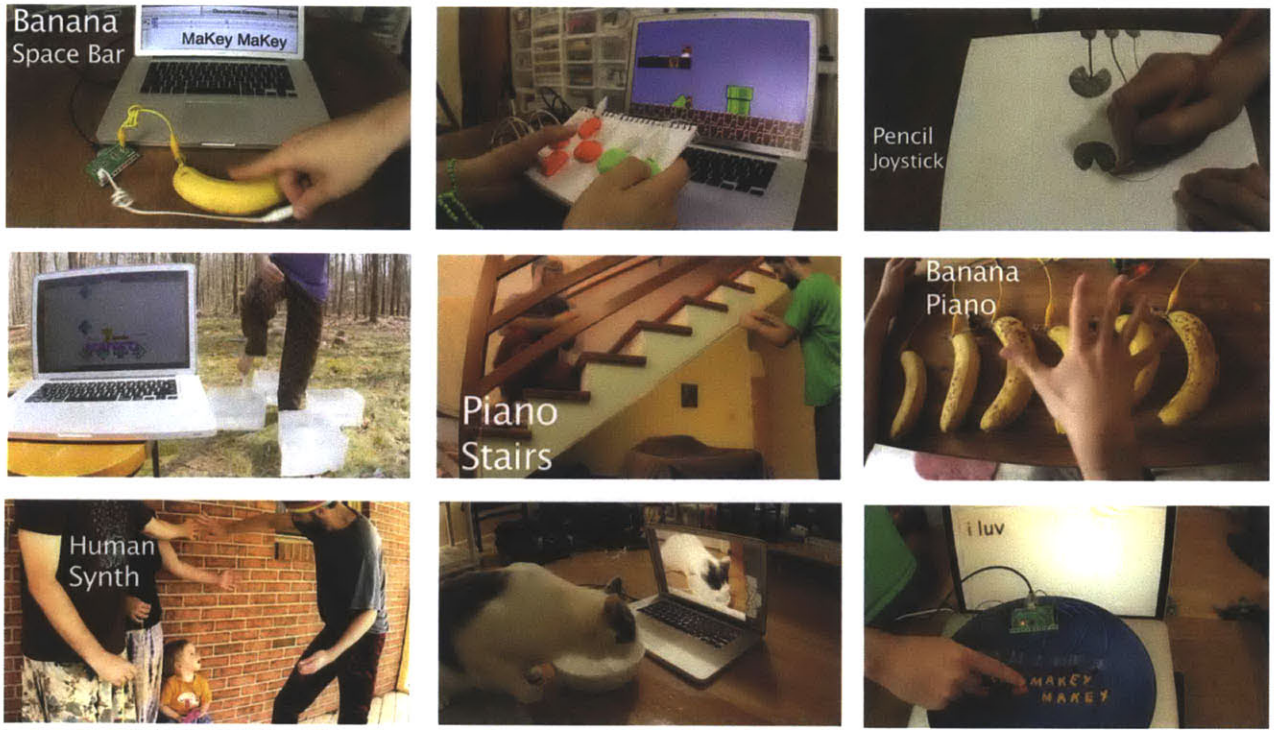
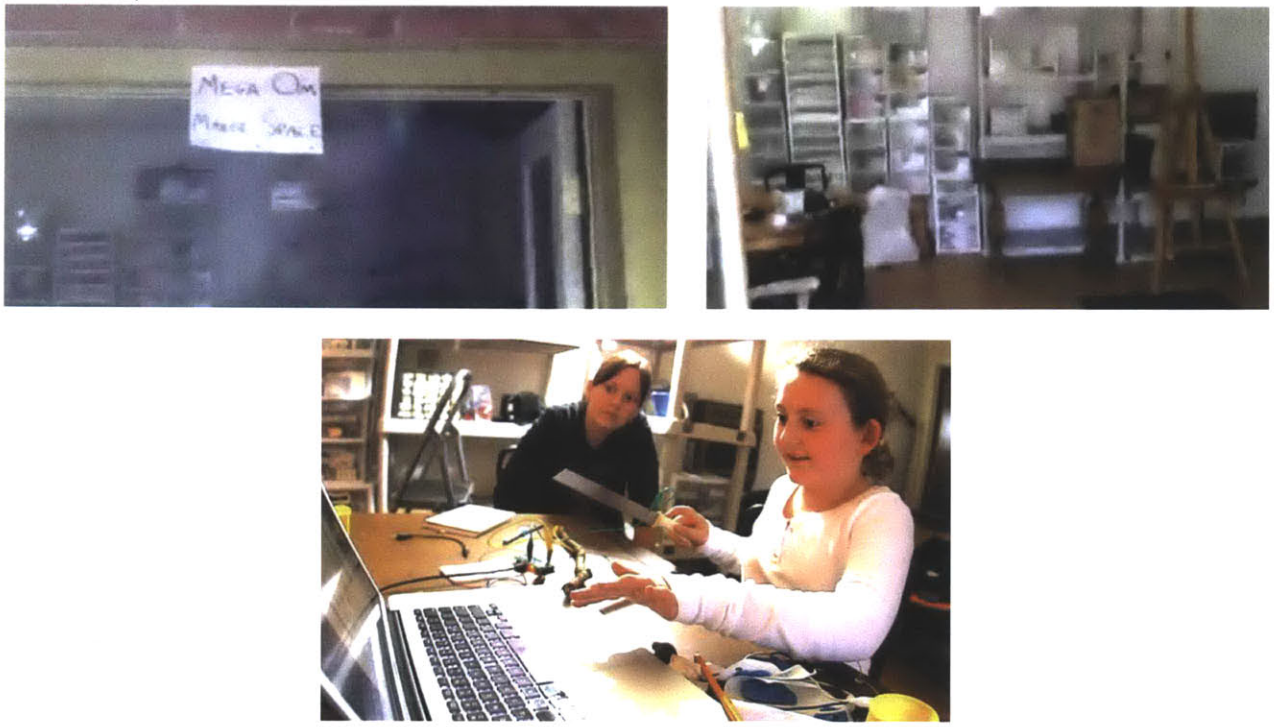


Figure 6.9. Representative stills from the Makey Makey example projects video available on makeymakey.com

The top left is our first example. Your first example must always be the simplest possible example, so we showed a single banana getting hooked up, with a word processor on the screen. Then when the person touches the banana, it types a "space" on the screen. The next three photos are of a game controllers made of play dough, pencils, and buckets of water. The Makey Makey is visually styled like a gamepad, and we wanted game controllers to be a category, but we wanted the examples to be different enough to show that there are these examples and many others beyond and between these ones. Before each example we showed a person typing in the game on Google to find the game via searching the internet, and we showed each being assembled in sped up time. The next three examples are music examples. We wanted music to be another category. Stairs, bananas, and humans are used and the instruments each play a recognizable tune or impressive rudiment. The last two examples are inventions, one is a cat bowl that triggers a cat selfie, and the other is a customized keyboard made of alphabet soup. There was actually supposed to be a third invention, but it didn't end up looking right visually. It was a gong that you could hit to make Pandora skip to the next song, but it was hard to understand. Anyways we intended to

have three categories and three examples in each category. That gives a nice rounded "three dimensional" set of types of things you can do with the Makey Makey, as well as three examples within each category.

In order to make a sample-project-space video, you have to try out making all kinds of things, and best to show them to people too. For a couple of months, at the back of my forested house at Yogaville, I opened up the back apartment as a Maker Space. I called it Mega Om (a play on "Om" from yoga and from electronics)



6.10. Mega Om Maker Space in the back of my house at Yogaville. Left. The sign is made of paper. Right. There were tables couches, shelves and parts and crafts bins for electronics and prototyping materials. Bottom. Workshop participant.

I had neighborhood kids over about once a week trying out ideas of their own and looking at some of my ideas and playing around. Here is one project my niece made with a knife that cuts a log as a controller to play a game where you have to cut wood on the screen.

One day I ran a workshop with three local kids. They were actually able to invent things and use the circuit board. I could see it working in action.

We were ready to Kickstart our project to raise money for the launch, so we started putting together the Kickstarter page which would be equivalent to a product page: the example-projects video, the photos, and the explanation. While we were putting together the page and getting ready to Kickstart, we also manufactured 100 beta test boards to give out at Maker Faire. For the final round of prototype revisions, we really paid attention to stylistic detail. We started to feel we were aiming well below the Arduino users in terms of skill level, which made it all the more important to have a visual feel that could make sense to more different types of people.

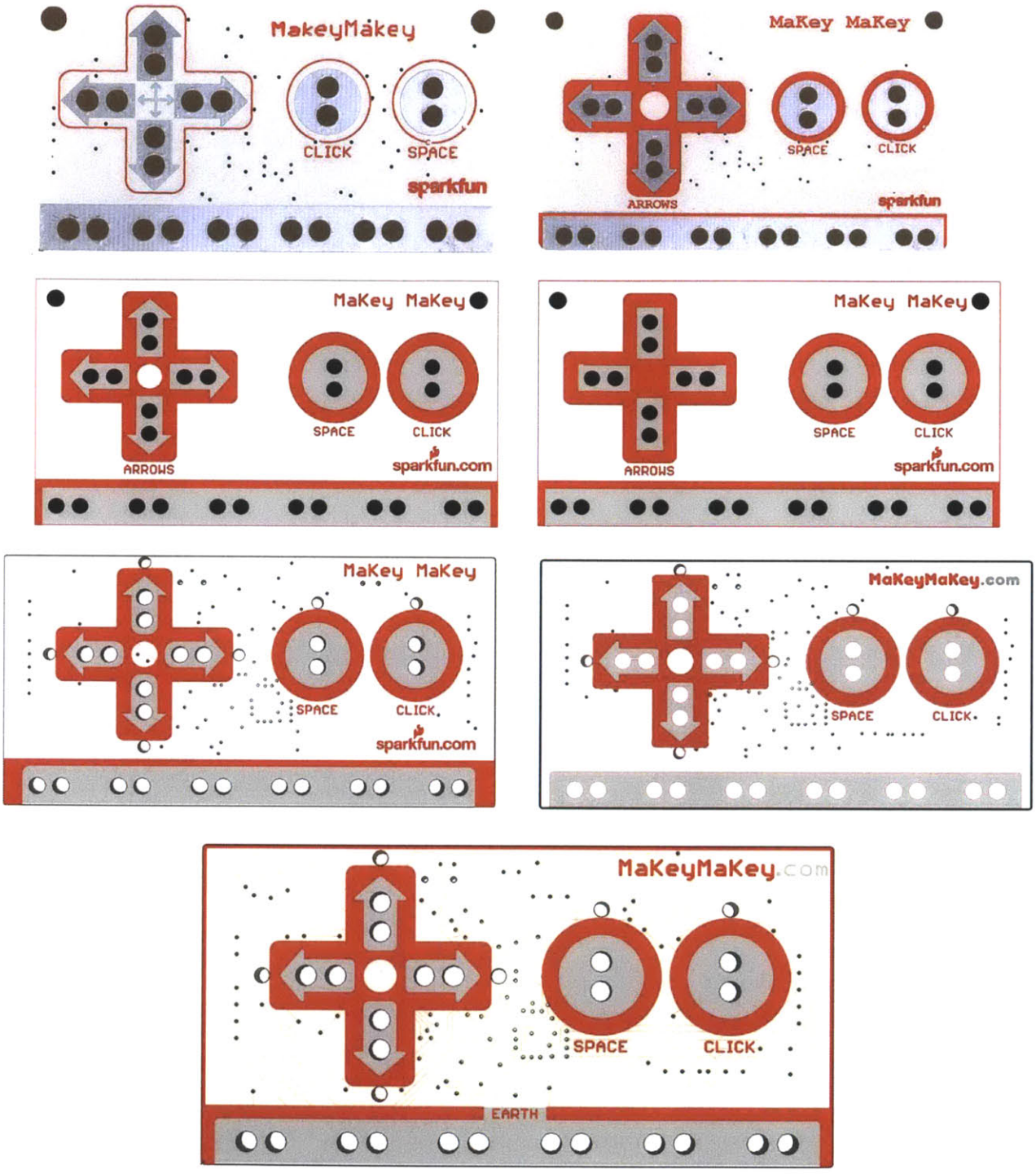


Figure 6.11. The evolution of the 3rd prototype of Makey Makey which is what Makey Makey looks like today

The top left board was just a color switch in Photoshop from green to white and white to red. From there we filled in the red around everywhere that you could attach something, that is around all the silver plates with holes, everything that was conductive, as if to say "here's where the stuff is, hook it up here." Both of these changes were done in Photoshop. We sent them to Jim, and he sent us back a circuit CAD version. We asked Evelyn Eastmond (introduced in the last chapter) what she thought of the design, and she

recommended changing the arrows, and gave us back the drawing in the second row on the right. We asked Jim to redo the drawing with more rounded arrows, and what the board would look like with the traces showing. We didn't like the result, so we spent painstaking hours learning about the proper curvature and trying different curvatures out in Photoshop until we got what you see in the third row on the right. We also added some icons into the traces of the circuit board. Jim and a designer went over the board based on our changes and modified the icons, and provided us the final sketch shown at the bottom. With minor changes, this is how Makey Makey still looks today.

As part of the prototyping process we workshopped the Makey Makey with individuals and in a group setting at the Tangible Embedded and Interaction conference (more on that in the Chapter 8).

Here is what the top of the Kickstarter page looked like. We started it in mid May 2012.

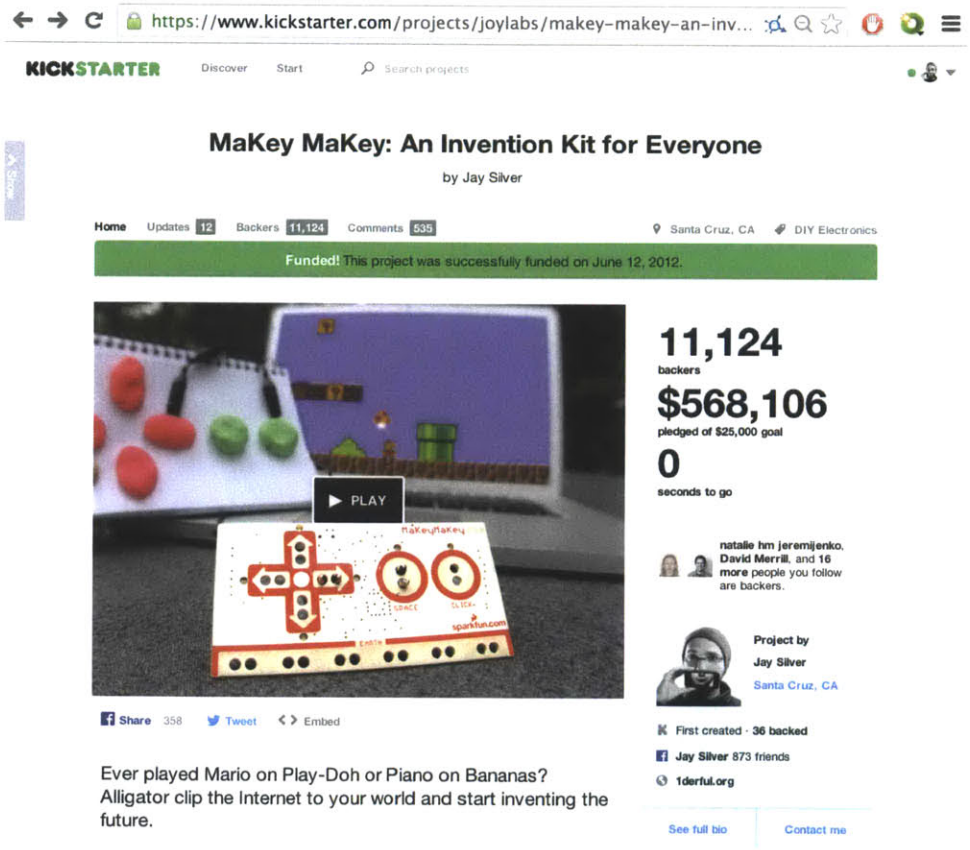


Figure 6.12. Kickstarter project page showing more than 11K individual backers

The goal was to raise $25K making a first run of 1000 units feasible. I made the Kickstarter page go live, and then Eric and I emailed our friends and posted to our social media and a few reporters. I left for the airport. We had timed the launch to coincide with a week of Maker Faire activity in San Francisco. There was no internet on my flight. When we landed I checked in and we had almost met our 30 day funding goal already.

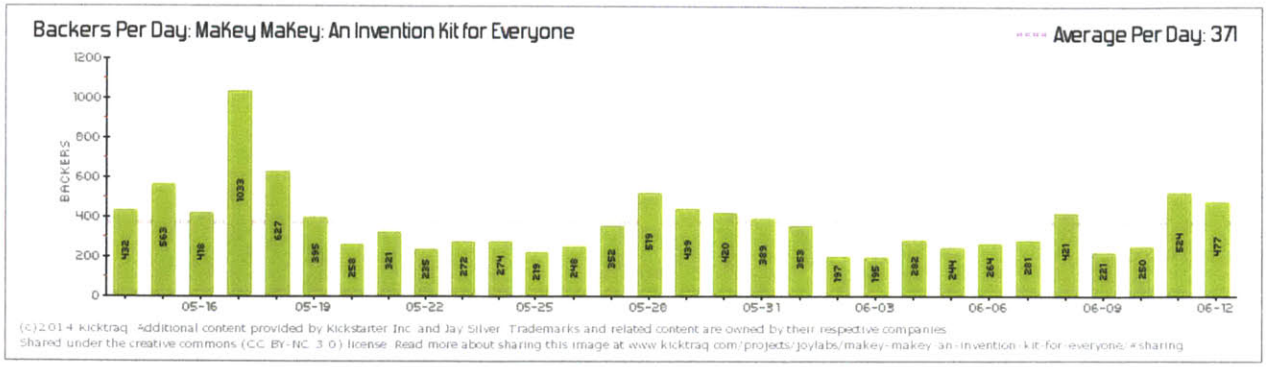


Figure 6.13. Backers per day throughout the Kickstarter campaign

We raised about half a million dollars from about 11,000 backers, shipping about 13,000 units. This was much more than expected, even though we knew it was theoretically possible. We turned Makey Makey into a company, and continued accepting orders after the end of the Kickstarter. Makey Makey then had two lives, as an academic and artistic project, and also as a business. Eric decided to stay as a co-inventor with me on the academic and artistic project, and I went ahead with the business side of things on his own.

III. Workshops and Discussion

7. Drawdio Case Studies

Introduction

There are about 40,000 Drawdio Invention Kits (counting both pre-soldered and solder-yourself) out in the wild. There are about 200,000 Drawdio pencils made by Benesse out in the wild (called Miracle Stick). And there are about 20,000 Drawdio Paint Brushes made by University Games out in the wild (called Brush with Genius). In these case studies, we will take a look at some workshops based around the Drawdio Invention Kit, known commercially as Drawdio Fun Pack as shown in Figure 5.30.

I have personally run 19 Drawdio invention workshops. Drawdio has been used in 100's of invention workshops around the world and in school and university classes and by artists and professionals in their practice and at companies. Here is an overview of examples of inventions made using Drawdio, first two examples from professionals in the wild:

Figure 7.1. Left. The Syntheslicer by Jonathan Guberman. Right. A musical puppet by Angela Sheehan. (Images taken by Jonathan Guberman and Angela Sheehan)

The Syntheslicer attaches one side of the Drawdio to the handle and the other side to the blade. In this way, electricity flows through the knife blade, through the food being cut, into the person's hand holding the food, through the body, and into the handle of the knife. The knife then makes sounds depending on the pressure and position of the knife on the food. This was made in the wild by a bioinformatician in Toronto. Right, Drawdio Puppet by Angela Sheehan. The puppet makes different sounds depending on where you hold the puppet. It works by sewing electrical resistors in series down the legs of the octopus to create a resistor ladder that results in a musical scale. This was made by Angela Sheehan who later became the Education Outreach Coordinator at SparkFun.

Now a few examples from youth in workshops:

Figure 7.2. Top Left. Strawdio made by Josh Gordonson. Top Right. Hula Looper by Claire. Bottom. Mushroom Organ.

On the top left the Strawdio is a resistor ladder made out of solder, hot glue, and a drinking straw. As you drink water up the straw the water provides a shorter and shorter path through the resistor ladder, much like the original Harmonium Circuit discussed in the Drawdio Genesis story. Josh was an MIT Freshman participating in an IAP Workshop that I ran. On the top right the Hula Looper repeats a series of sounds each time you swing the hula hoop all the way around your body. It connects a series of copper tape stuck to your clothes with the copper tape placed on the inside of the hula hoop. Made during a 1 hour block of free time at Not Back to School Camp working with me one on two (along with another camper). On the bottom is a Mushroom Organ by a youth in Taiwan at a workshop I ran at the National Taiwan Museum of Fine Arts. More on all three of these later.

Here are some examples made by adults during workshops I ran in Silicon Valley:

Figure 7.3.

Top Left. Intel Drawdio Workshop in San Jose. Musical Bugs. A vibro-bug-bot walks on a copper tape maze connecting different parts of the maze to actuate different pitched sounds.

Top Right. Gooey GUI in a Stanford class on user interfaces a set of gels, doughs, and styrofoam troughs were used to let people get messy and touch each other to trigger sounds. This was in a class run co-taught by a colleague of mine, not in a workshop that I ran.

Bottom left. Interactive ping-pong table at a Silicon Valley Startup BUMP in a workshop I ran.

Bottom right. Creative prototyping using a measuring tape + play dough plus a wet rubber band in an IDEO design firm workshop I ran in Palo Alto.

I will now present three pairs of cases studies
1) Youth
2) Academic
3) Business

Within each section I will give a thick description of the events. At the end of each section I will discuss lessons learned, with further discussions in Chapter 9.

Case Study 1. Drawdio Workshop at a Camp and a Museum

An Unschooler Camp called Not Back to School Camp

In this section I will give lots of short examples followed by one in-depth example including transcripts and

an interview.

Not Back to School Camp is described as "A gathering for unschooled teenagers: renew, ignite, strategize." I had gotten involved through Not Back to School Camp by meeting a stranger on the train one day. I had given my dad a ride to the airport in his rental car. It was summer so I didn't wear any shoes but there I was with no shoes needing to ride the train home. A stranger said, "Is your lack of shoes spiritual?" I said, "I don't know." He said, "'Cause at Not Back to School Camp there are some teens who..." "What?" I said. "We need to get off the train and talk about Not Back to School Camp. I've been waiting to meet someone from there." Well as it turns out he was perfect for a job opening in our group and he eventually got that job, and much later I ended up counseling at the camp.

Not Back to School Camp, and the accompanying book The Teenage Liberation Handbook, both by Grace Llewellyn, have been a big inspiration to me because of the atmosphere of self-empowerment created. At the camp there is lots of free or optionally structured time that gets used really productively, and there are a number of rituals from "trust circle" to "morning meeting" that create an atmosphere of safety in oneself and therefore positive experimentation and openness externally. Other practical details are attended to, like no caffeine or sugar, and lots of healthy all organic food disguised as delicious kids' favorites.

This is the front of their webpage which depicts kids basically hanging out, imagining, and networking while trying cool stuff.

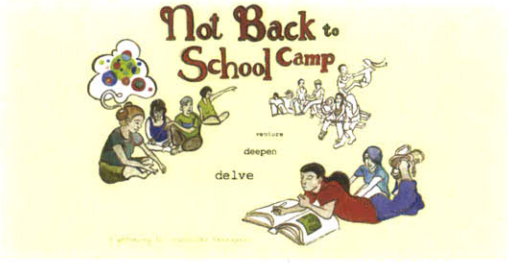


Figure 7.4. Not Back to School Camp webpage. Subtitled "A Gathering for Unschooled Teens."

Here was the scene as photographed by me just before the workshop:

Figure 7.5. The scene at Not Back to School Camp. On the left upside down tomatoes hang out of buckets attached to the Farm and Wilderness lodge in Vermont in late September. Teens gather during free time chatting. On the right, chard and a porch swing and a field, a typical setting at Not Back to School Camp.

Not Back to School Camp has lots of free time in between activities, and all workshops are optional, which means everyone who participated in the Drawdio workshop wanted to be there, no encouragement. I set up a bit of craft materials on 2 picnic tables.

Figure 7.6. Craft Table Setup for Drawdio Workshop at Not Back to School Camp

- *Some food in different bowls donated by the kitchen*
- *Paper, markers, pencils, rulers, and scissors*
- *Some leaves and sticks to give the idea of scavenging*
- *A glass of water*
- *etc.*

To start off the workshop I showed the basic concept of how the Drawdio makes noise when you touch it to yourself or to some of these objects. Then I said to play around and experiment and we'd reconvene in 10 minutes to show off our discoveries in a circle.

Figure 7.7. First round of the workshop: Just try stuff out and make some noise. Egged on and fueled by each other's experiments, the campers tried hooking up things to Drawdio that I simply don't have access to (like lip piercings).

People tried all sorts of experiments with parts of their bodies, grass, piercings, braces, hand holding, and other interesting things. It was a nice atmosphere because they are really just having fun and can leave if they want to. Also they are relaxed with no sugar or caffeine allowed at the camp so they are able to be authentic. There are a lot of important things that happen before a workshop, and there is a lot of momentum carried into a workshop that sets the tone based on previous experiences.

I had never seen anyone try any pseudo prosthesis like braces or piercings before this event.

After sharing some experiments in a circle, I announced there would be 30 minutes to build an invention,

musical instrument, or a toy, and then we would show them off at the end.

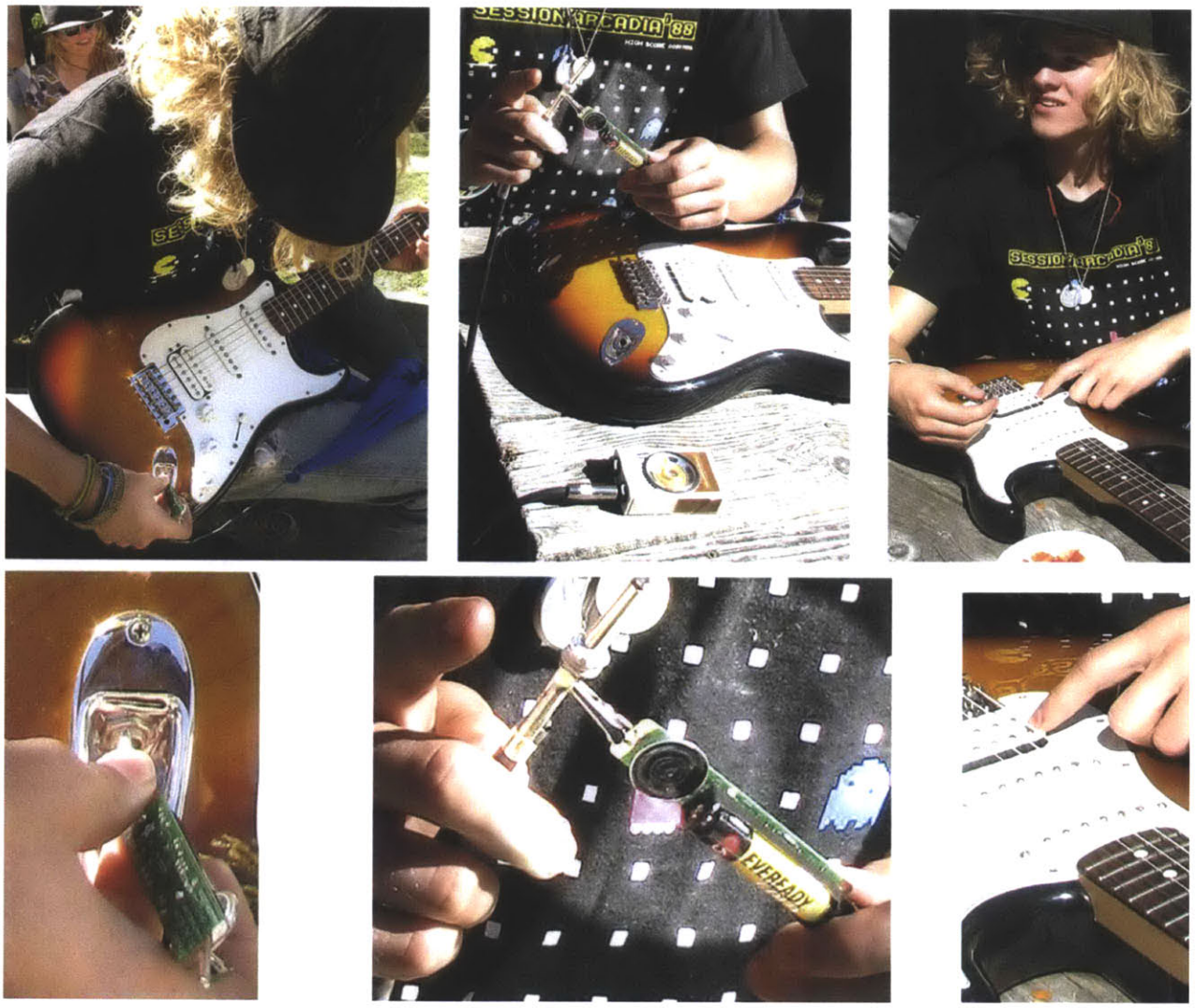


Figure 7.8. Guitar Drawdio Project

This young man hacked the inherent circuit that was his guitar. As it turned out, his audio input jack (bottom left) was connected to the rest of his guitar electrically, so he could effectively "plug the drawdio in" at the input jack, where you normally plug in a guitar cable. He showed how he could then touch his pickups (bottom right) to make sounds. The pickups are little magnetic vibration sensors that normally sense the vibration of the electric guitar strings, but he was able to touch them to make the Drawdio make sounds. He could also touch the bridge and the strings. He liked the idea that he could touch the strings to make Drawdio sounds because that is also how you play the guitar normally, so he explained that at this point you can play two instruments at the same time if you are clever about it. He was also trying something with a t-shirt hooked up to the Drawdio and the guitar at the same time (top left). Finally he had a cigarette-pack amplifier, showing that he has some inclinations towards either gadgetry or hacking already. Normally you hook up your electric guitar to it to use it as a speaker. He showed how you could make it make interesting sounds by touching the ¼" guitar cable to various parts of the Drawdio.

Figure 7.9. Mobile Drawdio Project with string and food

Elisia Blanton and a young woman Isaac created a mobile out of yarn, bits of vegetables, and thumbtacks, as well as a human hand for structural support. It turns out that the human hand is one of the best prototyping materials for extremely temporary prototypes and yes one of the least named as such. The mobile didn't play any sounds at first (right). They figured out that the yarn wasn't conducting electricity the way they would like, so they wet the yarn in a cup of water (left). The yarn holds the water and the electricity travels on the water if the yarn is saturated enough to hold the water. Then there are several ways to play. One is to touch the pieces of vegetable and slide your finger on the yarn. Another is to ground an object like a tree, the ground, or a fence and then spin the mobile so it strikes that object. The length and wetness of the yarn plus the nature of the electrical connection to the vegetable make the sound different on each veggie.

Figure 7.10. Rhythm in space Drawdio Project. A repurposing of the spiral copper tape that has become "semi-iconic" around the Drawdio pencil.

In this case a wet piece of yarn was lined up and the copper tape was connected to one end of the Drawdio. By either sliding the finger along the copper tape or by sliding the finger along the string, thus pressing the string into making contact with the copper tape (safer for fingers the 2nd way) the rhythm of the spiral could be heard making the same tone each time. This was less about different notes and more about patterns being heard through space by moving across them.

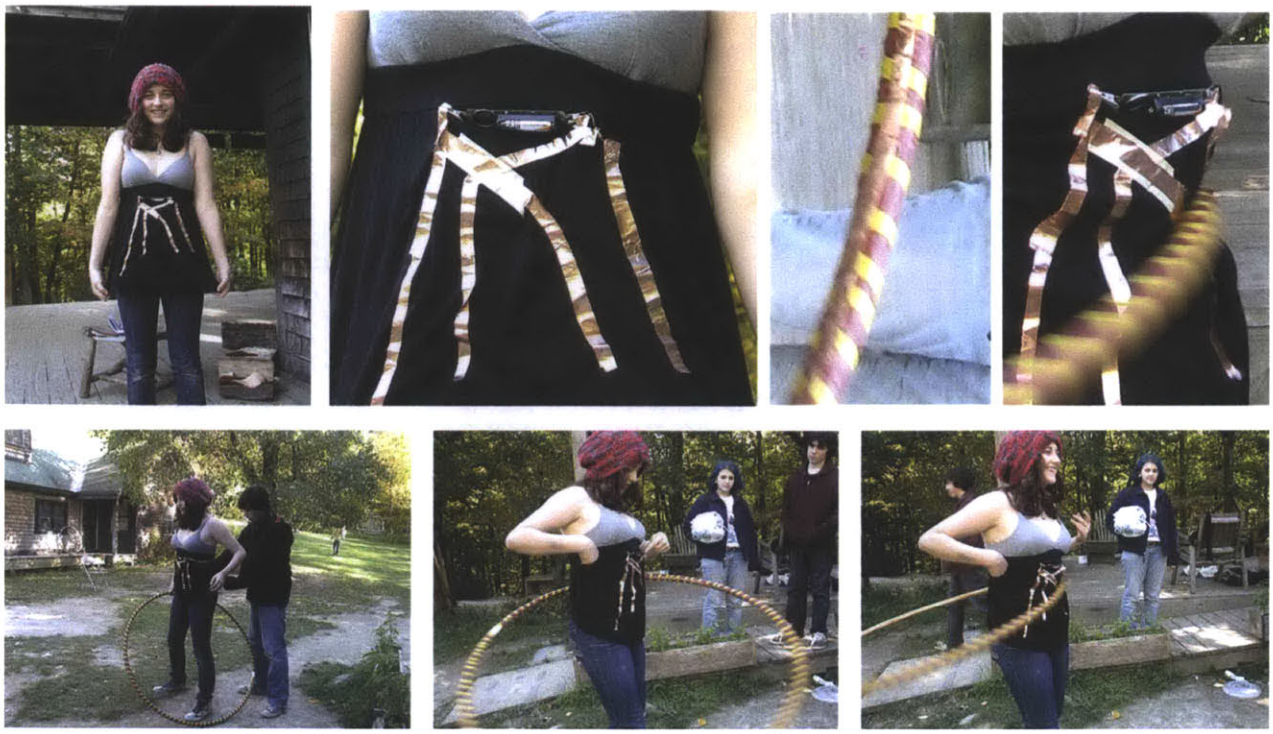


Figure 7.11. Hula Looper Drawdio Project

The Hula Looper came out of a spontaneous Drawdio invention session. Claire had seen the Drawdio workshop through the window when work-trading in the kitchen but couldn't participate since she was busy. After the workshop I was just wrapping things up and she starting asking about it and wanted to make something. She was 15 at the time. Isaac, age unknown (approximately 16), joined in. There were some self-made hula hoops and Claire decided she wanted to sonify one of them. Together with the Isaac, they worked on several plans to make the hula hoop make noise until one worked. The one that worked is depicted. The second from the right on the top row shows how they lined the inside of the hula hoop with copper tape (the barber pole pattern is from wrapping the hoop for mechanical sturdiness which was done ahead of time, the copper tape runs parallel to the linear direction of the hoop). The Drawdio was then affixed to the shirt, Claire is pointing to it in the bottom row middle picture. And there's a closeup on the top row second from left and all the way on the right. In these two photos you can see the copper tape patterns spread out on the shirt. The hula hoop is meant to push against two of these copper "legs" to connect them thus triggering the Drawdio to beep. Note the "jumper" or "bridge" which is most clearly visible in the top right photo. This allows the two middle "legs" to cross over each other without becoming electrically connected. The insulating bridge is probably made out of masking tape though I don't remember for sure. At first there were 2 beeps triggered and then a third was added on the back of the shirt with two more legs. The male Isaac can be seen helping adjust the back nodes on the bottom left picture. Throughout the design process many people were milling about, and there was no designated start or end time or start or end goal. Here is the dialogue that transpired between getting the 2nd beep and the 3rd beep to work. Note: dialogue is based on audio transcription from 10 different videos which are mostly, but not 100% contiguous in time. Lasts about 5 minutes.

> Hula Looper: "Bee Doo Bee Doo Bee Doo" (this sound continues throughout as Claire Hula hoops)
> Onlooker 1: Hahaha

Onlooker 2: Woah
Onlooker 3: That is sooo cool

Author's comments after the fact: The environment feels like after school in a living room, except with more people milling about, and this is much different from a typical public school type environment. Camps really are temporary intentional communities, and great places to grow and learn.

Isaac: So wait we could put them all the way around your back too
Claire: Ya we should
Onlooker 2: Oh my god that's awesome
Onlooker 1: That is soo....
Lizzy: You should put some copper tape on the back too
Claire: Ya I like that

Multiple participants converging on the idea of adding tape to the back

Onlooker 2: Is it just is it just [sic] pressure reactive?
Onlooker 4: There's copper on the inside
Onlooker 5: No it's based on touch
Claire: There's copper on the inside
Onlooker 2: Oh there's copper on the inside?
Onlooker 4: Ya
Onlooker 2: Oh I didn't know that
Claire: There's copper on the inside and then it touches these <points to copper pads on shirt>
Onlooker 2: It works through people too right?

It is fascinating for me to listen to a "natural" conversation about how something works while studying it somewhat formally. First the question is basically "Does it use a pressure sensor?" To which an answer is given, "No it uses copper closing a circuit by touching other copper." But less structured than that.

Onlooker 6: This is the Drawdio thing
Onlooker 2: You haven't seen this? It's fucking awesome
Onlooker 2: Wow
Onlooker 6: It's actually pretty sturdy too
Isaac: Ya
Onlooker 6: It's not like
Lizzy: I could put copper tape on my shirt and then it would beep when I hooked you up
Claire: <nods> <chuckles>
<Some laughing from around>
Onlooker 1: We could just stun ourselves by just looking at this so long

The activity is elevated by the group to an object of fascination, with a bit of commentary as to how long the prototype might hold up, "pretty sturdy."

Isaac: We made that happen
Onlooker 5: This is like the best possible ending of a camp

<laughter>
Isaac: A singing hoop
<monster roaring sound from someone's mouth>

This is a direct example of creative confidence being expressed by Isaac. He states directly that he and Claire (perhaps with influence from others) made this Hula Looper, which has just been elevated by his peers to the level of "fucking awesome." He fathoms what this thing is as he calls it "singing hoop." It can be hard to give words to something in the first moments of its creation.

<incoherent talking>
Onlooker 2: So who's idea was this?

Up comes the issue of credit. You can almost watch the creative confidence being valuated and distributed. Watch how it is handled.

Claire: Uh it was like a joint idea
Isaac: Claire was like Hula Hoops, and I was like doing capoeira inside, and Jay was like I invented Drawdio, and we were like Pshhhhh (sound similar to champagne bottle post-uncorking if preshaken)
Claire: I wanted to have a hula hoop that sings when you use it

So credit is shared between Claire and Isaac by telling a bit of a story about who had done what, while keeping it casual. Also there is this sense that the collaboration really was a meshing of minds, at least of Claire and Isaac, and Isaac is showing some signs of considering whether I was involved as well. The melding of the minds is hard to verbalize for anyone, but it is explained by Isaac here as "Pshhhhh."

Onlooker 7: Ahhhhh shiiiit <nods head approvingly>

This is a high compliment.

Isaac: <Paints water onto the junction thought to be disconnected>
Claire: Can you hear it?
Jay: Sounds like only 2
Claire: I don't hear it, I don't think the water worked
Isaac: <Paints the line a little thicker with water so that the hula hoop can make contact with the shirt>
Isaac: I'm gonna make it thick so... I'm just gonna make that a little more <dips paintbrush in water again>

Some debugging activity right in context. Performance, discussion of credit, debugging.

Isaac: And where has the hula hoop been on you? Just...
Claire: It's usually right here <gestures to a vertical area on her stomach that she thinks the hula hoop usually lands within>
Isaac: So will it reach that?
Claire: Should maybe make it just a little bit longer like <gestures with finger> (mumbles there or something)
Isaac: <paints a little longer>

Claire: That should probably
Isaac: Okay let's try it

Made alterations collaboratively. Now time to test.

<starts hula hoop again>
Isaac: Woah you're going a little high
Claire: I kinda hear it I dunno
Isaac: Is it like really low frequency? Would that happen?

Isaac and Claire are still not sure if they can hear it. So they check their understanding of the circuit diagram.

<goes to pencil and paper diagram to make sure "circuit on shirt" is hooked up correctly>
Isaac: So they come back, they come, they come from the front come around the back
Claire: This is the back of the shirt

Checking for mutual understanding of what the diagram represents

Isaac: Ya this is the back of the shirt, they both come down here, so then the hula hoop would connect the circuit here when it's on your back. They probably have to come down a little further so that (words can't be heard) <gesturing to paper diagram>
Claire: So do you want me to put this just straight behind? <gesturing on Claire's shirt>
Isaac: Uhhhhm well since the hoop has been like here on you <gesturing on Claire's shirt>
Claire: Ya it's kind of like here <gesturing on Claire's shirt>
Isaac: It might use less tape if we just put it up a little like <gesturing on Claire's shirt>
Claire: More <gesturing on Claire's shirt>
Isaac: Probably a little more <gesturing on Claire's shirt>
New onlookers 8 & 9 come out
Claire: So the hoop would like hit it and it would make noise
Onlooker 8 & 9: Ohhhhhh wow
Isaac: Okay it looks good
Claire: Should I try it?

Another round of collaborative alterations this time including a sanity check of understanding.

Onlooker 8 & 9: Ya
Isaac: I think I think so just just so you know this is right here <gestures to tape on shirt>
Onlooker 10: Ahahaha Claire your stomach's gonna make noise
Claire: Alright <starts hula hooping>
Hula Hoop: "Bee Doo Dweeoop Bee Doo Dweeoop Bee Doo Dweeoop" <third sound emerges, sound continues as Claire hula hoops>

They now have 3 sounds working, the debugging was successful on the 2nd try.

Onlooker 10: Oh that's weird
Isaac: You know what that actually kinda sounds like, for a second it sounds like the Darth Vader scene

Claire: Ya like <sings darth vader theme presumably>
Onlooker 11: That's hilarious
Isaac: That is awesome
Isaac: Just so you know the tape is falling <makes adjustments on back of shirt>
Claire: Is that good? <hoola hoops> Ya it does kinda sound like Darth Vader
Onlooker 12: "Oh you strapped a drawdio to your chest I see"
Claire: "Drawdio's here and copper tape's on the inside of the hoop"
Isaac: "You could totally put an arpeggio on a shirt, and I guess, so you could, that'd be crazy, so if you like got a shirt and you wove in conductive, and just put a little place to like clip on a drawdio, then you could plug it in"

This is where I stopped recording, and ends on a high note for me with Isaac starting to verbally imagine neighboring inventions he might be able to create.

Interview 7.1. With Claire, Isaac and 12 other Not Back to School Campers

As you can see the whole process is very fluid. Performance and design are tightly integrated which worked out very nicely for motivation as well as for ideation, which I noted and used again later when designing Start-Making experiences, which I'll explain later. Is this a workshop? Is this a design challenge? The noted lack of definition can be seen as an open-prologued process. There was no intentional recruitment nor theme setting. Not Back to School Camp simply provided open time which allowed spontaneous exploration. The vibe of this simply can not be simulated by any planned workshop. Note that even the rules of Not Back to School Camp explicitly forbid attending the camp at all against one's own will.

The performance and design combination provides for lots of natural authentic encouragement. "That is so cool" etc. as well as ideation "You should put some tape on the back too." etc. There's informal but direct discussion of credit, an important aspect of art and any other work. They acknowledge that credit is shared jointly between the two of them. There's abstract representation in the diagram. There's debugging with a paintbrush and water and by moving the tape on Claire's clothing when the circuit doesn't work as expected. The collaboration really is necessary due to the topology of the circuit, and the location of the circuit like Claire's back.

Throughout I remain almost completely silent. I only use my voice and nonverbal communication to demonstrate interest in their thoughts and ideas, as taught in Critical Exploration -- although critical exploration is usually practiced in more closed-ended situations. That is, the "end" of critical exploration is usually the path itself. This critical exploration has the ideas and the open ended design as dual goals.

Two years later I interviewed Claire on the phone.

Jay: When did you first hear of Drawdio? In story form, what happened?

Claire: I read all the bios <editor's note: on the website before camp> for staffers at Not Back to School Camp, there was a link to the Drawdio video or something I watched it I think with my uncle. I was showing it to people cause I was like look how cool this is this is so awesome. I watched one of the YouTube videos where there were demonstrations.

Author's comments after the fact: It's hard to realize how much bottom-up broadcasting and online learning and reading there is these days. I don't think it hits most people that when they

post something on Facebook (or elsewhere on the web) there are probably at least 10 more times people interacting with your ideas than you even know from evidence such as "likes."

Jay: That's interesting I didn't know you had seen those things first. In slow-mo if you rewind to when you first found out about that in the video, what was your thought process to the best you can remember.

Claire: Something that I had never seen before. I didn't know that you could do that. Something that I'd never thought about. Simple but unique. So simple. People holding hands starts singing. Drawing on paper touching areas, such a simple thing, it's a circuit and a pencil. So neat so simple. I never would have thought that you could touch something that you drew and it could sing to you.

While experts in interactive design may know that something like this is possible, most other people
1) Don't know it's possible
2) Don't think that they can partake
3) Don't think they can afford to partake

Those three factors combined are empowering.

Jay: Let's go to the next encounter you had with Drawdio.

Claire: I think you let me play with one of them cause i missed your workshop. I was sitting on the porch at not back to school camp kind of just playing with it. Trying to remember how you did... the hula hoop thing maybe that just came out of... hula hooping near the porch after playing with the Drawdio, maybe someone said we can get the hula hoop out and see what it does, maybe we can make it sing, I don't remember how it started, I think you started videoing after we started making it. I just remember having a lot of fun, it was like this science class I used to take when I was little lots of hands on, you got to be really creative, you were making something, not like drawing and painting anything, but it is like making something, almost like inventing.

In a sense "I just remember having a lot of fun" is the most important thing here, if you believe that real emotionally attached and lasting "learning," which is actually about much more than knowledge and is about how you see yourself in the world, happens in the midst of "lots of fun." Of course we have to remember that she probably wants to tell me what I want to hear. It's interesting that she says "almost like inventing." It shows how out of reach invention seems to people. She doesn't want to overstate her claim. But if this isn't inventing in this situation then nothing is inventing.

Jay: Tell me more about how it's not like drawing and painting and how it is like inventing.

Claire: I guess ummm, is it? It's almost like an art but it's not because you don't have to be able to draw circles or anything, you have to think about it, and you have to you know you can use a little bit of science you have to use the different tools you have, you put things together maybe you put things together that no one has put together before, so it's like art but also you're inventing something..... 'cause you're creating something new but you're putting pieces together as opposed to making watercolors or swirls.

I love the comparison of inventing to the arts here. Of course artists are constantly inventing new ways of seeing and new techniques for drawing, and Claire seems to have some experience with that artistic process. This is why the art is needed in STEAM (though a lot more than that is needed). Innovation happens through activities that appear more naturally in the culture around art.

> Jay: If you recall, what is that process like of putting things together, what goes on in your head or your eyes, like, "When I look around this is what I see or this is how I look around," or anything like that.
>
> Claire: Ya ummm hmmm, I guess ummmm I remember 'cause it was you and me and there was a boy Isaac I think and it was kind of fun because someone would come up with an idea or a way to design it and then like tell it to, share it with the other people and someone else would get an inspiration by looking at something or seeing something and then like ..... share it and collaborate on it ..... I remember I guess we would get a little thought or inspiration and an insight and share it with the other people and see if that sparks something in them to share and make ..... with the hula hoop.

Really a pretty self reflective and holistic analysis of how the whole event went down including remembering the main collaborator and the interactive way thoughts were shared and implemented.

> Jay: When you were making the hula hoop do you remember anything about what that process was like through your own eyes, not the facts, just the story how you would tell it.
>
> Claire: I guess I remember kind of each person was adding. I think we sketched it out first and started putting everything together and trying it out and changing a couple things and trying it again and I don't know I guess it was kind of exciting especially if someone would come up with a better way to wrap the tape or put this uhhhhm 'cause I remember I don't know what it's called the wire pieces <editor's note: resistors> that kind of change the sound a little bit.
>
> Jay: Ya I know what you mean the wire pieces <Note: here I adopt the language of the creator>
>
> Claire: Ya just like different ways to place things. Just kind of exciting very active I remember changing something and trying it again. Ya it was kind of fun exciting and active all at the same time.

She recalls the iterative nature of the design process

> Jay: Is there anything else in that session of Not Back to School Camp you wanted to talk about in relation to Drawdio?
>
> Claire: In a way Drawdio making the hula hoop was inspired by Not Back to School Camp because you're with... it's like a time when you have a week to spend with other people not worry about other things... a good place to be creative and make something, create something with the Drawdio and the hula hoop i think that was kind of cool it was like the

right environment to do that.

Interesting that she sees the spirit of Not Back to School Camp as conducive to creative invention with Drawdio, which I also do.

Claire: I remember being so happy when you gave me the Drawdio to take home I was so excited that I got to take the drawdio home and show everyone how it worked. I guess that's not related to the hula hoop but i was like oh my gosh i have one of these.

Jay: That's great I want to follow your thought processes here, so what specifically makes you excited, or you say you want to show people, what did you want to show people? What unfolded from there?

Claire: I think that the drawing with the pencil and being able to touch it is really neat really basic but really unique. At the same time I was really excited to show my uncle who used to be a science teacher, he's into stuff like that, sciency magic tricks, he's like a grandpa now, but he's always finding fun gadgets I was excited to show him 'cause he's really interested in stuff like that. I was going to Sudbury School <editor's note: Sudbury School is a democratic place for students to teach themselves without adult interference>, I showed some people at school how to use it and stuff, it was...

Jay: What did you show the people at Sudbury School?

Claire: I'm pretty sure I was just showing them how to do the pencil but then I think I might have showed them how to do a couple of other things like how you could all hold hands and it would start beeping, ya I don't remember if I showed them any other things.

This shows how powerful the pencil metaphor and example are in people's minds, and of course the name Drawdio comes from this use case: Draw + Audio = Drawdio.

Jay: You once emailed me about your uncle and the basement?

Claire: Something with the floor?

Jay: Ya that's what it was.

Claire: Shoot I don't remember. I kind of remember something. It might have been something with the floor in my basement like you could touch the floor and make a circuit.

Jay: Oh that's what it was ya.

Claire: I was trying to do something and I didn't get why it was beeping or something and I realized it was 'cause I was touching the floor cause my basement was painted on top of it I don't know what kind of paint it is i'm pretty sure the floor.

Jay: Oh here it is an email that you wrote to me in 2010 which says

Claire's voice in the email (Jay reading it out loud): We haven't made anything much yet, it was funny though when I showed it to my cousin in my basement 'cause it wouldn't

stop singing and I couldn't figure out why, it turned out the Drawdio conducted through the floor which none of us expected the floor is made of concrete and paint.

Jay: So do you know what you observed that made you come to that conclusion that it conducted through the floor?

Claire: I think it was just something like we were standing on the floor and holding it, and I was trying to get him to, I don't remember, I don't remember what happened.

When we don't remember what happened, how do events like this affect us?

Jay: Did you use Drawdio more after that or is that the end of that.

Claire: No.

Jay: Do you recall any time where you were looking at something and you feel you were looking at it differently as a result of having interacted with Drawdio?

I am leading the questioning a bit here to see where it goes, but results must be viewed with awareness of the leading

Claire: I think that for a little while especially right after I used it I would kind of think could I make this into something I wonder if this would conduct and a lot of times it wouldn't, I guess sometimes I would look at things instead of just for what they were like how I could use them, how I could do something with them apart from what they were made for.

That's a really nice result, since I only asked if she looked at it differently (re-seeing) and her answer was that she looked it as something to do something else with (re-making).

Jay: Can you say more about that? "How I could do something apart from what they were made for," could you elaborate about that?

Claire: I guess I can't think of a moment, but just for instance, the sink or the hula hoop or the pencil you kind of think this is just a pencil that you use to write with, but then it can actually be a pencil that you use to make music with, or this is just a hula hoop that just spins around your body, but it can do more than just spin around your body, but you can do more than that you can have fun and change it a little bit or use it in a different way. I think it inspires that kind of thought. It can inspire like that type of thought by doing things or using things in a different way in a way that they're not necessarily made or intended for.

So while I did encourage this type of discussion I feel her thoughts here are an example of how Drawdio might encourage repurposing and a mindset that the world is a construction kit.

Interview 7.2 with Claire by Phone

Workshop at a Museum: National Taiwan Museum of Fine Arts

This time I had flown to Taiwan with my wife, Jodi, to the National Taiwan Museum of Fine Arts. The workshop was commissioned by the museum as part of a show "Freeze" that also included a Drawdio Paintbrush exhibit and an ok2touch exhibit. The museum had advertised the workshop through their email, flyering, and brochure channels to interested parents and children within a specified age range. I was announced as a visiting electronic artist. Based on this information the parents of 20 children signed them up. The space had been prepared as a creative space with wood carved furniture in the entryway holding computers, and lots of recycled plastic jugs used as light diffusers, walls/dividers, and artistic expressions. I had provided them with a list of setup items I would need in terms of tables, chairs, facilitators, and craft materials.

Figure 7.12. Left. Participants gathering and signing in before the workshop. Right. Participants listening to Jodi (my wife and collaborator) giving an introduction to Drawdio.

There were 5 other facilitators, 1 of whom could translate. Other than the translator there was no significant verbal communication between Jodi or myself and anyone else. As usual we set up a materials table.

Figure 7.13. The craft tables for Drawdio workshop at National Taiwan Museum of Fine Arts. Left. Crafts, tape, tools, colors, string, etc. Right. Edible crafts in the form of locally available produce.

It is important to set up a materials table nicely. Although I don't really have the skill for making it look just right, I still try to organize things into piles and make it look somewhat approachable, out of the packages, and visually parsable to the best of my ability. I do some separation of materials from tools, and some organization of like materials and like tools, though I could certainly do more.

I also asked ahead of time that participants bring one item that is special to them to use in the workshop. Only a few people did so. It's great if people have some material contribution in the beginning and then they also have something they're intimately familiar with and something they find personally meaningful.

I sometimes like to separate human-made craft objects from more-nature-made (with human farmers intervening of course) craft objects. I did so with this craft table.

First we introduced ourselves. It's important for everyone to get their voice heard right in the beginning. Energetically it sets a tone that everyone knows there is a minimal importance to the voice of each person, at least that we have heard from them. Often times I also ask for some other information, like who is your hero, or one I learned from my advisor what is your favorite toy.

We first stood in a circle and held hands with the Drawdio to show how it could connect and disconnect by people all around the circle, with everyone taking a turn to touch the person next to them skin-to-skin to activate the circuit, a good activity that goes beyond words. Then, through the translator I explained it was time to explore and everyone should try to make sounds with different materials.

Figure 7.14. Try Anything lightning round of the workshop. Participants were told to grab any craft and try to make Drawdio make some sounds for 15 minutes.

We had pre-arranged that everyone would sit in groups of 4 to 5 at tables, so there ended up being a lot of group work in the experimentation within the tables. Also it was good to have the tables close to each other as everyone watched everyone else's experiments and knowledge built in the room as if it was its own universe of knowledge about what was possible with the Drawdio device. As seen in the top row people picked over the materials. I like having the materials mixed around on all the tables before the "final projects" begin, when everyone is still just messing around. I think it provides for a more

heterogeneous starting condition that leads to more diverse outcomes of projects. Diversity of outcomes is a standard measure of success in a constructionist workshop, which is also important to me. Although if outcomes are similar but people's ideas were valued in the process, and the participant had some time to traverse the idea terrain with their own feet, I am just as satisfied.

In the second row, I gave the instruction "Touch everything with your hands and listen to what happens" through the translator. In the third row, you see everyone playing with metal rulers. There was a point where someone got some good sounds out of a metal ruler so about half the people tried to replicate what they had heard.

In the last picture on the bottom, a group had gotten different notes to reliably be played on some Taiwanese candy which had to first be chewed and then connected by resistors in the classic Makey Makey "resistor ladder" circuit. At this point we called a transition to "now design a final project that makes sounds, it can be a musical instrument, or a magical creation."

Figure 7.15. Three projects using a linear resistor ladder architecture.

At the end of 2 hours, we asked everyone to write the name of their creation on a paper. In each of these three columns we see a different "resistor ladder" style creation. The one on the left is different local vegetables connected by a resistor in between each one. The one in the middle is pads of copper tape attached to a piece of cardboard. On the right we have yet again copper tape attached to cardboard, but this time wrapped onto straws and decorated with green electrical tape and some markers.

Figure 7.16. A collaboration between two participants, a pineapple Drawdio creation with parallel circuitry

In juxtaposition to the ordered linear creations, these two collaborated on a piece that visually seemed to center around a pineapple, and which was ultimately called "The Crazy Machine". It is somewhat time ordered from left to right, top to bottom. In the top left, I believe the boy was first experimenting by himself and was then joined by the girl. From the beginning the boy was very enthusiastic, and I was told by the translator that perhaps he is not following instructions. In the top row third and fourth picture, he has connected the pineapple to several resistors using some twisting between the resistor legs, then to a couple of other vegetables. He and the girl are seen physically collaborating many times as depicted in the first two pictures of the 2nd row. In the third picture of the 2nd row, they are seen considering their near final product which now has a drawn spiral button that almost seems like a "start button" from how they use it. It has colors but is conductive with graphite and perhaps some water. They have modified the pineapple to be connectable in parallel to the series loop of vegetables by sticking various veggies and candies into the pineapple.

When they hook one end of the Drawdio up to the spiral the machine they have built turns on. They don't disconnect it and reconnect it as would be the typical mode of operation when using a Drawdio. Instead they leave it connected as they touch different candies on the pineapple and with the other hand touch different parts on the spiral or the vegetables to change the sound the Drawdio makes by "short circuiting" (not with a 0 resistance but with a lesser "body" resistance) the circuit to change the sound coming out.

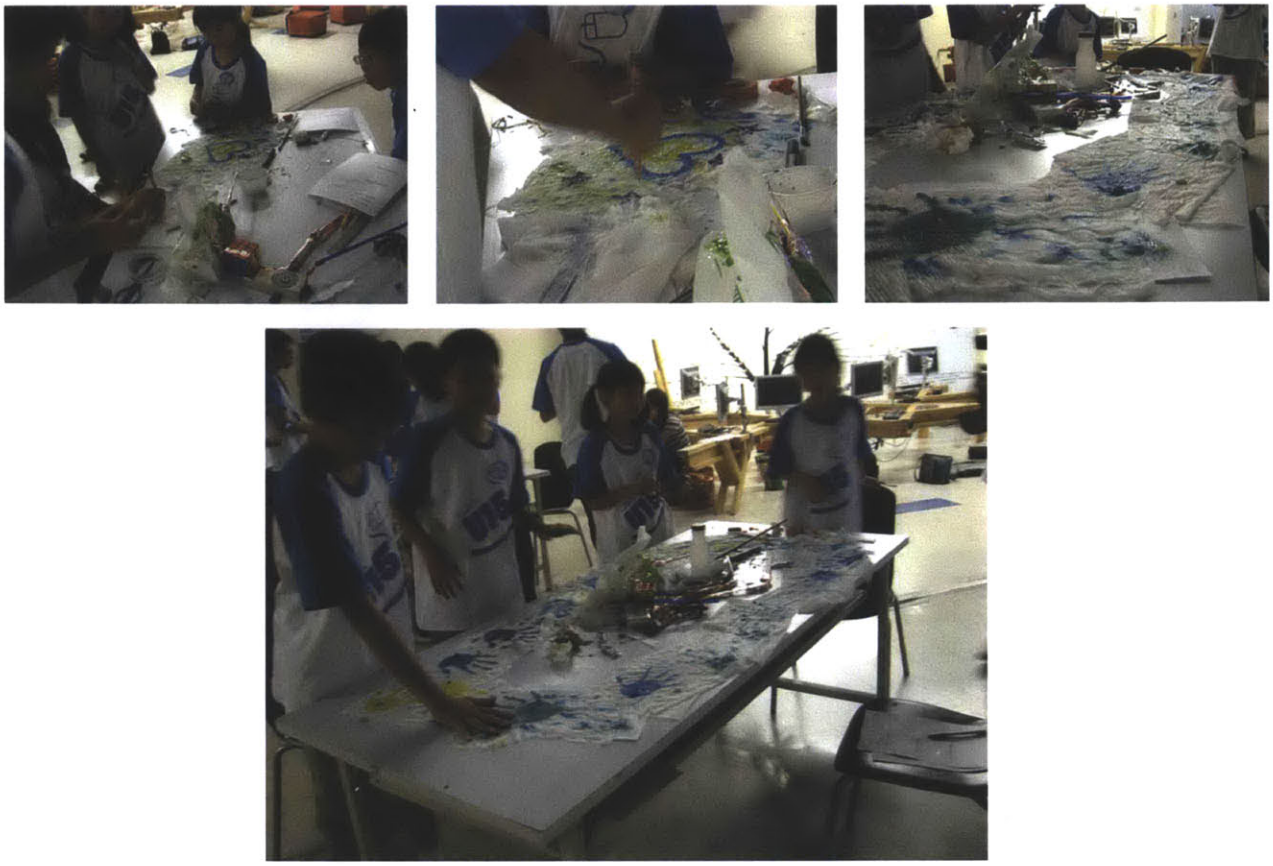


Figure 7.17. A team effort to make a Drawdio "village"

This creation was called the "Tower Village." It consisted of damp paper towels with hand marks stamped on them. I was told they were meant to represent train tracks encircling a center town. The center town consisted of various conductive and nonconductive junk. The group played the creation as they built it at various times, watching them, though others also played their piece as they built it, watching them in particular demonstrated to me that the performance is always ongoing. Discovery, performance, presentation, invention, are all mixed together, not time ordered. They held hands and touched Drawdios and their town. They painted on their town to change the noises. This is the most confusing and interesting Drawdio creation for my brain to parse to date.

Figure 7.18. Green Bean Drawdio

This girl slowly and meticulously built her green bean piano by herself. By trial and error, she hooked up each green bean and checked to make sure the sound connected through to the next greenbean, which often it did not. Sometimes a line of green beans would be abandoned and a new line would be started when the first line could not be debugged. The process left her with an organic feeling set of connections both parallel and series at times, and a cobbled together look.

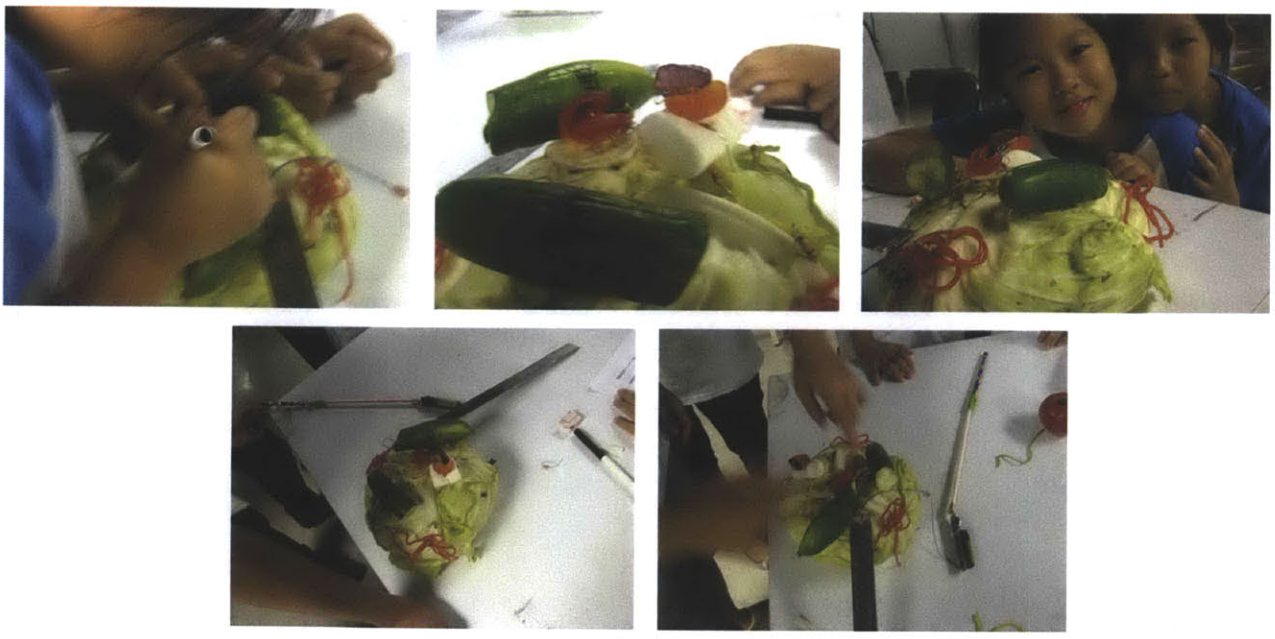


Figure 7.19. Mr. Cabbage Head Drawdio

These two had decided to make a loosely translated "cabbage head". I am not sure of their process because I didn't follow it closely enough. They seemed younger than the others. They worked a lot on the

visual anthropomorphic representation.

Figure 7.20. Mushroom Organ Creation (top) and Critical Exploration Techniques (middle) and final results (bottom)

In the top row, the girl has already set up her basic structure, mushroom bits hot glued down and wrapped in orange electrical tape with brass tacks inserted into each stem at the top. In the leftmost picture she can be seen trying to make sounds with the Drawdio, but only the first one will sound, the rest are not connected by any conductor to the first.

I am interested in her process, and so in the second row you can see me watching her work at what seemed to me anyways like a comfortable distance but close enough for me to see in detail and to communicate to her that I was interested in watching her process. Sometimes I would just watch her from my peripheral vision as in the third picture in the 2nd row. In the third row, you can see some of the detail of her work and that she starts to connect the mushrooms with resistors in between the pads. The brass tacks act as buttons. Then perhaps because the mushrooms are not visible she adds three mushroom chunks out in front, and then she decorates the cardboard under each note with either a music note, a heart, or a flower, and it is finished. she works intensely, alone, with some seemingly unwanted suggestions from facilitators.

Figure 7.21. Very long curving copper tape resistor ladder attached to two "huge poles."

After learning that he can change the sound discretely by adding resistors, this boy sets in and gets to work taping down resistor after resistor. It is finicky to get the tape to guarantee a connection with this many connection points so he goes back and checks again and again and uses his fingernail and a metal ruler to push the tape sharply down onto the resistor underneath. He goes back for more resistors several times. If he has a plan about the shape, I can't see it as I watch: he reaches the end of one row and snakes the row around to continue adding more. He reaches the end of the 2nd row and adds another piece of cardboard. Then in the first row second picture yet another piece of cardboard. In this picture he can also be seen meticulously testing each connection. FInally, like a real-estate developer who has run out of space, he builds up with straws and even connects a wire, but never connects it to his snaking musical structure.

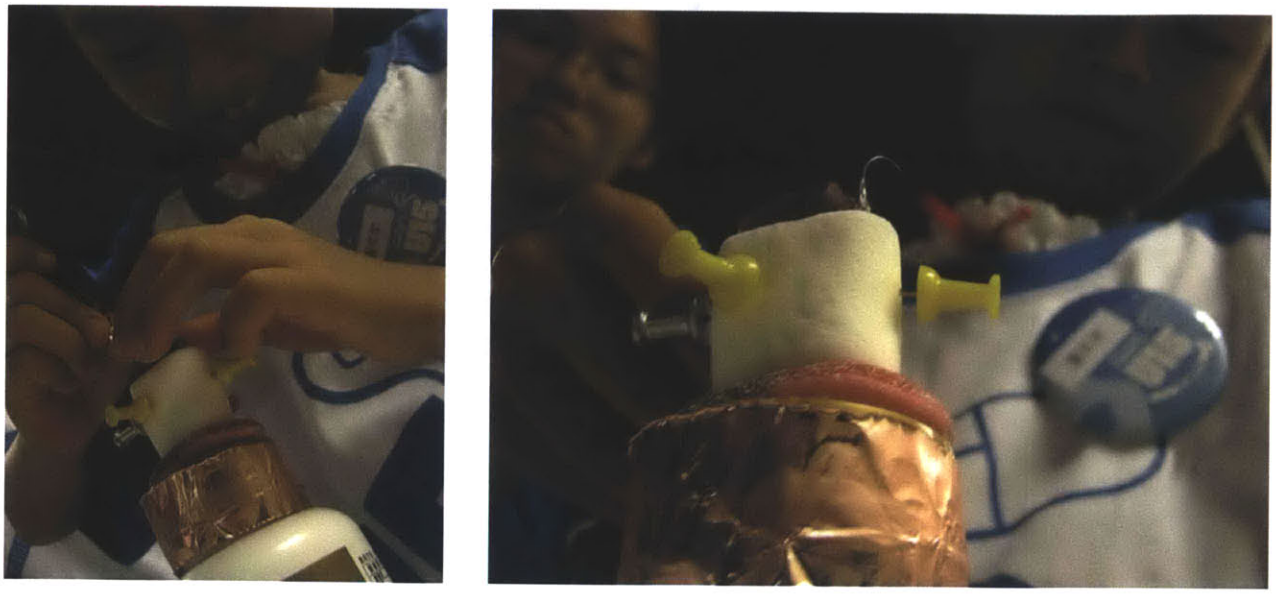


Figure 7.22. Vitamin Marshmallow Drawdio

This youth has brought a vitamin bottle from home as a "special object" as requested by us, and is the only one to use the home item in a final project, which also seemed anthropomorphized. While building the child asked many peers to touch and give input and act things out with the creation.

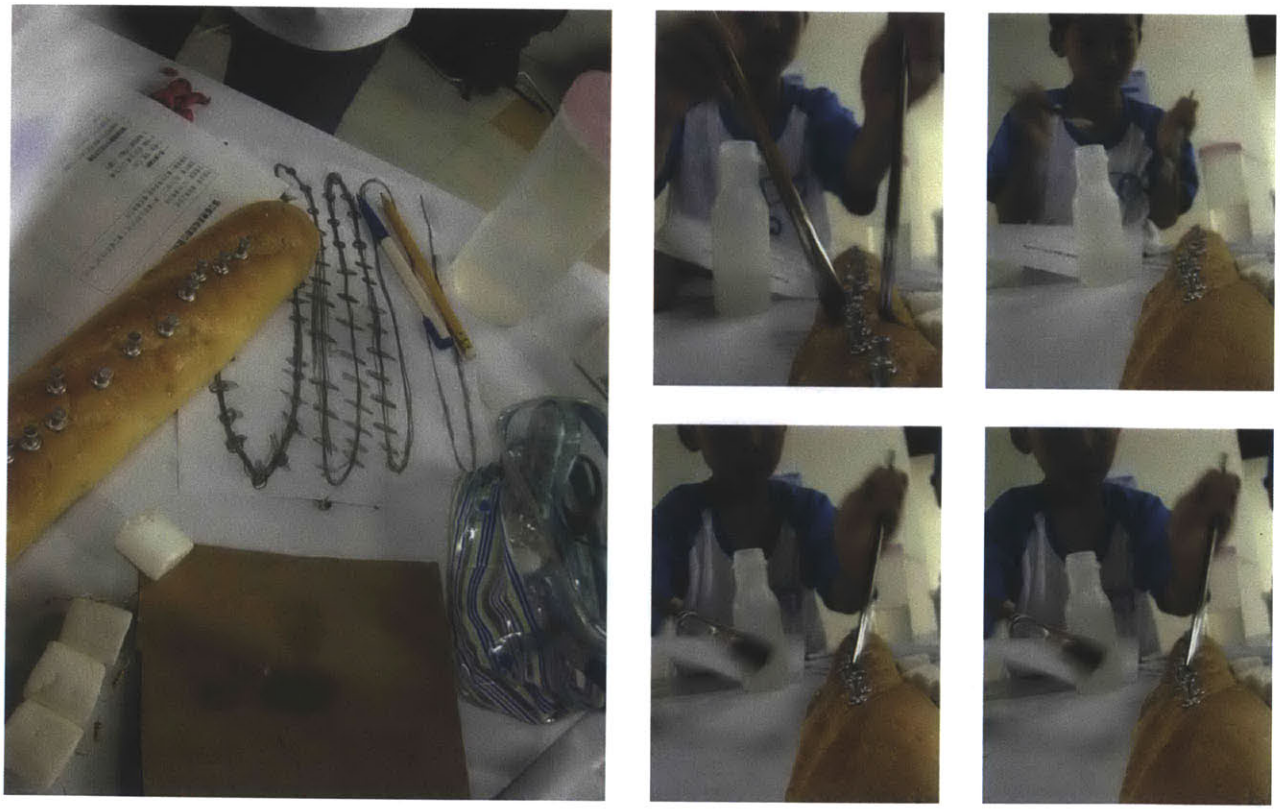


Figure 7.23. Paint the Bread Drawdio

In this bread construction, an initial construction that I only noticed later in the photos could have influenced the thinking, though I'm not sure. Underneath the bread is a long line of conductive graphite with notches placed in the line along the way. The bread has the same topology with respect to resistivity. A long line of continuously increasing resistance (the bread itself) with notches in the form of thumbtacks placed along the way but which don't influence the resistivity of the bread itself. Then during the performance (right) it was not played in the way I had originally imagined, which would have been to touch the various thumbtacks along the bread. Instead the bread was painted with water using not one but two separate brushes at the same time.

Figure 7.24. Fruit Man Drawdio

This native fruit for which I do not know the name was first impaled with plastic thumb tacks, top left. It seems the strategy changed by the end and metallic thumbtacks were used. Through some collaboration, top right, two antennae were added and wired up with wire so that the Drawdio could be attached at the top, again using the "once attached, always on" model. At times another purple fruit was attached to the green fruit, though I am not sure the purpose.

Reflections

The amount of time is always a factor. The camp workshop only had 1 hour scheduled for the whole thing, because their workshop sessions naturally allow for 1 hour activities unless you set up something special. That timing is reflected in the amount of crafting that people were able to accomplish. Also since I provided almost enough Drawdios for each person to have 1, this led to small group sizes of 1 or 2, which also leads to less hands adding to each project. One interesting result is that when there are less

resources of time and hands (sweat resources), people do more with what is right in front of them. Guitar Drawdio, Mobile Drawdio, and Rhythm Space Drawdio, all made do with what they had. The guitar was already there. The pencil with the copper tape spiral was already there. Both were used in a different way. The mobile did use crafting but as little as possible. The museum workshop on the other hand had lots of facilitators, the opportunity for some big teams, and a 90-minute session for working on the main project. As a result you can see more iterations, and more elaborate crafting.

There was evidence of repurposing everywhere, as literally every project involved using something as something else. Out of the final projects presented, all 4 from the camp were heavy on human-made objects being repurposed, with just a bit of food included in the mobile project. Out of the 12 final projects presented from the museum workshop, 8 of them centered around food. Food was better represented in the museum workshop, so no huge surprise. Now let's think about using crafts designated as such vs. repurposing items that were not presented as crafts in the first place. Anything on the craft table, regardless of whether it would typically be a craft, becomes a craft to some degree. By presenting items on the crafting table as a workshop designer, you are simultaneously doing your participants a favor and a disfavor. The favor is that you are suggesting that all these things (carrots, string, etc.) ought to be repurposed. So you've opened the door to repurposing some items, and of course provided them for convenience, but you haven't gone all the way and said what that new purpose should be. However, and this is in tension with the favor, you have done your participants a disservice by not allowing them to make that initial choice to repurpose something in the first place, as that is an important experience to have gone through as well. All is not lost as you are planting the idea and modeling it for them to repeat later.

Now, with that in mind, let's take a look at what kind of items people repurposed that were NOT from the craft table, so that they were actively involved in both phases: categorizing something as repurposable, and deciding the new purpose. In the experimentation phase of the camp workshop, every example displayed in Figure 7.6 is actually an example of repurposing a non-designated craft, I'll call this a wild-craft: braces, blade of grass, hair, piercing, human bodies. In the first and fourth project examples of the camp workshop the participants focused their project on a guitar and a hula hoop, both wild-crafts. In the second and third project example, the participants focused on string and veggies and copper wrapped pencil and string, all of which were provided crafts.

Now let's look at the museum workshop. In the experimentation phase nothing was wild-crafted out of those items pictured in Figure 7.13. In the project phase, we see paper towels wild-crafted in Figure 7.16, and that's about it.

What factor led to the difference? Was it that age and number of facilitators? Was it the outdoor setting vs. the indoor setting? Was it the number of other items lying around and the participants' familiarity with those items and permission within their surrounding due to number of days spent at that location? Or does less time lead to more wild-crafting? My suspicion is that all of these things contributed.

Case Study 2. Drawdio Workshop in (my own) Academia

In this section we'll take a look at two workshops that I ran at MIT, one during Independent Activity Period

and one during Sponsor Week. Again reflections will be at the end.

At MIT during Independent Activity Period (IAP)

This workshop was advertised to MIT students and the extended community (open to non-students) through the Independent Activity Period website. Each January MIT has a 1 month "timeout" during which students study and do projects or internships on any topic of their choosing with no requirements.

Note that in this workshop we used the Drawdio Kit that is unassembled and requires soldering, whereas elsewhere we used the Drawdio Fun Pack which is pre-assembled. Here is what the Drawdio Kit pieces look like:

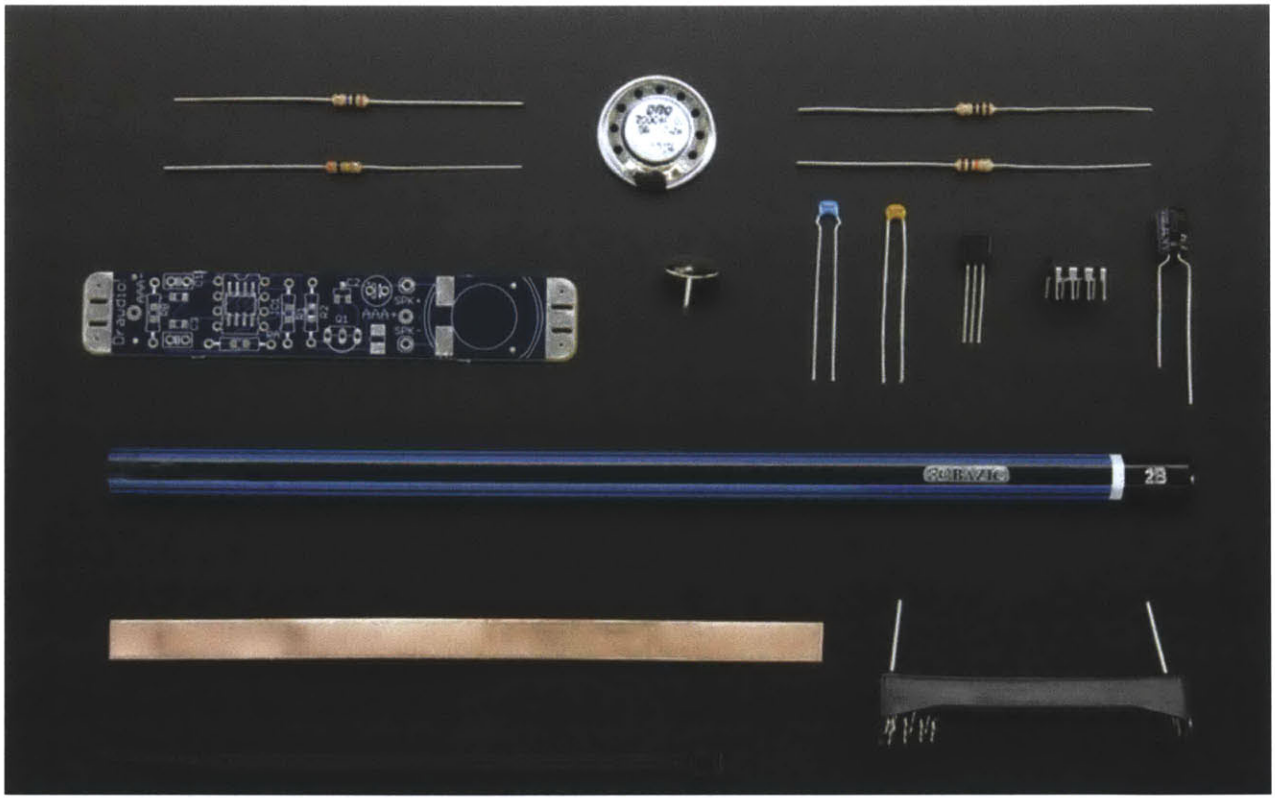


Figure 7.25 Drawdio Kit Pieces (Unassembled, requires soldering, Image taken by Adafruit)

Figure 7.26. Drawdio Workshop setup at MIT in the atrium of the original Media Lab building. Right. Craft Table for Drawdio Workshop. Left. Aerial view of participants getting started on soldering their circuits

Figure 7.27. Closeup view of participants learning to solder

We started off the workshop by watching the introductory clip to MacGuyver. Then we announced we'd be soldering together and inventing things with Drawdio kits. Then we showed a video with many examples of what you can do with a Drawdio. We had printouts of instructions of how to solder Drawdio together. People gathered around round tables (top left) and we laid out craft materials and electronics (top right). Each person had a third hand clip device to help hold the circuit, a magnifying glass with weighted bottom, and a cheap soldering iron, all provided by us (bottom).

Most people were able to solder together the circuit in about 2 hours. We had 3 hours prepared for the workshop. That left only about 30 minutes on average (more for some less for others) to hurry up and "invent something" with the circuit they had soldered together. Note the intense amount of energy put into making the circuit takes away both time and creative energy from getting to the invention part. It can be confusing to people what the true focus is. On the other hand it is empowering that they put the circuit together themselves. But when the goal is to repurpose something in the world, soldering together first just doesn't seem to help people focus on that 2nd goal, which is a finding in itself for me.

Figure 7.28. Eight of the final projects created during the invention phase of the workshop. The first six pictures also have a closeup zoom to the right of them to show some detail.

One of the crafts we had set out was a bucket of these old metallic museum tabs, thin pieces of pliable metal about the size of a coin with a flap sticking off of it, that are used to identify people who had paid to enter a museum. Leah (top left), made a copper tape choker necklace attached to Drawdio on one end, on the other end a chain of these museum tabs were combined together to make a snake-like chain that hung down from her neck. She could then jump and dance around while holding the end of the chain and the fluctuations in the electrical connections between each "chain link" caused the Drawdio to make various sounds as her body moved. Leah was a professor at the Media Lab. While the inherent

bendability of these metal tabs makes them a good candidate for a construction kit, note the way in which Drawdio shapes her view onto museum tab as well as the ensuing structure. Each connection between each pair of tabs is an electrical connection and a mechanical connection, and as the chain/snake bends and moves the electrical connection is also changed. The attachment point at the neck allows for a connection to the human body. Every Drawdio invention requires at least two objects that will come into contact with each other, and it turns out the when the human body is one of those objects it becomes particularly fascinating to play the object by touching it with the bare skin. The human body as a natural part of most constructions makes wearables like this a natural outcome, and also makes the person inventing with Drawdio naturally consider the human as part of the design constraint.

Josh Gordonson (top right) made a "Strawdio", by piercing a straw 5 times and sticking the legs of 2 resistors in each of the 5 holes, then hot gluing them up to keep the water from leaking out when drinking. This forms what is sometimes called a resistor ladder so that as the water travels up the straw, the water makes a connection, first through 4 resistors, then as the water level rises it bypasses one of the resistors and connects through just 3 resistors, the pitch of the sound dropping lower as the water rises, discretely and suddenly like a note on a piano. Josh was a freshman electrical engineering student with significant experience in hacking at MIT. Note that there had been a straw example in the video at the beginning (more on this in Chapter 9: Sample Project Spaces), however it was not augmented with the resistor ladder, instead the sounds were just made by connection between the person's mouth and the water in the straw.

Claudia (2nd row left) worked with her daughter to create a Drawdio brush out of straws, pipe cleaners, and zipties. Note there was also a Drawdio brush in the sample video at the beginning, though it was a normal brush, not one made of pipe cleaners. Note Claudia was trained in my field at Media Lab and was a visiting scientist at the time of the workshop.

A visiting sociologist made the Drawdio Bug or Drawdio Bot in the 2nd row on the right. Notice she uses resistors as legs so that as the bug crawls on the earth (both electrically earth as in "ground" and physically the planet earth's ground) each leg makes a different sound. Notice J. B. in the background showing overwhelming enthusiasm (even for him who is already known to be spontaneously overly enthusiastic) for the project. Well before making any Drawdio kits industrially, I handmade a few and sent one to J.B. What he sent back was the first (the 2nd being the one in this workshop) Drawdio Bot.

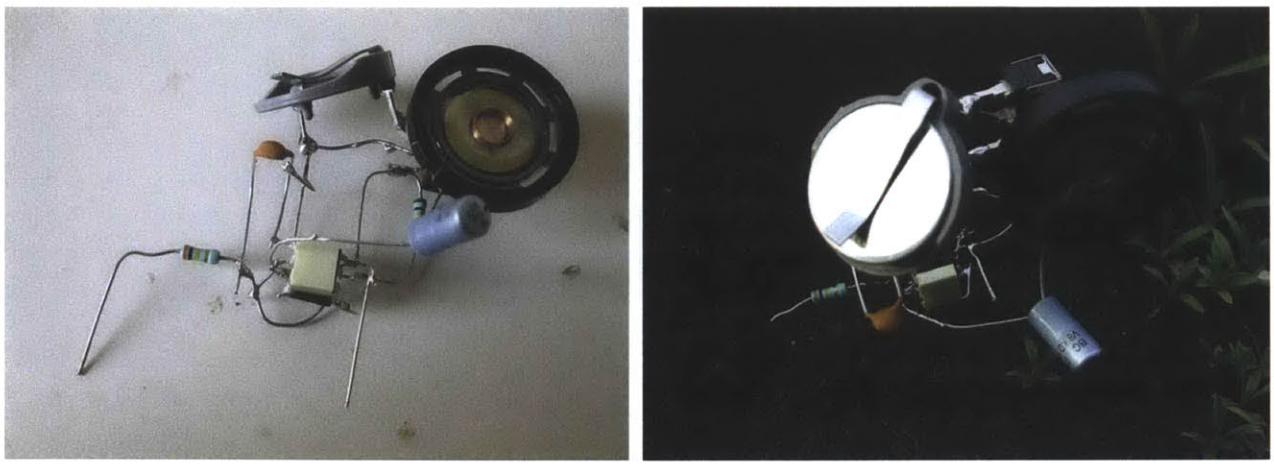


Figure 7.29. Drawdio Bot by Jean-Baptiste Labrune. (Images taken by Jean-Baptiste Labrune)

Note that this Drawdio Bot doesn't take advantage of different resistors to make different sounds as "legs" but instead this is a free-form solder of Drawdio with no circuit board, but all solder points are made in the air so that the circuit itself is in the shape of a bug. The nature of the dirt (left) is what makes the different sounds based on how the DrawdioBot is walked along the dirt (like a bug).

Third row left is a mushroom instrument that changes sound when you squeeze it or reconnect the Drawdio wires to it in a new place.

Third row right is a chain of grapes held together by paper clips.

Fourth row left is a musical bracelet.

Fourth row right was a guy who I believe graduated from MIT a while back and I have seen him around at various events. He took the Drawdio legs and connected them up to a light dependent resistor. Since the Drawdio reads resistance in, this means that the Drawdio was now reading the resistance of a light sensor, who changes its resistance based on the light that hits it. Now this means Drawdio became a light sensor instead of a resistance sensor, converting light into pitched sounds. A few things he demonstrated were quite interesting. First of all different types of lights gave off different types of sounds. Incandescent had some warble to the pitch, and fluorescent had a much different pitch signature. What that means is that your ear is faster than your eye, and you can hear fluctuations in light levels with more accuracy than you can see them. While that wasn't terribly surprising to me, what followed was. He demonstrated something else he had discovered in playing around before the final show and tell. He showed that different parts of the computer screen have different sound signatures, and not based on the color. If we listen to a webpage, just regular HTML then we heard one sound signature, and moving to another color varied just slightly, making me think that the monitor itself has a way of displaying particular colors. Different intensities of light (lighter or darker colors) from the screen also shifted the pitch overall but the sound signature was mostly the same (the movement of sound within the overall pitch). Next, he pointed the light sensor at what we later realized was a Flash program, instead of static html color. It was still just a solid color, but displayed as part of an embedded flash program. The sound signature for this part of the screen was wildly different and particularly complex. This indicated to me that the way the Flash program was updating the visuals on the screen was a different algorithm than the html webpage. This was very interesting and surprising to most of the people in the workshop including myself. This project may have had some influences on my later pursuing a project described previously called Twinkle, which converted colors to sounds.

Watching the ideas at this early workshop and participating in the discussion with the people expanded my ideas of how Drawdio works in a unique way due to the wide variety of deep expertise with technology and creativity.

At MIT Media Lab during Sponsor Week

Twice a year Media Lab holds what was called at that time "Sponsor Week" during which representatives from corporations would visit for inspiration and idea exchange. I engaged six sponsors in a 45-minute workshop. We sat and worked around one large table and had a craft table setup adjacent:

Figure 7.30. Media Lab Sponsor Week Drawdio Workshop. Left, a table for participants with Drawdios awaiting. Right, a crafts table.

While there wasn't much time there were some interesting results. Perhaps my favorite was this Drawdio Book.

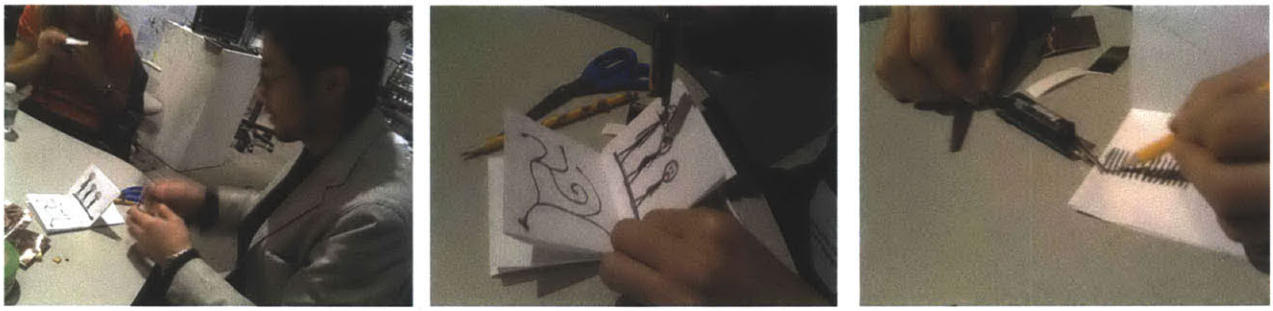


Figure 7.31. One of the results from the Sponsor Workshop. A book of pencil-drawn musical instruments that can be played by Drawdio.

This participant took printer paper and cut and folded it up to make a book. Because graphite is conductive and works with Drawdio, he drew various musical scenes on each page of the book. When he demonstrated, he flipped through the book and played different sound patterns on each page, sometimes with an accompanying story.

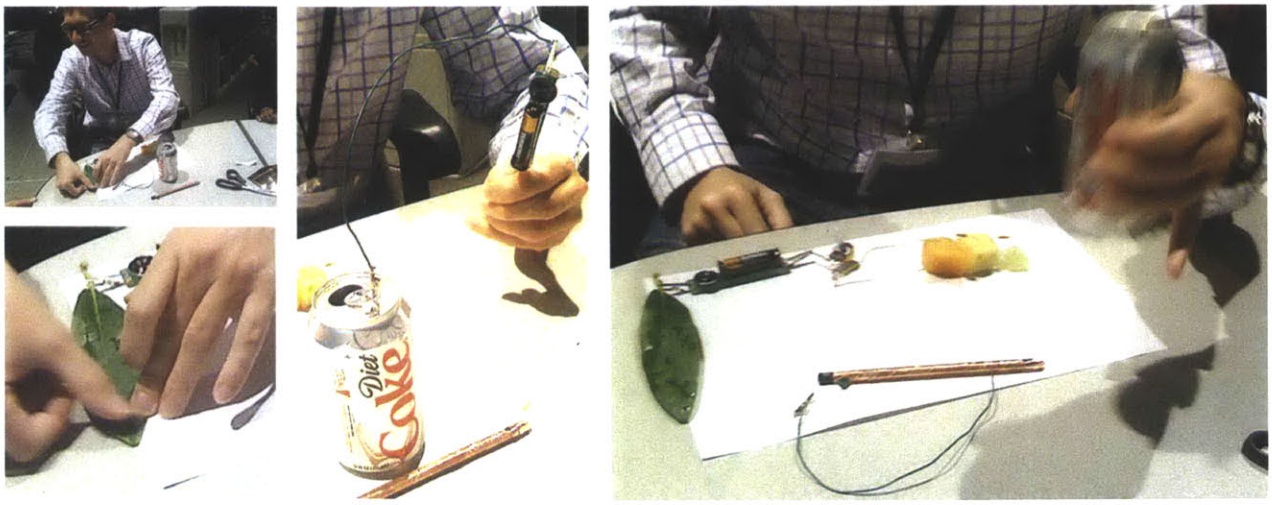


Figure 7.32. Leaf and Coke can switches

On the left you can see this creator pushing down on the leaf to close a circuit connection (thus making sound) and letting up on it to open a circuit connection. In the middle a Coke can tab is used the same way: flexing it on its hinge to close the connection to the rest of the can and flexing it the other way to open the connection. On the right you can see the whole circuit in context with the Coke can used as a way to think about "drinking as a switch for on/off".

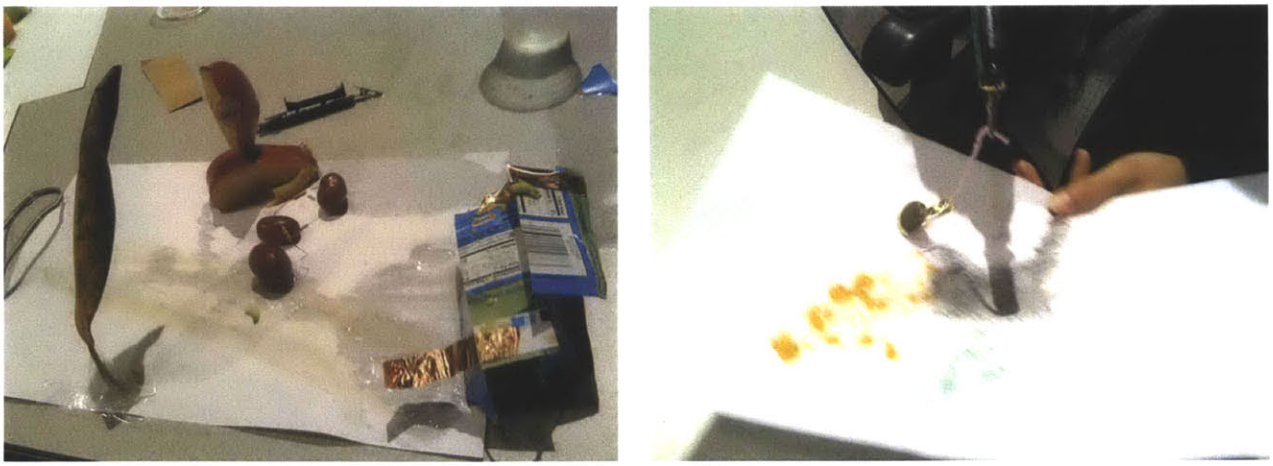


Figure 7.33. Left. Model Drawdio interactive soundscape in landscape architecture. Right. Swinging pendulum musical instrument.

In the creation on the left, the participant walked a little Drawdio man up through the entrance on the left past the feather and apple monuments and into and on top of the cardboard building, acting out an architectural interactive musical model. When extra conductance was needed water was added to the paper.

In the creation on the right the participant made little fields of graphite and jello on a piece of paper. Then a metallic clip (same as the museum clips used in the MIT IAP workshop in Figure 7.26 top left) was attached to a piece of string which was clipped to the Drawdio. This created a pendulum or as someone joked a musical weapon. The pendulum was then swung across the jello'y and graphite'y landscape to produce various sounds as the circuit connected. Note the creator is holding one end of the Drawdio in

his fingers and in the picture is touching a graphite trail at the bottom of the page to connect electrically to the rest of the drawing and jello on the paper.

The attendees of this event can sometimes have a feeling of being responsible as serious adults paying a lot of money and don't feel responsible to themselves or anyone to "play around." So I find the playfulness of the results viewed here are impressive. Note two of the six participants either didn't complete a project or I didn't document it well enough to recall it.

Reflections

One thing I learned in the IAP workshop was simply that soldering for the first time takes a long time, and some people took up to 3 hours to finish. Since I am more interested in how people can repurpose the everyday world, and in general how people invent, than I am with how people learn to solder, I focused the rest of my workshops on using the Drawdio Fun Pack which is already soldered together. That said there was something empowering about putting together your own tool and then inventing something with that tool. So even when some of the inventions were fast, such as the Mushroom Drawdio, there is still a lot to the feeling of making that, because the soldering happened and the repurposing happened which together feels empowering.

Having the voices of Professor Leah Buechley, hacker Josh Gordonson, Post Doc Jean Baptiste Labrune, and other talents from MIT, definitely helped me learn about Drawdio's capabilities in this, one of the first Drawdio invention workshops, that I had run. After making their own inventions, they were catalyzing discussions while other people worked on their soldering and inventions. I don't know if this is why, but Josh used a resistor ladder in his Strawdio, and I started putting out resistors so that people could more easily make objects chained together in future workshops.

I liked the way Leah's metallic chain explored the materiality of the metal pieces en masse when chained together, via the sounds produced. As she is prone to doing, she treated the metal as a fabric to be "woven" together, and looked at the interactive art as a wearable.

Because this was one of the first Drawdio workshops for inventing, I had some ideas, but didn't really know what kinds of crafts would be useful for inventing with Drawdio. I put out crafts typically useful in Lifelong Kindergarten workshops. It is useful to have come from a practice of running workshops in the Lifelong Kindergarten. I copied their basic model of workshopping and evolved it for Drawdio's needs starting with this workshop.

Note that straws were used by Claudia and by Josh in two different ways, Claudia repurposed the straws as structural elements in a paint brush, while Josh used the straw as it is meant to be used (to drink liquid) but hacked it to add additional functionality (musical steps) to it.

The optical Drawdio idea is very similar to optical theremins or optical noise makers that have been seen out in the DIY community, and really captured my imagination for audiolizing the invisible as an expressive medium. I had seen optotheremins before, and this synesthetic pair (light to sound) had been available using the Camera for the Invisible, but his demonstration, and the quick responsivity of the Drawdio circuit, of the device in conjunction with the computer display has left me wondering what other kinds of invention kits to make ever since.

By the time sponsor week came around, I had the workshopping down to more of a science. Because the participants were from industry, and therefore had practical experience thinking about products, and yet

they were in an academic situation where they were encouraged to go wild, the results were pretty expansive in terms of what is possible with Drawdio. From an exploration of leaves to interactive model landscape architecture, to audio-kinetic sculpture prototyping, and of course a Drawdio book. I really relish the Drawdio book, and if I make a set of guides some day for open-ended Drawdio activities, a homemade book would be one of them.

In these workshops we see people sticking almost exclusively to the materials offered as crafts, rather than searching out and repurposing surrounding materials. I don't know why, perhaps out of politeness as it was not their own surroundings.

Case Study 3. Drawdio Workshops in Silicon Valley Corporations

This section will cover workshops run at Intel and BUMP, both located south of San Francisco in Silicon Valley.

Intel All-Hands Meeting Workshop in the Interaction Research Group Run by Genevieve Bell as Part of Intel Labs

The craft materials were set up on long tables around the periphery of the event. Here participants are shown in the beginning lightning round with instructions to get materials out and start making sounds. There were about 5 people to a table and people tended to work in teams as there were only about 2 Drawdios available per table, and it was a team-building event. Also, I was interning here at the time of the workshop.

First was a lightning round of 90 seconds to grab a Drawdio and bring it to your table and make any sound at all with it. It turned out that people played sounds together musically jamming with their table-mates, and that they needed more like 3 minutes.

Figure 7.34. Intel Employees electronic crafting with Drawdio

They were then given 30 minutes to invent something, and this is the result with what I believe is every team's invention represented. Note, the atmosphere at this event is fun and lighthearted and I had primed the participants with a motivational speech about creativity. Also note that attending this workshop was mandatory for everyone in the lab and as employees they were effectively paid and required to participate.

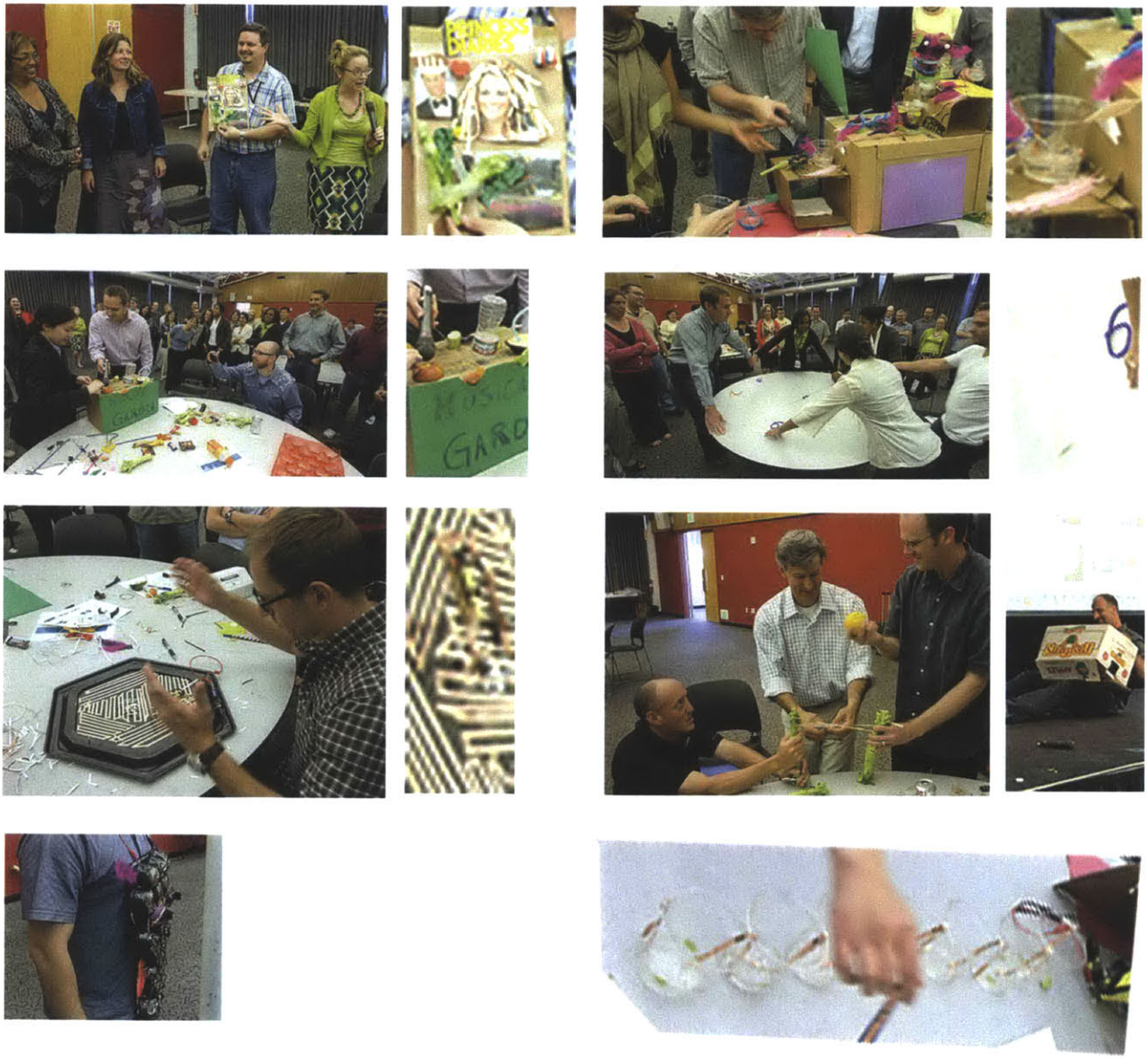


Figure 7.35. Intel employees' inventions. Each picture is a final project during the presentations. The first 6 pictures are paired with a closeup detail shot. (Images in 7.34 and 7.35 taken interchangeably by myself and an Intel employee)

The top-left project is a multimedia collage that makes sounds when various places are touched. For example the princess's hair is made of copper tape and connected to Drawdio on the back of the cardboard.

The top right project is a multi-tiered water fall installation that makes various sounds upon the connection of water as the water cascades through the different tiers. The tiers use a mechanism whereby when one cup fills up with water the next cup does not start filling up with water until the previous cup reaches a certain height because the hole cut in the previous cup is at a certain height, and the water can't escape until it reaches that height. Each cup was connected to the one of the several Drawdios and as the water hit each cup, a new electrical connection was formed and the chorus of sounds changed. The whole process took more than a minute to cascade the water. In the photo you can see one of the creators holding a microphone up to the sculpture so everyone can hear the resulting sounds.

In the second row on the left, a "Musical Garden" was created where each "plant" makes a different sound. The garden is presented popping out of a cardboard box with the circuitry completely hidden inside the box.

In the second row on the right, a multi-player hand-holding game, in which it was necessary to slowly and carefully slide one's hands across the traces on the table through a series of numbers, like a cooperative version of operation, but where you "always want to keep contact" instead of never.

In the third row on the left, a vibrating bot "bug" dance floor was created. It makes different sounds depending on where in the copper-tape-maze-dance-floor the "bug" is walking. Each of the legs of the bug is made with a different resistor and an off center motor was used to make the bug vibrate and thus walk around the maze, which consisted of an upside down catering platter covered in zig zag patterned copper tape.

In the third row on the right, the team created a sound-generating slingshot. The rubber band for some reason absorbed water fairly well, whereas I would have expected it to repel water. Upon stretching the rubber band back the resistance sounded like it was increasing as the Drawdio lowered in pitch. Then the orange was fired and caught on stage in a cardboard box. So I guess it was a game or challenge, which functioned as performance art in the situation.

In the fourth row on the left is a body plate that squeals at different pitches depending on where you touch the person.

In the fourth row on the right is a chain of cups with water which were tuned with sugar and salt until they played a scale.

BUMP Workshop

This workshop was part of a getting to know each other process. I gave a talk about my work over lunch, and then I invited employees to participate in 30 minutes of interactive crafting. There was no lightning round we just jumped right in and started making things. The craft table was the same as the invention table, one big long row of tables, as I didn't have any influence over the table layout.

Figure 7.36. Crafts Table at Bump with people sitting around it getting started with their Drawdio ideas.

I just showed people how the Drawdio made sounds and told everyone to hurry up and invent something.

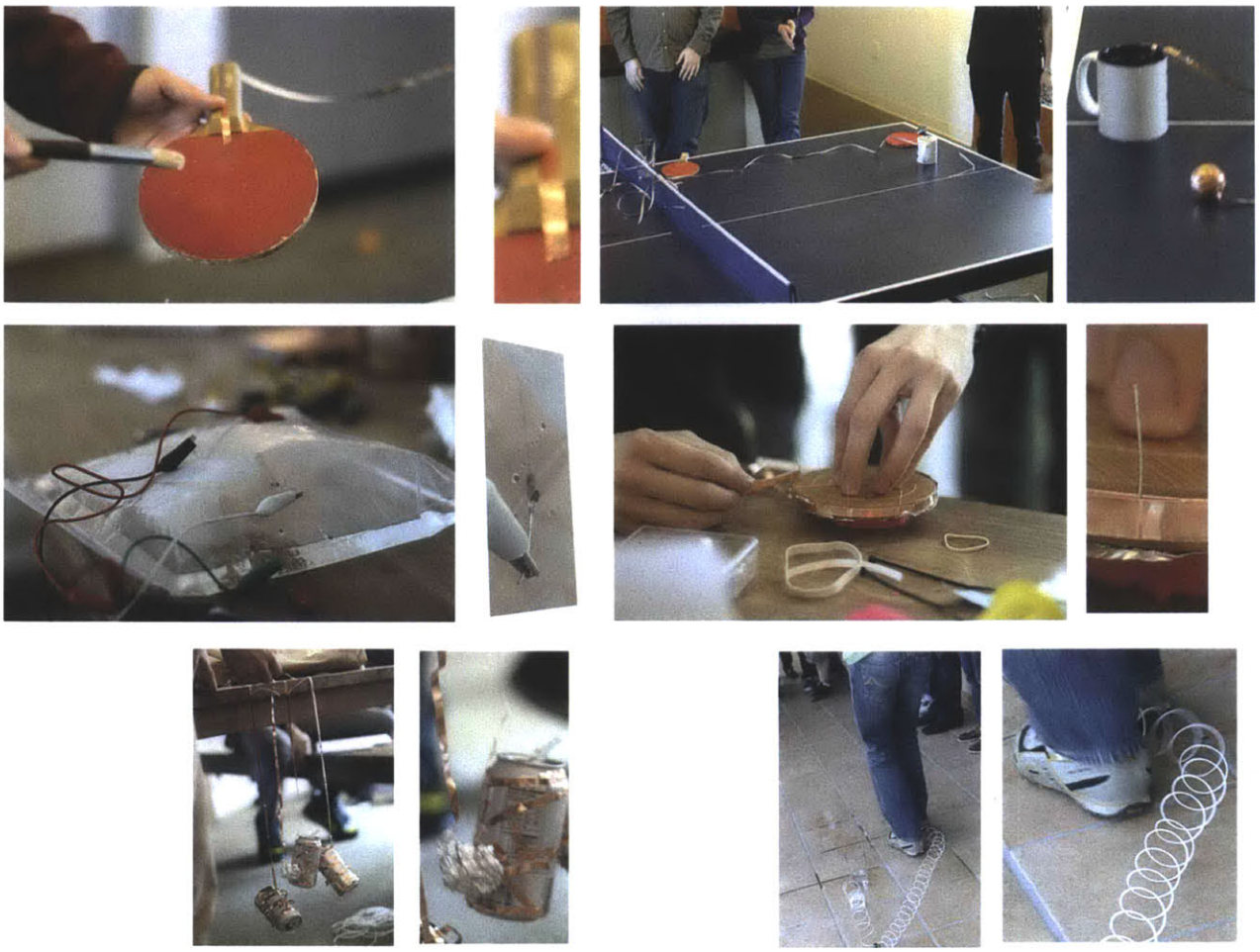


Figure 7.37. Inventions at BUMP.

In the top row is an interactive ping pong table. These guys worked well after the end time to figure out how to create a pingpong game that was audio activated. They had a few different setups. In the top left you see copper tape running down the handle of the paddle to a paddle surface that is being painted with water using a paintbrush in order to make the whole surface conductive. On the right you see a copper tape covered ball. There were at least two games, one in which both paddles were hooked to one side of the Drawdio with their surfaces wet, and the ball was hooked to the other side of the Drawdio by a long piece of copper tape, and then each time someone hit the ball the Drawdio chirped. Another version had the goal of trying to get the ball in the cup, and upon success a sound would be made. The context of the pinball table and game made a lot of interesting ideas pop up throughout the development process because the structure and physics of ping pong is simultaneously constraining, suggestive, and rich.

Then in the second row on the left is a "pillow" that makes sounds depending on how you lay on it. This was made by Magic Seth, a former Media Lab collaborator of mine, and someone whose suggestions were influential on Drawdio.

In the second row on the right was a "toy turn table" that you can spin and make sounds with. They got a wooden disk form somewhere and built it on top of something that let it spin freely. On the sides they added conductive tape with resistor legs sticking out which when spun came into fleeting contact with a wire that was connected to Drawdio. Each of the resistors was also connected to the other side of

Drawdio. By adjusting the resistance (adding more or less resistors in a row or using bigger/smaller resistors) the pitch of each note could be changed. By adjusting the speed at which the disc was spun, the speed of the notes could be changed.

In the bottom row on the left are tin can windchimes. One side of Drawdio is connected to a copper tape string which is hooked to an aluminum foil ball. The other side is hooked to 3 strands of copper tape each ending with an aluminum Diet Coke can. The inventor demonstrated by blowing on the cans and they would come into contact with the foil ball and make sounds. One of the cans was out of reach of the foil ball, but when the can next to it touched it while the foil ball touched the can next to it the sound changed vs. just the ball and the can next to it being in contact.

In the bottom row on the right is a sound-active self-jump-rope toy. The one on the market like this is called Skip It and has a counter that says how many times you've "skipped it." This version makes a beepy sound each time you go around.

Reflections

The Drawdio Turn Table topology is interestingly similar to the Hula Looper topology with a circle of copper, and resistors that spin around and come into contact in a repetitive looping way.

There was excessive use of wild-crafted objects in the BUMP workshop, which I feel strongly is because of home team advantage: They were workshopping in their own space, an office that they work in everyday. Just in the photos seen above there's the pingpong table, paddle, and ball, the large Ziplock bag, the water inside the large Ziplock bag, the wooden disc, and the Coke Cans, which makes 4 out of 5 projects explicitly dependent on wild-crafted objects. I can't help but think it is best to run workshops that are looking to have people repurpose everyday objects in environments with which they feel at home (or "at office") and are familiar with. This is the highest proportion of wild crafting in any workshop.

The Intel workshop had a good amount of social commentary, and games, as opposed to just musical instruments and inventions. My best explanation for this is that the group is ⅓ anthropologists, ⅓ designers, and ⅓ technologists. This is the case by design, which I think does make for interesting collaboration, and has more thinking about user experience than a typical Intel group.

I was especially fascinated by the cascading waterfall sound, partially because most Drawdio inventions lack a slow unfolding process which this piece had, and I am also just interested in water art. I was also interested in the dancing bug, as it could automatically continue to dance around making sound forever. The lead on that project also happens to be the lead of the technical group at the lab, and later went on (and I'm not suggesting this experience had anything to do with it) to become involved with many experimental burning man art installations, which I find interesting looking at what he made with the Drawdio.

Each piece was fairly well decorated on average, and though there wasn't much time, only about 30 minutes, there were lots of hands on each project, on average probably about 5 people.

8. Makey Makey Case Studies

In this section I will describe use cases of Makey Makey in three scenarios:
1) An academic workshop at a conference
2) A high-throughput Maker Faire booth
3) In the wild without direct facilitation from us

Tangible Embedded and Embodied Interaction Conference

So we are at the point that we (Eric and I) have the 2nd prototype, the green circuit board that looks like a gamepad shown in Figure 6.8, and we have written a studio paper which was accepted into TEI Conference (Silver, Rosenbaum, Shaw, 2012). Instead of giving a talk or having a discussion, a studio paper is specifically something that requires a hands-on workshop to explore a topic. The topic of course is Makey Makey. Two years earlier I had helped pioneer the "Studio" category (with Amon Millner and Jamie Zigelbaum and Marcel Coelho) as an explicitly hands-on workshop category, separate from typical "workshops" at conferences, so I was ready and understood what needed to be done. Eric Rosenbaum collaborated with me on preparing and running the workshop. We collected all types of craft materials and brought them with us. In addition, upon arriving we bought a smattering of conductive'ish foods at the local grocery store. Finally, on the way to the studio setup, we picked up tree limbs and other trash to use as craft materials. Here in an overview of our primary craft materials:

Figure 8.1. Craft Materials including cardboard boxes, finger paints, scissors, food, paper cups/plates, play dough, model magic, condiments, pencils & sharpeners, electronics and breadboards, pipe cleaners, tape of all types, popsicle sticks, ameture wire, conductive copper tape, clothing, straws, beach balls, snorkels, bow ties, water paint, stuffed animals, etc.

We took care to lay out each craft material in a pile, stack, or container, in a way that feels accessible and plentiful, and attractive so that people really go for it.

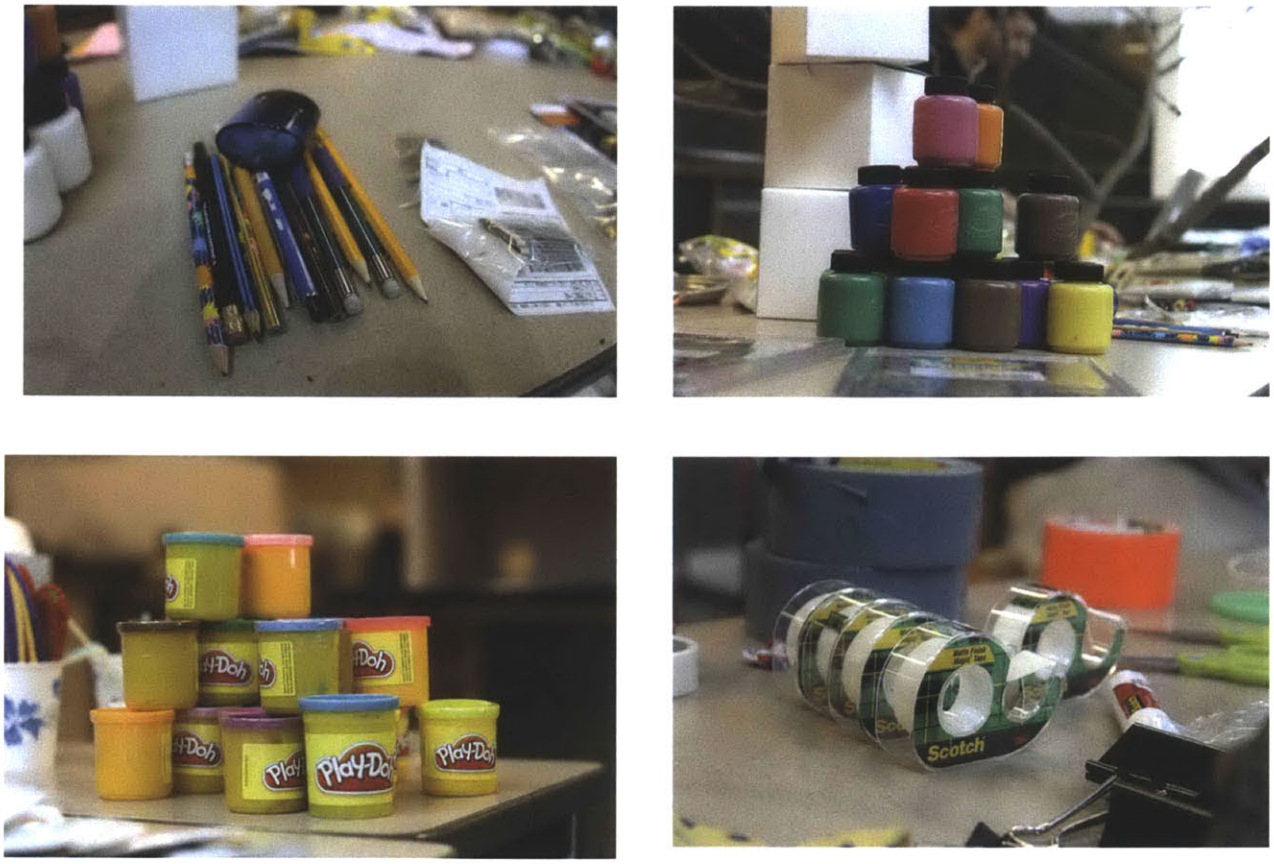


Figure 8.2. pencils, paints, play dough, and scotch tape, laid out attractively (packaging removed, ready to go).

Below you can see what the beginning of the workshop looked like when the people arrived. You can also see the tree that we found in the trash which we put in the center of the tables as a craft material.

Figure 8.3. Tree as craft material and craft materials in tree. Also the beginning gathering of the workshop.

We also placed some craft materials in the trees. The more of a landscape of craft materials you can create the better. It should just feel like you can almost discover a new craft material by looking around.

This was an ideal case because we had Intel funding the craft materials so we were able to spend a few hundred dollars on them, which isn't always the case. But this was a fully facilitated workshop that was fully funded. That's an empty cigarette pack we found in the trash in the tree, a peanut butter pack from the hotel we were staying in at the breakfast table, a pack of play dough scotch taped into the tree, and an inflatable mushroom toy way in the top (visible in the top photo).

With a good craft material setup, we explained the basic idea of a Makey Makey. At this point there is no video available because the product had not launched yet. Just a description verbally and a couple of live examples that we were able to show. At this point there are lots of caveats and glitches to the circuit board that make it difficult to use.

At this point we let them loose on a constrained exploration activity of finger painting a temporarily (cause paint dries) conductive user interface.

Figure 8.4. FInger Painted User Interfaces made over 10 minutes of exploration with the Makey Makey prototype version 2 board

Everyone, including Eric and I, were just getting used to what the Makey Makey is and what it does. Since

it was so new with so little documentation it took longer to wrap one's head around at this point in time than it did later.

We then spent 90 minutes creating various user interfaces. The participants were mostly grad students with a user interface design background, so many of them experimented in lots of directions and imagined how they could use Makey Makey with their own projects. At the end we had a show-and-tell where I captured some of the ideas in photos below:

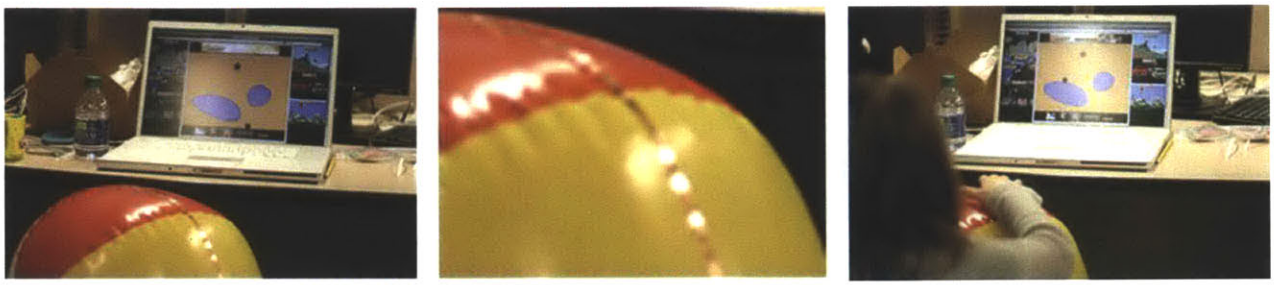


Figure 8.5. A beachball with a copper tape stripe to control a one-button game: Flabby Physics.

This was a beachball one-button game controller. The strip of copper tape serves as a hack to make the non-conductive surface of the beach ball connect to the Makey Makey circuit At first it may seem as if needing the copper tape negates the purpose of using the beach ball. But the size and shape and color of the beach ball are interesting, and the mental connotation of beach ball has a large effect. The most amazing part is the squishiness and bounciness of the resulting controller, which turns out to be perfect for playing an online game "Flabby Physics" in which you must push a button to squish the blobs on the screen and bounce your character to victory. Squishing the beach ball in real life to control the squishiness of the blobs on the screen is an amazing feeling.

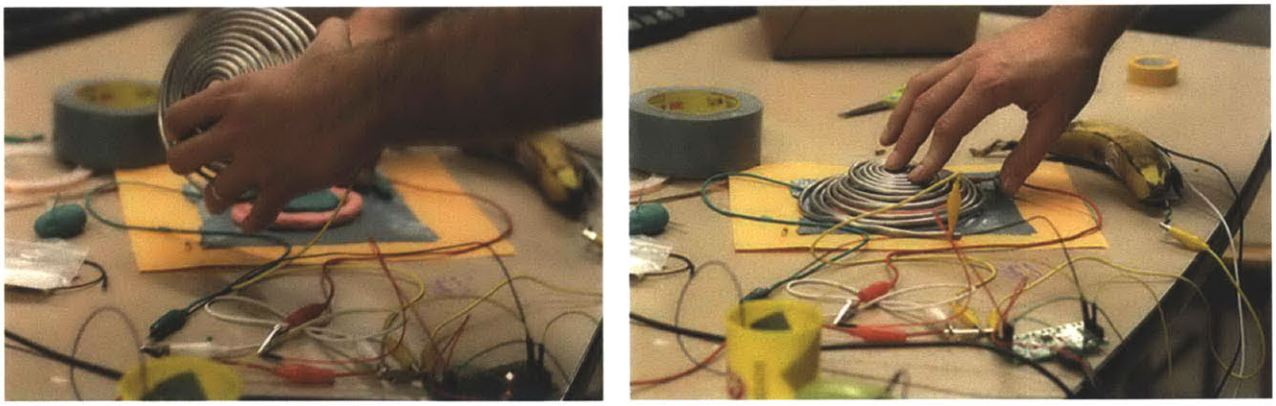


Figure 8.6. A multi level switch for people with different abilities prototyped out of armature wire, play dough, paper, and Makey Makey.

In this invention the armature wire is used as a spring, and as the spring is depressed it comes into contact with different levels of the stacked layers of play dough triggering different key presses which could be detected by an application which would take different actions based on the depression of the multilevel switch.

Figure 8.7. Stool PacMan Controller

In the top left a grad student is hooking up some alligator clips to the stool. The top right picture shows the stool, which is also a controller for the video game, along with the video game on the screen. The bottom picture shows the controller in action. By tilting the stool PacMan is made to go in different directions as the legs come into contact with the ground.

Figure 8.8. Three inventions. Left. Candy and Bread arrow keys. Middle. Apple Bump trigger. Right. Wind based interface.

The project on the left was a set of arrow keys made of candy held on a slice of bread. When touched with the alligator clip the arrow keys would trigger key presses on the computer.

The project in the middle involves bumping two apples together to trigger a reaction on the computer.

The project on the right had a floating boat with copper tape that connected the boat electrically to the water, and when it came into contact with one of the red pipe cleaners on the side, which were wet, it would trigger a key press. You could blow the boat by its paper sail and make it move around and run into one of the two triggers.

Reflections

One major helpful part of running this workshop was that we saw just how hard it was to get the current prototype to work properly. The USB headers popped off half of the circuit boards and were really delicate. That's because we used a Micro USB connector, which has teeth that hold it in place. Also there was no strain relief, and connectors were surface mount. We later switched to Mini USB (no teeth) and larger pads on the circuit, and have since had no problems. The sensing was also not sensitive enough. The prototype we used had 10Mohm resistors, and there was not yet any 60 Hz noise cancellation in the firmware. Running the workshop was a very practical test of all these factors.

The other thing we tested was interest. Not through any formal test, but just by interacting we found that the faculty members and all the graduate students were unexpectedly enthusiastic about the possible future uses of the Makey Makey. The enthusiasm verified our hunch that Makey Makey would be really useful and empowering for people, which led me to pour all my energy into its success, working pretty much day and night non-stop.

This workshop was the first time we saw a user input device made for someone who can't use the typical mouse and keyboard devices. Uses like this were never something we imagined, and later when we launched the project to the public, we got a lot of interest in accessibility uses of Makey Makey, which now has its own section on the makeymakey.com forums called Hackcess.

The use of the beachball to get a squishy button showed me the value in being able to break the keyboard buttons out into the physical space even if order and arrangement wasn't part of the issue, and

even if the physical contact is still with the copper tape. Like a clear finish on stone or wood which still allows the visual and tactile properties of the stone or wood to come through to the person's senses, the copper on the beachball did not impede the beach ball from compressing and pushing back underneath your hand providing a truly bouncy UI. The game played was called "Flabby Physics," and involved squishy objects on the screen deforming just like a beach ball. A perfect match. The toy boat UI (Figure 8.7, Right) stretched my idea of how far a Makey Makey UI could truly go. While something like this could have been achieved with a light sensor, there is something very basic in understanding the idea of "two things touching triggers something." It is very much like a button but without the button -- that is to say the world becomes the button and the sensor somewhat disappears or at least is put to the background as in the IPE model of Figure 2.17.

With Makey Makey we finally get to analyze the repurposing of applications, which I like to call digital dumpster diving. The documentation of this isn't done so well, and perhaps that's because I was so accustomed to taking pictures of the physical objects, or perhaps it was hard to get this particular prototype of Makey Makey to work consistently enough with the laptops. I don't know which. But we can see Flabby Physics and Pacman (Figure 8.6) being given new interfaces. There is also evidence of wildcrafting behavior. In PacMan the stool and floor are used as part of the "JoyStick". As stated previously, when people are out of their own environment it becomes much more difficult to wildcraft.

Maker Faire Workshops

I have run plenty of tables and booths at Maker Faire in which we show what we're working on and let people touch it, basically a demo where someone plays a musical instrument or a game, but to really scale up and give a unique creative experience, not just a demo, to thousands of people in one weekend was a challenge. I was at Intel as a Maker Research Scientist and one of my jobs was to interface to the public on behalf of Intel at the Maker Faire. We, led by myself and Jay Melican, created a 1000 sq. ft. booth at Maker Faire San Mateo, which we first piloted as a 500 sq ft. booth at Portland Mini Maker Faire 6 months prior.

Start-Making Design

Our premise for doing what we do is that not everyone thinks of themselves as a maker and not everyone knows how to start making. So we created an idea called "Start->Making" which is meant to provide tangible proof that you can make something unique, technologically active, and creative with a small amount of resources provided on our part (scalable), and which is attractive to people currently underrepresented in technological making, and which takes a short amount of time. While this experience would only be a brush with making, it would give any interested party a real start-to-finish example that they can create something and perform with that creation, and then take something home to remember it by.

Portland Mini Maker Faire, "Sketch It! Play It!"

Sketch It! Play It! is an activity designed to fit the Start-Making criteria mentioned above and analyzed in Ch. 9 Discussion. You walk up and see lights flashing and hear music being played through loud speakers. You come a little closer and you see that the music is controlled by the people standing in front of the performance stations as they move their fingers on a clipboard. You then either watch more, leave, ask a question of the facilitator or a participant standing at the performance station, or just decide to make one yourself based on the sign. More on the making part in a moment, but here is an overview.

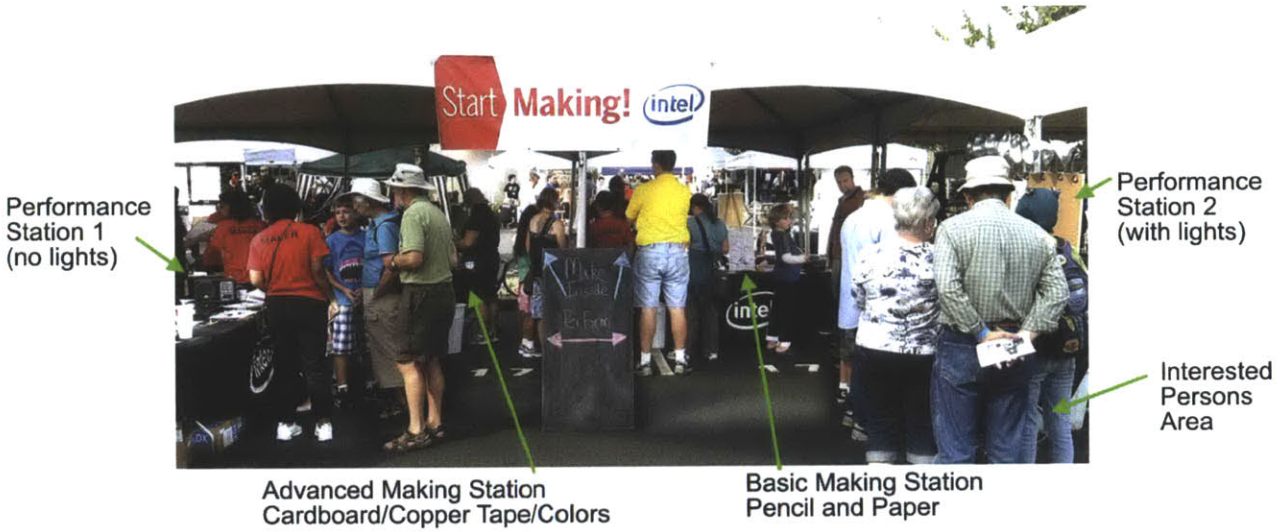


Figure 8.9. Front facing photo and overview of the Start->Making Sketch It! Play It! booth

A performance station looks like this.

Figure 8.10. Performance Station later called "Jam Stations." On the top is a jam station with colored lights that all turn on whenever you connect one of the keys on your musical instrument. The bottom is the same setup without the lights.

Note the strain relief in Figure 8.10 pictured in the top picture on the bottom right and in the bottom picture

on the middle left. It looks like a grey piece of wood screwed into the table with colored Makey Makey alligator clips running underneath it. This is one of the many important modifications you need to make when you go from servicing a workshop of 20 people to running people through on the order of 1000/day. The strain relief prevents the inevitability of wires unplugging from getting pulled on throughout the day. The other components are a loud speaker, a "previous works' bulletin board (Figure 8.10 top only), alligator clips labels with what sound they make, and a system to make the sounds and flash the lights when the alligator clips are connected (this consists of a laptop running Soundplant, a PowerSwitch tail II, and a Makey Makey).

This station is the first station onlookers encounter by design to attract participants by honestly showing them what the outcome of their work may look and feel like in performance mode.

Next, after perhaps playing someone else's instrument or just watching, you might decide to come to a craft table and make your own instrument.

Figure 8.11. Left. Basic "Start Making" crafting table with clipboards, pencils, paper, and connection testing station. Right. "Take it Further" station with cardboard, copper tape, colored markers, and other construction materials.

The instruments are either drawn with regular pencil on white paper at the "Start Making" crafting station, or constructed in 3D out of copper tape and cardboard and decorated with colored markers at the "Take it Further" station. After making something and testing the connections at the basic station, you would typically then take it to a performance station to try out the instrument. You might then bring it back and tweak it, or take it further, and then perform again, or maybe leave, taking your creation with you or pinning it up on display.

Here's a depiction of some of that process.

Figure 8.12. Top Left. Checking it out. Top Right. Drawing an instrument. Bottom Left. Hooking it up. Bottom right. Jamming Out.

As shown in Figure 8.12, a basic loop through the Start Making! experience might include taking a look at the performance station (top left), drawing an instrument with a pencil (top right), hooking up your instrument and playing with it (bottom left), making another instrument this time out of cardboard (not depicted), and hooking that one up and jamming out on it (bottom right).

We had two places for people to show off their work: on the sample instrument board behind the jam station and on clothes lines strung above the Start Making! crafting station.

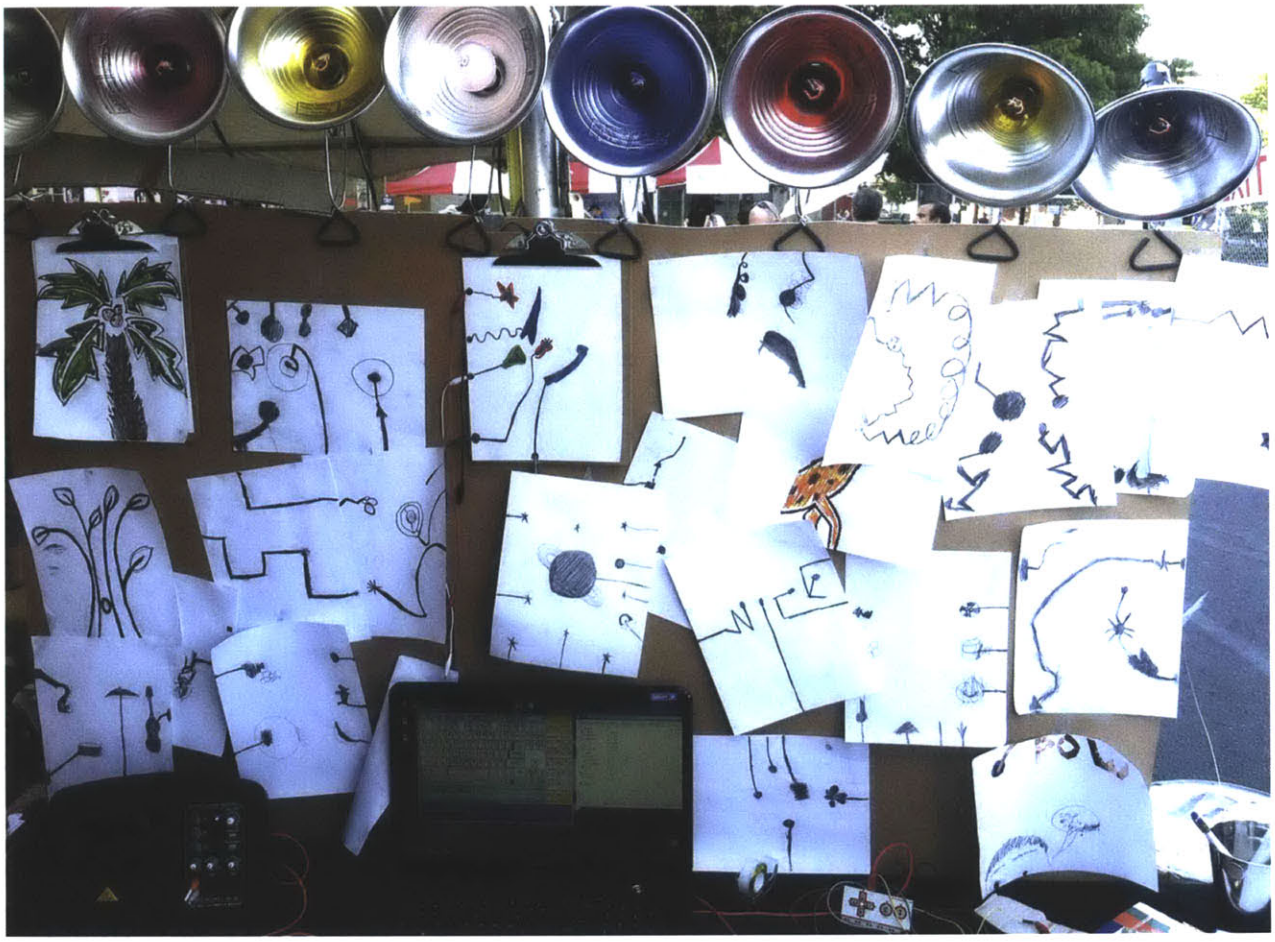


Figure 8.13. A closeup of the sample instrument board, one of two places participants can pin up their instruments after trying them out if they choose not to take them home.

It's important to have sample instruments in both locations. When onlookers first approach it's important to show that there are a variety of ways to make your instrument and yet one thing is in common: they all have graphite (or copper or conductive paint) traces that connect to the edge of the paper to be clipped onto with an alligator clip. Then when sitting at the crafting station it's important again to have examples of working instruments so you know how dark to make the lines, and to get inspiration as to what might be possible. While this could constrain what some people are willing to try, it will open others up to what is possible, and you have to be practical when you have 1000 people.

Here is a sampling of graphite based musical instruments produced during the Portland Mini Maker Faire over 2 days.

Figure 8.14. Graphite musical instruments drawn in the Start Making! tent.

In row 1 column 3 we see what looks like a single button that can control one sound. Yet the topology of the single button does allow for some interesting patterns by sliding one's finger across the spiral in a straight line which would connect and then disconnect the circuit at least 3 times, thus triggering the same sound but three times in a row, with the timing dependent on how fast you slide your finger across the drawing. On the top left you see a drawing that was at first all connected so as to produce the same sound when hooked up. But that was not the intention. The person drawing the circuit likely did not know that you had to separate the traces in order to trigger different sounds. After trying it, they went back and erased little gaps of graphite just up and left from the circle and just up and left from the triangle.

> This can be interpreted as debugging the circuit, but instead of working with a soldering iron and rework station, just a pencil and eraser are used.

These two erasures give rise to three different graphite "buttons" that can be pressed: one consisting of the star and rectangle, one consisting of the circle and rectilinear spiral, and one consisting of the triangle and natural spiral. In row 1 column 2 we see five identical buttons laid out in a grid-like manner. In row 1 column 4, we see a very minimal instrument with just two small buttons, but the drawing depicts natural objects. In row 1 column 5 we see a set of three darkly drawn buttons with what could be a first try drawn

very lightly in pencil but which likely did not connect the circuit.

In row 2 we see several examples of drawings that are just not clear whether they will work as intended or not without hooking them up. I can recall one person's drawing who had a whole doodle that was connected to itself as to form one big circuit node. I "knew" that it wouldn't be able to play separate notes when connected, but I waited for him to connect it up anyways, so he could "find out for himself." At that point to my huge surprise the drawing played three separate notes. Upon further investigation it turned out that the graphite was just light enough on some parts so that the visual graphite connection in the middle wasn't an effective electrical connection.

Row 4 shows visual variation in representation, and are some of my favorite examples. First a drawing of a person with what might be puffy clothes on, with a crown of sorts, and three musical nodes connecting to the crown. The person is most likely not dark enough to conduct electricity. Second, a planet, moon, and stars, each as a separate node. Third a beautifully drawn face that likely has two separate working nodes. Fourth, an abstract arm or building-like drawing with fine detail work that likely doesn't conduct and an outline that is probably all one circuit node. And last, a "drum set" complete with shading and arrows, in which each drum makes its own sound. We used this as a demonstration example for quite some time.

Some people stayed around for a long time and made all kinds of instruments. The "Take it Further" station with mixed media generally took longer to execute and understand. Here are some representative examples from that station.

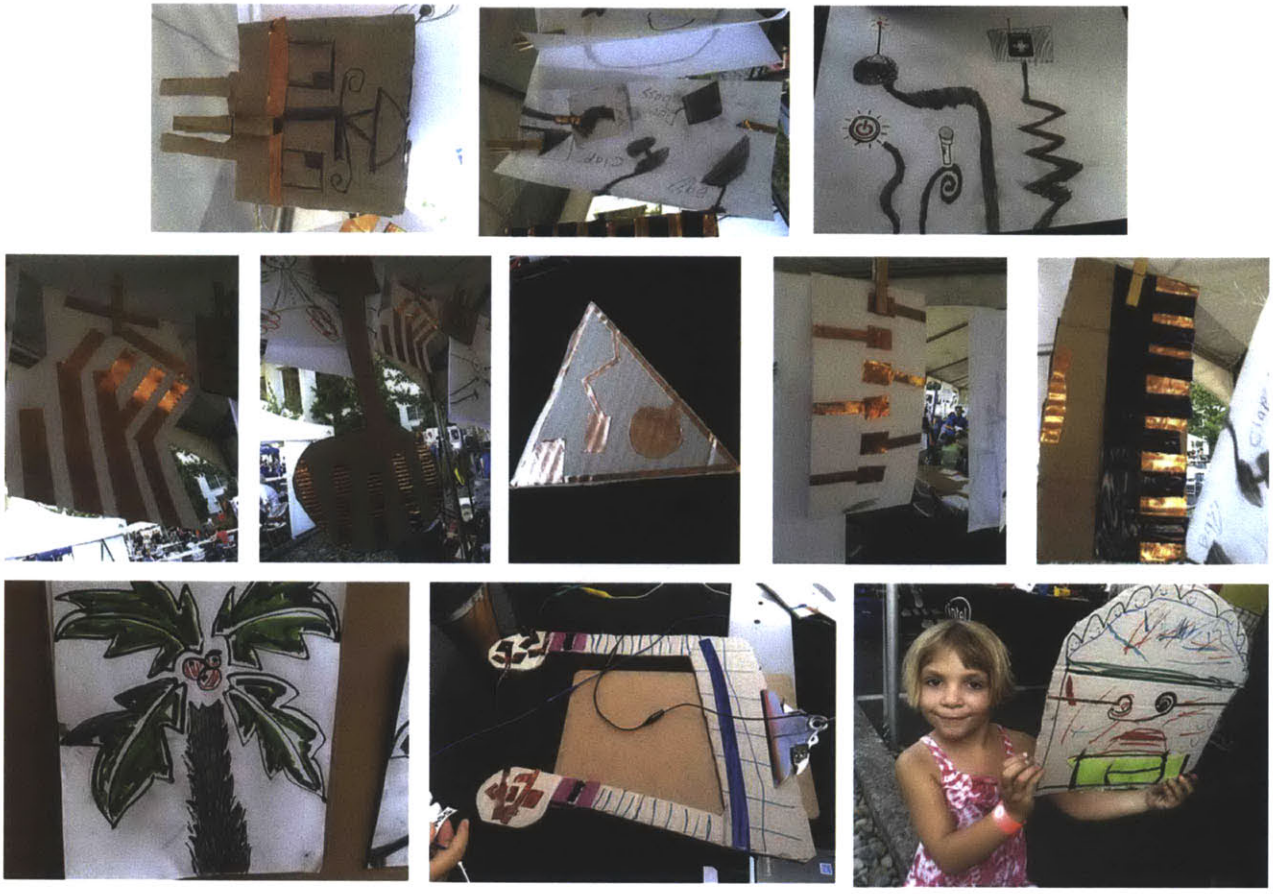


Figure 8.15. Projects created at the "Take it Further" station with copper tape, colored markers, cardboard, and in the case of the palmtree on the bottom left, some conductive ink.

We took what we learned at Portland Mini Maker Faire, and we went all out for the Bay Area Maker Faire 2013. Intel sponsored the 1000 sq. ft. booth shown below.

Figure 8.16. The Sketch It! Play It! booth at Bay Area Maker Faire (image taken by Jay Melican)

We had all the same stations. This time we had 4 performance stations in the front each with their own lights and up to two people could jam on each performance station at the same time for a maximum simultaneous throughput of 8 people simultaneously with about 2 minutes on average per person. We had one big Start Making! Sketch It! Play It! crafting station in the middle where people could draw graphite instruments. We also had two Take it Further stations this time in the back corners.

Figure 8.17. A typical crowd at the Sketch It! Play It! booth at Bay Area Maker Faire. (Image taken by Mikey Siegel)

Based on paper usage I'd say we had 3000 participants over the 2 day period.

Figure 8.18. Closeup of each station. (Images taken by Jay Melican and Mikey Siegel)

On the top left is a closeup of the Sketch It! crafting station, which also has a huge arrow with the words "Start Making." Top right you can see the Take it Further station in the back with a slightly closer view of the Sketch It! station. Second row shows two of the four "Play It!" performance stations where you can see facilitators are actually going too much hands on with the alligator clips, which would be better attached by the kids themselves, although those alligator clips are pretty slippery at first so it's

understandable, and perhaps the clips should be designed better for an event like this. The third row shows closeups of the "Take It Further" stations. The one on the right was used as a "wearables" station most of the time and people were encouraged to make hats, sunglasses, and additions to their shirts and bodies.

Figure 8.19. 3D Creations at Sketch It! Play It! (Images taken by Jay Melican)

On the top row you can see a facilitator who happens to be an awesome artist showing one of the 3D instruments she personally made earlier that day as inspiration for others to try making something. In the second and third row you can see some examples of instruments with their creators that are fairly representative of what was made at the Take It Further stations.

Reflections

Getting a chance to execute this over and over again (we actually ran this event a 3rd time at San Jose Tech Museum) really allowed me to start to think about it at an abstract level. There are many situations in which it is necessary to be practical about costs, time, and number of participants. How can we keep an open ended-ness to the project while at least hinting at the possibility of open-middled'ness and repurposing? Many of the platforms/toolkits built by Lifelong Kindergarten, such as Scratch and Makey Makey, are meant to be used in a 30-minute plus session ideally with some facilitation. Now one can make the argument that if you're going to engage in something for 3 to 30 minutes, as is the case with the vast majority of people in Sketch It! Play It! then why do it at all? But the reality is that situations like this arise or are forced on people based on institutional structures or in other ways. So how can we think of the platforms/toolkits built in the Lifelong Kindergarten, and related types of creative tools, as best used in settings where there are either too many people, not enough money, or too little time, to use these tools in the originally intended manner?

Here, I'll lay out a thought on Sketch It! Play It! which I will generalize to apply to other situations in the Discussion chapter. Is Sketch It! Play It! actually its own creative platform built on top of Makey Makey? And can you generalize that concept and say that there are guidelines for taking a creative platform on the level of Makey Makey, and making another platform on top of that one? More in Discussion.

Makey Makey Online and In the Wild

Makey Makey projects took off in the wild. There are so many projects documented online that it could be possible to present only Makey Makey case studies that happened outside of the workshop context. Since these case studies will come more from the wild, it is fitting that I provide a description of Makey Makey through the words of a user online:

> **Title: What is a Makey Makey? Uploaded by: Pasco County Schools. Uploaded to: YouTube**
> "Makey Makey is this uhm system where you use this flat piece with all these little dots and stuff [editor's note: Printed Circuit Board] and you connect these uhm jumper cables to them and then connect them to your computer, and you can use them wires and stuff to control the computer. You can also use it with apples, bananas, fruits, and maybe even paper. I like that you control computers with fruits <laugh>, it's actually kinda funny. I wish I could program at school everyday."

Figure 8.20. Kid online explaining Makey Makey to an online audience

As an indicator of the amount of wild documentation of Makey Makey projects, let's take a look at some searches for "makey makey" in quotes to eliminate anything that could be extraneous (a search for "makey makey" in quotes returned nothing on Google as of 2011). This is of course only an approximation to internet popularity. As of the writing a search for "Makey Makey" in quotes on Google has about 400K Google results. By comparison, Drawdio gets about 100K Google results, GoldieBlox gets 600K, and "Lego Mindstorms" gets 1M. "Makey Makey" gets about 20K Youtube videos, whereas Drawdio gets 5K, GoldieBlox 100K, and "Lego Mindstorms" also gets about 100K.

Breadth: Games, Inventions, and Instruments

The original Makey Makey video shows examples using Makey Makey with games, inventions, and music. Let's cover some representative examples of how people use Makey Makey in these ways online in the wild, without having any contact with the Makey Makey team.

Here are six game examples:

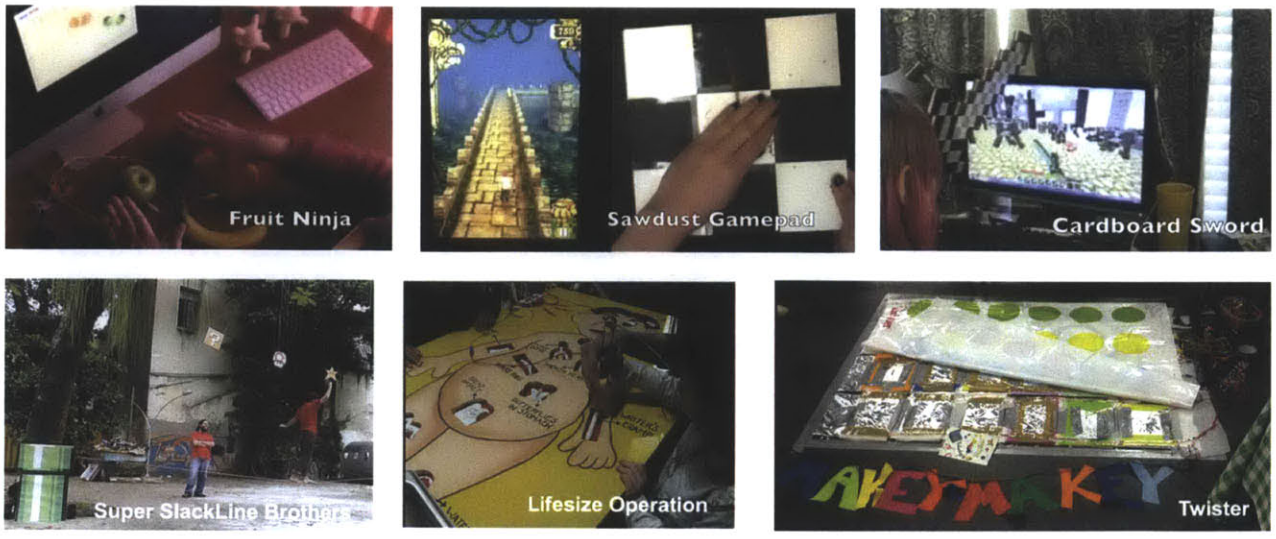


Figure 8.21. Makey Makey game examples found online. (Images reproduced from respective projects online)

The top row left is the most direct type of game controller where one item stands in for each arrow on the

arrow key. The apple is the up arrow, orange is the right arrow, banana is the down arrow, etc. Then instead of using the arrow keys to play the item is simply touched. The first row center is an example of a joystick-like device in that one object is moved in order to give a command to the game. In this case instead of a "stick" it is clump of sawdust. I am not sure why the clump of saw dust is conductive, perhaps it is moist or perhaps it is just the person's fingers that are conductive, but it is interesting that instead of moving a stick up/down/left/right it is a clump particles being moved around to control the character on the screen. First row right is an example of embodying a single button push into a form that mimics the action being taken on the screen. The keyboard is still used to move the character around, but to swing the sword a cardboard sword must strike the monitor. The cardboard sword has aluminum foil or conductive tape and so does the monitor, so that when the two come into contact the character on the screen swings the sword.

In the second row we see less straightforward and more embodied and embedded gaming examples. Second row left contains a slackline as an element of the gameplay. A slackline is like a low tight rope. In order to play the game one must not fall off the slackline. If one does the "death song sound" from Mario Brothers plays through a speaker. The slackline is covered with wires which presumably detect the presence of a person on the slackline. Then objects familiar from Super Mario Brothers are placed above the slackline and they must be touched. In the second row center, a full scale model of Operation. And on the right a computer modified version of Twister.

Here are six music examples:

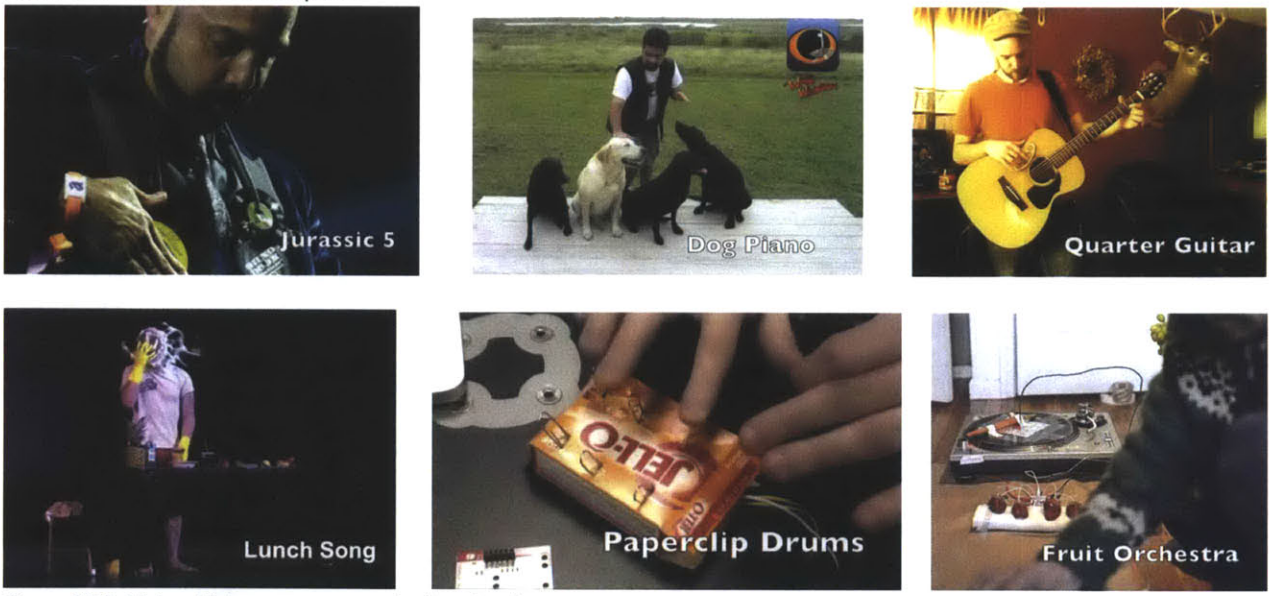


Figure 8.22. Makey Makey game examples found online

Top row left, at Coachella 2013, a music festival, DJ Numarc uses Makey Makey on stage to play some samples. Next a piano made of dogs. In the five-minute version of this video, they experiment with the best way to attach to the dogs without causing pain and still getting an electrical connection. The guitar on the top row right has bass notes added with quarters attached to the guitar. The inventor and musician, who calls it a DIY Midi Harp, says he wanted to buy a guitar that does this, but this was much cheaper. He jams out a great song playing bass and guitar notes at the same time. Second row left is an undergrad from Texas who won his school's talent show by playing the "Star Spangled Banner" via

"eating lunch" including listerine as one of the foods and whip cream pie to the face for the last note. A box of Jello and paper clips are used to make a drum set second row center. And finally, second row right is DJ J.Views from Brooklyn playing Teardrop by Massive Attack on a carrot turntable, grape bells, and eggplant drums along with mushrooms, strawberries etc. He got a great response and 1M video views online.

Here are six invention examples:

Figure 8.23. Makey Makey game examples found online. (Images reproduced from respective projects online)

Top row left a boy and his father collaborated on making a pencil-drawn control panel that could modulate the LED stars on the bedroom ceiling at night. Top row center was an entire dinner party set, table, flatware, and food, that was interactive. Top row right was a set of physical fitness courses made using aluminum foil pads, masking tape, and Scratch programming language. Bottom row left is a category we saw more than initially expected: accessibility. In this case it was a submission to our contest from a dad who proposed to make special gloves to navigate the web for his son who had cerebral palsy. Note this is the one example of something that is a proposal and not a finished documented project. Bottom row right is a simple piece of custom software and aluminum foil to make an interactive cat toy. And bottom row right is an interactive engagement ring.

These three areas, games, music, and inventions, give a sense of the breadth of what is out there. Now let's look at a couple specific areas to see how deeply people are using the product.

Advertising Examples

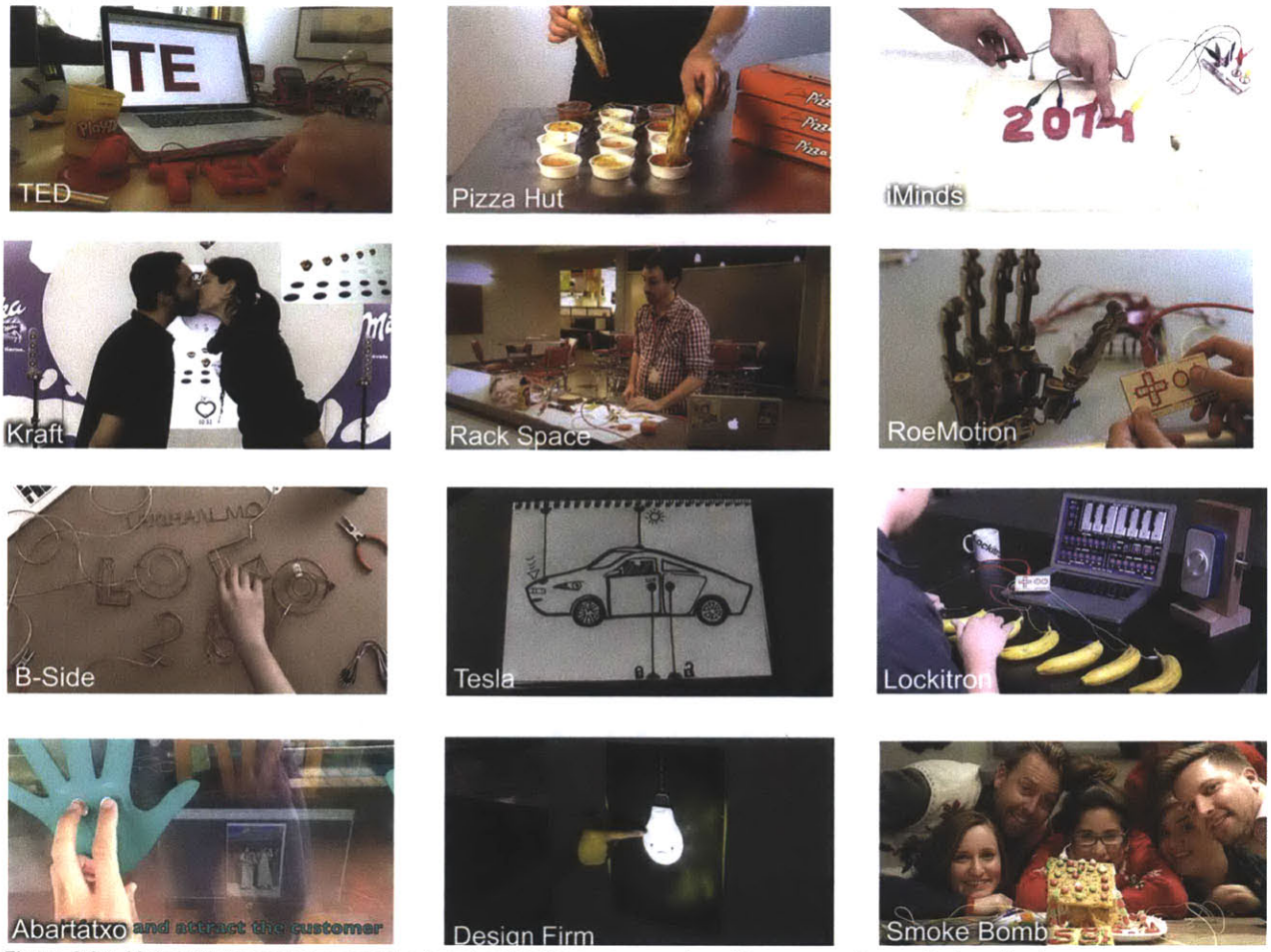


Figure 8.24. Makey Makey game examples found online (images reproduced from respective projects online)

All 12 of these images come from freeze frames of a video made by someone advertising their product. The numbered examples below go left to right starting at the top row and working down.

1) The first image is an advertisement made by a TED employee for TED Talks, in which he describes the thrill of TED talks and says that if you are the kind of person who likes making keyboards out of play dough, then you're the kind of person who will like TED Talks. Meanwhile he hooks up the play dough letters and types "TED" onto the screen by touching each letter. There was a Makey Makey TED talk, and this isn't a fancy done-up video, just a home brewed video by an employee.

2) The next image is from a Pizza Hut video. The design team who made this first contacted us to make sure it was alright to use the Makey Makey. They were advertising Pizza Hut's new dipping sauces and decided to make the equivalent of a "sequencer" out of a 3 x 4 grid of dipping sauces. Each time the pizza was dipped in a certain sauce, a sound sample would be played. The samples and rhythm they chose were from the Hip Hop style, and the beat ended up being a catchy hip hop beat, thus they dubbed the project "Dip Hop."

3) In a video titled "What if... everything is connected?" iMinds makes a baked treat with flour separating various components and multiple layers in the cake each of which makes different sounds. They then say

"iMinds Just Added One More Reason to Wish You a Happy and Successful 2014."

4) Milka is a chocolate brand in the UK owned by Kraft. In this "Kiss Kiss Revolution" or "Kiss Kiss Hero" game, people had to kiss at the right time to the beat of the music while lips scrolled down the screen, similar to Dance Dance Revolution or Guitar Hero. They displayed the game publicly and filmed several couples and families kissing to play the game, which as far as I can tell is only related to chocolate through some mind map of "kiss" or something. Their logos are displayed prominently and people are running the booth branded with their clothing. This is a fairly sophisticated setup in that there is a custom game that had to be made to go along with the setup, several people recruited, and all details were attended to visually.

5) Somewhat of a gimmick, this is a Rackspace commercial for how easy it is to setup a cloud server using their service. So easy they claim you can do it *by eating a BLT*. The BLT is hooked up to a Makey Makey to allow it to control mouse motion, clicks and some keyboard typing, and using their web interface the person in the video sets up a cloud server by eating a BLT.

6) This is a simple example of someone hooking up a Makey Makey to control their robotic hand, in an attempt to advertise "Roy the Robot Hand."

7) Armature wire was used to create a musically activatable announcement about a music event.

8) 2lemetry wanted to show off their skills at controlling complex software API's so they built a project that shows how you can control a Tesla's horn, windows, etc. from a pencil drawing using a Makey Makey.

9) Lockitron's Kickstarter video includes a short clip of playing a secret tune on bananas to open a deadbolt lock as a zany example of what you can do with API's and Lockitron.

10) Abartatxo, a design firm, rigged up an interactive shop window as an example of the types of interaction experience they can offer their clients.

11) Another design firm setup this video of how they can make interactive posters using a projector and Makey Makey to get attention.

12) Smoke Bomb made an "Interactive Dubstep Gingerhouse" for Christmas 2013 to generate traffic and good will for their company, and just to have fun.

Reflections

One of the best things about studying a Constructive Lens in the wild is that you get a true sense of the wild-crafting possibilities, and it's the only real proof of whether unfacilitated interaction will lead to true repurposing behavior. In the games section we see sawdust reused as a joystick, and a slack line as a context for a side-scroller reality-based video game. In the music section we see dogs thought of as piano keys and the process of "eating lunch" reimagined as playing a song. Perhaps the most meta-repurposing is in the advertising section when Lockitron takes a banana piano, already a reimagining of its own, and repurposes the entire thing as a coded entry system for unlocking a door. Perhaps the most fleeting

example of repurposing is Mika's: to reimagine a "kiss" as something with which to play a game. It is nice to see examples from practical, the Quarter Guitar, to completely impractical: Rackspace spinning up a web server with a Bacon Lettuce and Tomato sandwich.

9. Discussion

A Note About the Unspokens of a Thesis

The first crystallization of this thesis into a title or name came in 2009, "Gifts for Intertwining with Modern Nature." I first spoke of it aloud to my wife in our dorm room after final relaxation at the end of a hatha yoga session. The second I spoke of it was to my collaborator, Eric Rosenbaum, on a walk to a group dinner at Moulan Taiwanese restaurant. There on the sidewalk I tried to explain my idea out loud for the second time. I referenced the common knowledge within our research group that Froebel had founded Kindergarten along with a set of "gifts" that were nature inspired, such as wooden blocks. I went on, "Nature" in today's terms has become much more complex, and human-made objects can also be treated like nature, thus "modern nature" being the combination of traditional nature and the human-made everyday environment. I felt that too many technological tools were ignoring the relationship between people and this *modern nature*, that is to say how people relate to the world they live in, and were focusing too much on ideas like "programming" or "architecture" or "color" without explicitly invoking the context of the world that people live within. What if we designed tools, which would be "Gifts" that catalyzed people to *intertwine* with *modern nature*, where by "intertwine" I mean become intimately knowledgeable about the sensual experiences and usages of modern nature. And by modern nature, I really just meant the everyday world.

Over time I abandoned the use of the phrase "modern nature" and usually instead call it "everyday objects" as I have done in this thesis. It requires less explanation. But in my internal dialog I still use the term modern nature. The words tool, construction kit, platform, or Constructive Lens, are used in place of gifts throughout this thesis, depending on the context. And terms like creative confidence and seeing the world as a construction kit are used in place of the original term "intertwining." I do feel the new language is easier to explain more quickly to a wider audience, but if you have made it this far in the thesis, I thought it could be instructive to tear back a layer or two of the evolution. Eric and I went on to write a paper about this idea called "Gifts for Intertwining with Modern Nature" [Silver & Rosenbaum +, IDC 2010, Gifts for Intertwining with Modern Nature], and that paper was one of the tributaries into this thesis.

I think it's important to mention the original linguistic formation for the thesis. What is now titled "Block x Lens" was once titled a Gift.

Linguistic Pointer / Terminology	*2010*	*2012*	*2014*
The Tool	Gift	Block x Lens	Constructive Lens
The Object	Modern Nature	Everyday Object	Everyday World
The Point of View	Intertwining	Creative Confidence	World as Construction Kit
The Subject	User	Creator	Participant

Table 9.1. How my language evolved over the course of the thesis.

To step outside of the narrative of the thesis itself once more, it is important to understand the academic context in which the thesis was conceived, as all contexts have a bias, and all academic departments are a context, which is helpful actually to making progress. The idea of seeing the world as a construction kit actually goes far beyond the ideas presented here as Constructive Lenses. The entirety of the idea of the world as a construction kit could be carried out without any technology at all, as demonstrated by Andy Goldsworthy and countless others. I could write an entire thesis on how to evoke the world as a construction kit in people's eyes with just activity guides, and without any new media tools or computational or electronic implements. And in fact, I can argue that I have not substantially introduced any new tool with the Drawdio project, only a new context with some tweaks to an old tool. However, given that this thesis was written at the Media Lab, and given that I am by my nature predisposed to investigating the results of new media artifacts like circuits, the tools have ended up taking precedence in this writing, or at least they are placed alongside the activities which guided their use.

Lastly, nowhere else spoken of, I took 2 years "off" (at least from the writing part) from early 2012 to early 2014 in the middle of writing this thesis in order to pursue the full-scale launch of the Makey Makey business.

Intro

This discussion section, Chapter 9, is meant to be as useful as possible. More on the side of guidelines on how to make Constructive Lenses, rather than an exact proof that I have accomplished any particular goal.The degree to which you have or have not demonstrated your goals is apparent to the reader anyways, and actually will differ based on the reader.

The previous 8 chapters are designed to be a thick how-to manual by imparting stories and examples. That is to say an experiential modelling of how to create Constructive Lenses, or cross Lenses with Blocks, or at the very least demonstrate the way in which I went about it. This last section is a more directly stated manual for creating Constructive Lenses, crossing lenses with blocks, and helping catalyze the viewpoint that the world is a construction kit: Complete with tips and tricks (the first section), and including a discussion of activity organizing (the second section), and finally a reflective theoretical section.

Constructive Lens Generative Tricks

This section talks about how to make a tool/activity more open, and more of a Constructive Lens. Even if you are not trying to make a Constructive Lens per se, or an open construction kit per se, but just like the feel of open activities or the way Constructive Lenses work, it is possible to apply these techniques just to brainstorm around in the space of your tool or activity to try to find ways you would like to make your activity/tool better even without making it into a "Constructive Lens" per se.

Input/Output Pairs

Drawdio senses electrical resistance and generates a pitched sound based on what it senses. In that sense it is a synesthetic (or cross-sensory) pair: resistance to sound. Makey Makey senses resistance and outputs HID Key Presses to a computer. Taking this input/output approach, and applying it to all the tools listed in this thesis (Drawdio, Makey Makey, and the other 3 Constructive Lenses mentioned briefly at the very end of chapter 4), we can generate a table showing where these 6 Constructive Lenses fit in on the synesthetic pairs table like this:

Outputs ▸ Inputs▾	*Resistance*	*Sound*	*Color*	*HID*	*Light*	*Image*
Resistance		Drawdio		Makey Makey		
Sound			Singing Fingers (also outputs sound)			
Color		Twinkle				
HID						
Light						
Image						Color Code

Table 9.2. Input/Output Sensor/Actuator Matrix predicting new Constructive Lens possibilities.

This shows how tools are related, any tool in the same column has a corresponding output modality, any tool in the same row has a corresponding input modality. But what is especially useful about a table like this is its predictive ability. The above instantiation of the table predicts 36 Constructive Lens possibilities out of which only 6 have been realized, leaving 30 to be explored. But these are not all the inputs/outputs. We don't have to limit ourselves to just the traditional human senses, we can imagine adding proprioceptive senses like muscle tension, and inner-body stimulations like transcranial direct stimulation as outputs. Further, we can see that HID is already included as an input/output. Anything that a computer can sense, and by sense I mean any API by which a computer can communicate, could be considered an input or an output because ultimately we can sense that which a computer can sense. These two tricks can easily add more inputs/outputs to the table creating a multitude of space to explore for technological Constructive Lenses.

To this day, I'm not 100% sure I understand exactly why synesthetic pairs work so well as Constructive Lenses, but it does seem like first of all they capture the imagination, just like a good lens/magnifying glass. The second part is that the thing that captures the imagination is a phenomenon that involves transforming some phenomena in the everyday world into, if designed correctly, something that a person can sense either directly or indirectly. Finally, because the "something" that was transformed is the world people live in, they are already familiar with it and have a lot of ideas about it, and it is a natural next step,

especially if the support materials suggest and demonstrate it correctly, to remix the world so as to enjoy the effect of the lens in fun ways. In this way, we have almost created a trap, or what a designer would call a forcing function:

1. User becomes intrigued with "lens"
2. User multiplies lens on entire world and sees expressive result of lens
3. User, if supported correctly by support materials, remixes the everyday world

Synesthesia and Magnification

Exploration is readily sparked by re-presenting the world in a new way. This can be done simply be asking someone to look at the world and focus in on all the circular shapes or everything with the color green. Simply reframing the world can give rise to new observations about the contents of the world, and practices like this are common in communities like art, nature awareness, and science. However, there are limits on human sensory capabilities and a tool, such as a lens, can help overcome these limits. The reason "Lens" was chosen in the title is because a lens literally changes the way we see the world when we look through it, thus helping us re-see.

Tools like lenses are direct catalysts for re-seeing. A magnifying glass will show you details you can't see with the naked eye, or give you a different perspective on something you think you already know. The idea of a "synesthetic lens" is actually much different than the idea of magnification. A synesthetic lens crosses sensory modalities, letting you see sound as a color, feel electrical resistance as a vibration, or hear temperature as a sound.

When trying to create a Constructive Lens, synesthetic lenses are especially useful. When someone can use a different part of their brain to explore a sensory modality, such as using their visual brain to explore sound, it gives them a new perspective on what the original modality means. One of my tricks for designing Constructive Lenses is simply to start with a synesthetic pairing, and see if I can make it fit the other design guidelines, specifically expressivity.

Attention

In design, and in life, I really can't put enough emphasis (and attention) on attention. As a designer, I am always thinking of where my user will allocate her attention-energy. If I don't want that attention spent on fighting with the technology part, I had better take the idea of "Low barrier to entry" very seriously.

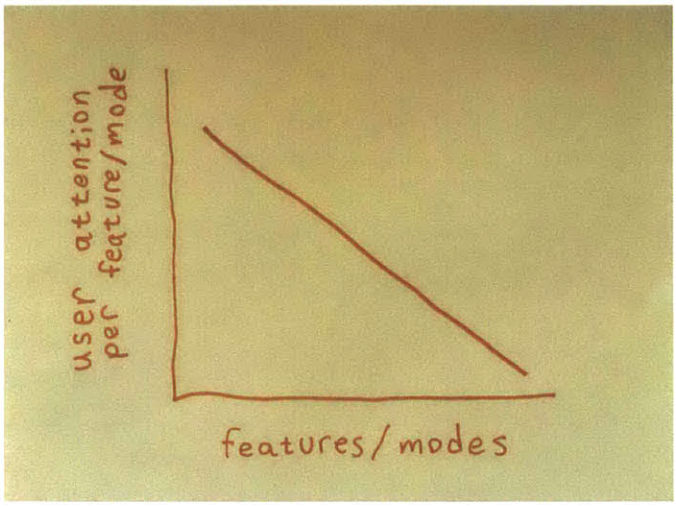


Figure 9.1. Attention per feature vs. number of features.

When it comes to Constructive Lenses, where the world is a construction kit, I really want approximately ONE mode of operation (that said, please don't forget that we want the simple mode of operation to still produce a wide variety of possible activities). This way all of the "fighting" which now looks a lot more like "tinkering" is spent on tinkering with the world. Since that's the explicit goal of the Constructive Lens and this thesis, it's even more important for me to take seriously the idea that attention spent on tinkering with the environment is the main way I want the user to spend thinking-energy, intuitive-energy, and physical energy.

Along these lines here are some questions:

- For each product feature, does this product feature directly contribute to focusing the user's attention on *re-seeing* the environment?
- Does this product feature directly contribute to focusing the user's attention on *re-making* the environment?
- For each part of my instructions and introductory videos, does this part show people remaking and repurposing everyday objects and the world they live in?

Opening Traditionally Closed Kits/Projects/Tools

In the last 5 years, and during the popularization of the Maker Movement and hands-on STEM education, it has become more mainstream to place value on open-ended projects. Sadly, many still do not, but at least people no longer look at you funny when you discuss it, as most have heard of it and many now value it. With a rise in interest in creative thinking, divergent activity becomes the method of choice for all but the most rudimentary skill building (and even for that). Often neglected up to this day, however, is that projects don't just have endpoints. One must pay attention to all phases of a project, from conception, to beginning, through the middle, and even past the end into the afterlife of the project. In this way we can remember to offer projects, when appropriate, that are:

- Open Beginninged
- Open Middled
- Open Ended
- Open Epilogued

These really aren't meant to be strict categories that your project, toolkit, or activity does or doesn't meet the criteria of. Instead, use these categories as thinking tools in planning and designing your tool or your activity to help bring to light the various parts of the projects and how they are structured, structured differently, or not structured. Too much structure and too little structure are both detrimental to a good construction activity or construction kit. It's all about consciously selecting the appropriate amount of structure in the appropriate places.

As discussed in chapter 4 with an extended example of Opening a Traditional LEGO kit, construction kits can either be closed or open in a number of ways.

Phase of Project	*What this phase means*	*Meaning of Opening this Phase*	*Classic Example*	*Import or Export*	*How to Open Example*
Beginning "Open Beginninged"	Loose Materials	People look to their everyday world and decide which materials to incorporate	Collage	Import	Remove loose parts, give guidance on how to find in environment
Middle "Open Middled"	Tools that Act on Materials (sometimes Methods or ways of acting on materials)	People look to their everyday world and decide which things can be used as tools	Painting with Objects	Import	Remove tools, give guidance on how to scavenge tools
End "Open Ended"	Final Project Crystallized	People choose their own project ending point	Creative Writing Assignment	n/a	Remove convergent requirement. Guide and scaffold the participant on making meaning and choosing a unique, meaningful endpoint
Epilogue "Open Epilogued"	Placement or Afterlife of Project, the project's "Container"	People decide where the project shall rest or live on or be interacted with	Graffiti	Export	Remove standard container. Give guidance on the space of possible containers.

Table 9.3 Phases of a project and suggestions on how to make that phase more open.

While open construction kits are generally interesting, and open-ended projects are very important, it is not the case that you always want to open everything. An entirely open project is an absence of any project at all, which isn't helpful for creative action. However, in a world overpopulated with very convergent products and lesson plans, advocating for how to open some phases of an activity up helps restore the balance. A project with "just the right amount" of openness is the best kind, lots of constraints

so no one feels lost, but lots of openness so people can make meaningful original creative contributions.

In summary:

> Balance scaffolding with openness: appropriate constraints are helpful for creative process

As seen in Chapter 4, importing and exporting are an important and simple lens to look at your toolkit with in order to open it up to other ecosystems, be they natural, human-made physical, or computational. In the computational world, this is usually called API when automated, or simply importing and exporting if non-automated.

> Importing: Bringing something into the platform/tool environment that was not originally part of the platform/environment inherently
>
> Exporting: Making the project made with the tool/platform visible and interactive and usable in places and environments beyond the scope of the tool's environment itself.

Based on the example of opening a LEGO kit, at the beginning of Chapter 4, we can derive this list of suggestions for opening your construction kit:

- Import
  - Add attachment points for other objects
    - suction cups
    - eyelets
    - tape (stickiness)
  - Add Connection points for objects
    - Magnets
    - Snaps
    - Velcro
  - Add Media Importation Mechanisms
    - In the physical world, add transparent media compartments
    - In the digital world make sounds, images, and videos importable
- Export
  - Add flow-through ways for your projects to live in various physical environments
    - Floating
    - Wearable
    - Car Visor Clippable
  - Allow flow-through digital ways for your projects to live in various media
    - Video
    - Webpage
    - PDF

Table 9.4. List of suggestions for opening a construction kit organized by importing and exporting

Creative Platforms, What do They Consist of?

Platforms are typically a designation given to a construct upon which a number of actions can be taken. Take a gaming console like the Nintendo. This is a platform upon which many games can be built by many developers, and then further users can enjoy those games in many ways. In the non-tech world, we might think of a platform as a good theater. The term platform may literally come from a raised flat area, so a stage is etymologically a great example. In a good theater any story can transpire, it is just a venue helping to show that content. A creative platform is just like a Nintendo console or a theater with the added important part that the actions taken should be creative. Now what differentiates a platform from a tool? The simple answer is that a platform is the whole shabang while a tool is an important part of the shabang. Let's discuss:

As holistic technology designers, it's good to take a step back and look at the big picture every once in a while. What is it, exactly, that we are trying to do? As we design tools or products, we need to think of them in the big picture of how they are made and how they are used.

How They Are Made

What is the story behind how something is made? What was the mindstate from which it came? What are the driving motivations? Nothing is ever "pure" but everything has a story or set of possible stories, and everything has a driving force or set of driving forces. In describing how Drawdio was made, I went into great detail bothering about the context in which it evolved. Those forces had a direct impact on what it became. Going into the birth of Drawdio, I was in the Lifelong Kindergarten group whose stated goal is to "develop new technologies that, in the spirit of the blocks and fingerpaint of kindergarten, expand the range of what people can design, create, and learn." I was running PicoCricket workshops and playing with PicoCrickets and the Scratch Sensor Board a lot. Meanwhile I was exploring my own relationship to natives, and my modern nature that surrounds me. I was situated in India, where wires and hacking electronics are more prominent, more part of the everyday culture. I was also out of my ordinary space, which allows, or forces, me to see many things with new eyes. This is the context in which the "Curious Caterpillar" which would later give rise to Drawdio was first born. Then back at Media Lab, there is a corporate sponsorship model that brought Crayola into a meeting with us, which was a design moment, a moment of pressure and focus around the Curious Caterpillar that I was working with, which provided a space and focus for me to introduce a musical pencil idea that is where Drawdio takes its name (Draw + Audio = Drawdio). Then, Drawdio was taken to a party, a Maker Faire, a fashion show, and onto a paintbrush. It became my own personal invention kit, until finally I brought it back around to the group's theme of making tools, and turned Drawdio into an invention kit for others to use.

How They Are Used

All of this may seem irrelevant to a person looking at the final product, but I would argue that thinking about these issues is essential to any designer of such tools, and helpful and informative to users of the tools. Because what is being offered is actually so much more than a "tool." Then what is it that's being offered? Well I hope that I am offering my adventures in India, my awe with Natives' relationship to nature, my experience with technology in the Lifelong Kindergarten group at MIT Media Lab, and my own enthusiasm for personally making inventions with the Drawdio. But how can all of this be wrapped up into a tiny tool? Well a little bit of it can be in the design of the tool. Instead of thinking of the "Product Specifications," think of the "Behavior Specifications" or the "Process Specifications" or even the "Experience Specifications." That is, don't worry about the "processor speed" or the "number of inputs or outputs": these are Product Specifications which describe the product itself. Instead think about the Experience Specifications.

> Experience Specifications: The specific attributes you hope to see induced in the experience of the user's reality through the process of bringing the tool, and indeed the entire creative platform, into their life.

By thinking about the Experience Specification, one can see how certain aspects of India can be folded into the product design, say by including alligator clips or hack saws or bright colors.

Parts of a Creative Platform

But even then, only a little can be put into the design itself. The truth is that a tool is not without supporting materials. Ask any marketer, and they will tell you that a tool's success or failure can be determined by the story that is told around a tool (or product) with things like

- packaging
- commercials
- instruction booklets

And then there are more subtle driving forces behind what a marketer does, some of which are put forward, like

- outward-facing slogan,

and some of which are never offered to the public, such as the

- inward-facing slogan

This is the story that the team tells itself when it wants to make a decision. This motto then goes into the fabric of the team and inspires, or doesn't, various direction with the product and the other supporting materials.

In the case of a Creative Platform, such as an online programming language like Scratch, other offerings are taken into account, such as

- online communities and forums with moderators that curate a community culture
- conferences
- organized days of action/creation
- tutorial videos
- curated projects submitted by the community
- sample projects that ship with the product

So a "Creative Platform" starts to become much more than just a tool, it is also all the bullets above along with the tool. And further, I think you need to give people a story to buy into. Marketers already know this, but as academics, activists, or whatever kind of world changer it is that you want to be, I think we need to learn something here. You need a backstory as much as you need these other aspects to your platform. It gives people something to dream about, something to hope for. That's where you get into offering more than just the end product, and even more than support materials and community facilitation, this is where you really get into sharing vision: both sharing

- Genesis stories
- Motivations and Hopes for the Future

You'll see two genesis stories here in the thesis. And I will offer some hopes at the end of the discussion.

So a good creative platform is something that people can generate a number of their own adventures or outcomes with. And the components to a creative platform can include any of the following (along with some suggestions for the form each component might take depending on the form of the platform):

Creative Platform Components	*Hardware*	*Software*	*Non-Tech*
Tools	uC-based Device	App, Webpage	Guide Book, Ritual
Loose Parts	Peripherals, Plugins	Images, Sounds	Small Products or Extras to find, make, or order
Places for creative work to live (Containers)	Online photo/video gallery, Exhibits	Online Galleries, Photo or Video Snapshots	Enacted in the community, mailed or collected online
Genesis Story and Hope Story	TED-style Talk	Pecha Kucha Talk	In-Person Oration
Instructions	Printed, Webpage	Interactive, Webpage	In the Guide, Print, Web
Example Actions	Trading Card Style Tutorials	20-second mini tutorials	Short Paragraph Scenarios
Sample Projects	Text, Images, Videos	Ship with the app	Described Tex/Images
Packaging	Literal "Cardboard" Box	Splash Screen, Icon	Guide Cover
Commercials	Video	Video	Image
Outward Facing Slogan	Text	Text	Text
Inward Facing Slogan	Text	Text	Text
Communities and Forums	Online Forum	Creative Community	Meetups
Conferences	Meetups	Online Webinar	Natural:Enact the Ritual
Organized Day of Creation	Decentralized Meetups	Online Meetups	Workshop Practices
Tutorials	Video	Text + Images	Video
Curated Projects	Video Gallery	Video Gallery	Video Gallery
Sample Projects	Video Gallery	Video Gallery	Video Gallery

Table 9.5. Creative Platform Component List, and suggestions for manifestation of each component depending on the medium of the creative platform

Low Floors & Other House Metaphors

My advisor has taught me that it's important to design creative tools with a low floor. This simply means it is easy to use, which is to say a low barrier to entry to start using it. This is so important for one obvious reason, which is that many people can access use of the creative tool without a lot of time invested. But there is another reason to make things incredibly easy to use. Everyone, including experts, will have more creative freedom when they are freed from thinking about the technical details of how to operate the tool. In this way, a low floor actually leads to virtuosic creative action more readily than an equivalent tool even after expertise is established, due to the lower cognitive load. So when in doubt: simplify simplify simplify. The other advantage to a low floor is that you get a larger community thinking together about the use of the tool, and a swarm of people can think of things that a sparse population can't.

Another principle many people talk about is a high ceiling, meaning you can use the creative tool for more and more advanced topics. This has value, but needs to be traded off sometimes to ensure the accommodation of the other aspects of the house (e.g. low floor).

My advisor also talks about wide walls. This is the concept that many different types of people can make many different types of things using the creative tool. For example, blinky bugs use coin cell batteries and LEDs to make a bug that blinks its eyes when it moves. This doesn't have wide walls, because you can only do one thing with it. Scratch on the other hand has wide walls in the sense that you can make music, animation, games, and many other genres of creations within it.

I would like to introduce the concept of "Many Rooms." If you want to have a good party, I always say you need different rooms so people can focus and specialize on having a good time in different ways and at different music volumes and in different lighting. So when designing a Constructive Lens, think about how it could be used by different communities and subcommunities. The MaKey MaKey kit has been adopted by gamers as well as people wanting to provide accessibility. They're both at the party, but they're in different rooms. It's great if they cross over, but it helps to think about both contexts to help hone the design. Think of how your Constructive Lens could be used in

- formal and informal education settings
- in the workplace, especially for rapid prototyping
- purely for fun at home
- with special communities addressing specific problems
- as a piece to a part of another endeavor
- in performances
- with very young people or very old people

In this way you can consider the many rooms principle.

Inspirational Learning Philosophers

In Window Into my Thoughts 1.3, I list 8 inspirational learning philosophers. There are also 3 more that I have inherited from seamlessly through my lineage of working with Mitch Resnick, who worked with Seymour Papert, who worked with Jean Piaget. Here are the 11 philosophers and my briefest possible

takeaway to inspire transformational tool design:

Learning Philosopher	*My Personal Pithy Takeaway*	*Translated into Creative Tool Design Advice*
Eleanor Duckworth::	If you look carefully enough at each learner's idea patterns, perhaps best facilitated by watching them think through a problem with some manipulatives, you will be able to see every person actually has unique and wonderful ideas almost constantly.	When watching a user work with your prototypes, don't try to get them to any goal, instead keep your mouth almost entirely shut and become a connoisseur of that person's idea path / thinking path. Then use your mouth for something constructive toward the goal of revealing the learner's idea path "What made you do that?" and "Tell me more"
Rudolf Steiner	Develop free human beings who can impart purpose and direction. Imagination, truth, responsibility, are more important than knowledge. Good teachers focus on who they are.	In your creative tool design practice, put who you are into the tool: that's what people want to see. Breath life from your lineage and personal inspiration into your work, you'll be surprised how much people will learn and create with your tool as a result.
Ivan Illich	A bakery can give you bread, but a hospital can't give you health, and a school can't give you knowledge, these are things you do to yourself.	What kind of learning process are you offering people? Will the tool be part of an institution or in the hands of a person, or both? Now imagine what *substance* (like bread or learning or health) you want the person to have. How will they truly get that *substance* with your tool. Can the person really use your tool to get that substance? What does the process look like and who are the actors in control?
Maria Montessori	Give people stations with manipulatives!	In any activity or workshop, never underestimate the power of stations. In any tool design never underestimate the power of making things as tangible and manipulable as possible for the situation.
John Taylor Gatto:	The current dominant school system was designed intentionally to create industrial	Is your creative tool not fitting in with school culture or the modern school requirements for

	cogs.	learning plan? Maybe you should just part ways with the desire to meet those goals.
Paulo Freire:	Can we use a pedagogy of questions? Can we teach people to see the invisible repressive walls around them rather than or even better in the process of teaching them skills and knowledge?	What questions does your creative tool offer to people to explore? How does your tool catalyze the investigation of invisible boundaries in a person's idea of how they can navigate the world?
Grace Llewellyn:	Learning happens. Follow what makes you come alive.	Make your tool highly action focused and allow your user to take your tool in a direction of their choosing. Give structure with open space around it.
Larry Harvey	Make real culture and creative community happen, they will come.	Consider what changes you might make to your creative tool if you were bringing it to Burning Man. Now imagine other possible gatherings that are fanciful and that don't exist yet that you would create in your dream of an interesting cultural experience. Now consider what changes you might make to your creative tool for people in that imagined world.
Mitch Resnick	Creative technology is truly for everyone, so lower the bar, and create the technology as a literacy: You need an inspirational literature to learn reading, and not everyone who learns to write has to be a professional writer.	Make it easy to get started! Is it easy yet? Make it easier! It's not about simplicity of thought, it's about removing unnecessary annoyance and complication. How is your tool part of a literacy or fluency? How can you create that in your tool?
Seymour Papert	Focus on powerful ideas. Learn how to learn. People learn best while making things.	Just cut straight to the most powerful idea you personally resonate with, and make a tool to engage with that. Let people learn with your tool through *making* something *personally meaningful.*
Jean Piaget	People are individuals and education should help them learn to do new things, not repeat things. People cannot have knowledge added to them	Your tool would be more interesting if it did not deliver any knowledge or quiz anybody. Just stop that (okay flashcards and tests do have a place in society,

	from the outside, they have their own unique tree of knowledge and they attach new bits on themselves	but they are overused so I'm pulling the other way here). Remember that the only way the learner will grow their tree of knowledge is by reaching in with their own invisible "brain hands" into their own brain and adding bits of knowledge. So it's up to you to make that knowledge available and worthy of adding to the tree, but not to add it. Create a catalytic environment where things are bound to be run into and added to the tree.

Table 9.6. Inspirational philosopher takeaways and suggestions

Expressivity

This is absolutely key to generating Constructive Lenses. Is the Constructive Lens an expressive medium? By which I mean, can you use it to

- generate artifacts
- perform
- make changes to the world

For example, MaKey MaKey is strong on expressivity. You can use it to make new controllers or musical instruments, which you can then perform or play upon. If you made a synesthetic lens that converted sound to electrical resistance, I don't see how that would readily allow people to express themselves. One aspect is that people need to be able to sense the output. So converting resistance to sound takes something you can't normally sense and changes it to something you can readily hear, as in the Drawdio. That pairing alone is not necessarily enough to produce expressivity. In the case of the Drawdio we then added alligator clips to the circuit and positioned it so that there were two sides pointing out to the world, and designed some support materials to suggest that you ought to both explore and create things with the Drawdio. Finally we workshopped it in many different scenarios. So the real measure of expressivity is whether when put in people's hands (the tool *and* the support materials), they are typically catalyzed to create expressions, to express themselves.

Design In Context

My best design work happens when I design outside of a generic setting. The surrounding helps inspire me and the context creates constraints or focuses me on a specific audience. So I try to generate my initial designs outside of a lab/office setting. Drawdio was sparked in India in a setting totally foreign to my ordinary experience, in the context of a slum school. Since there were so many objects I was not familiar with I was more able to see with a beginner's mind, and more curious as to the makeup of my surroundings. Especially until the basic concept of your Constructive Lens is formed, explore it in an inspired context separate from your daily workspace, perhaps where you imagine it being used.

Sample Project Spaces

Sample Projects Defining the Creative Space

How do you know if your Constructive Lens is expressive? In fact can you create anything at all with your Constructive Lens? You may imagine you can, but it would be a huge step forward if you can

1. propose one single example of a project (artifact, performative concept, experience) that someone could carry out using your Constructive Lens.

This first example is crucial to concretizing your Constructive Lens' Creative Space. Now since your Constructive Lens should be generative of more than one project (in fact it ideally could produce more projects than you could predict yourself), you should add

2. a second example project as different from the first one as you can imagine, while still being compelling and evocative.

Once you have two sample projects, you now have a line of possible projects interpolating between the two. This is a huge step forward from having one project. You now have two concrete projects, and several more imagined projects in between the two, as you can probably imagine third and fourth projects that are combinations of the first two projects in various ways.

Now

3. propose one more project, a third project, so that you have more than a line, you have a project space.

I find that once I have 3 projects, all different from each other in at least a few ways, I have a huge space of possible projects that are implied by the in between space between the points.

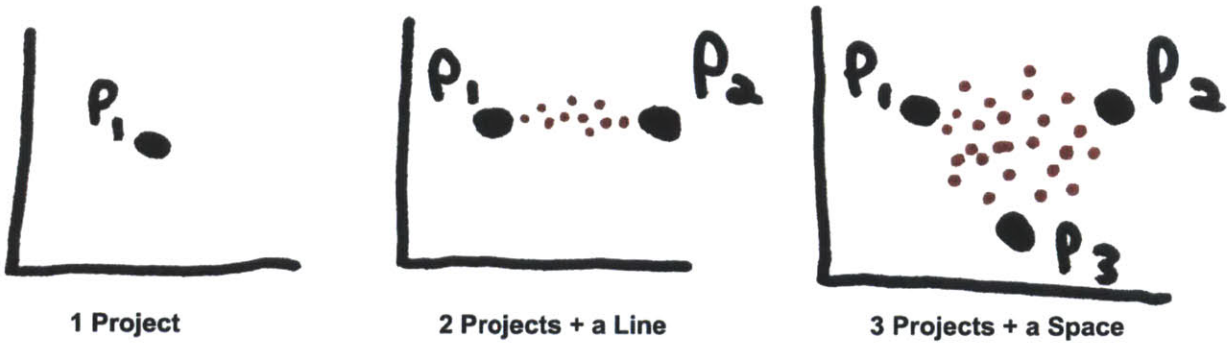
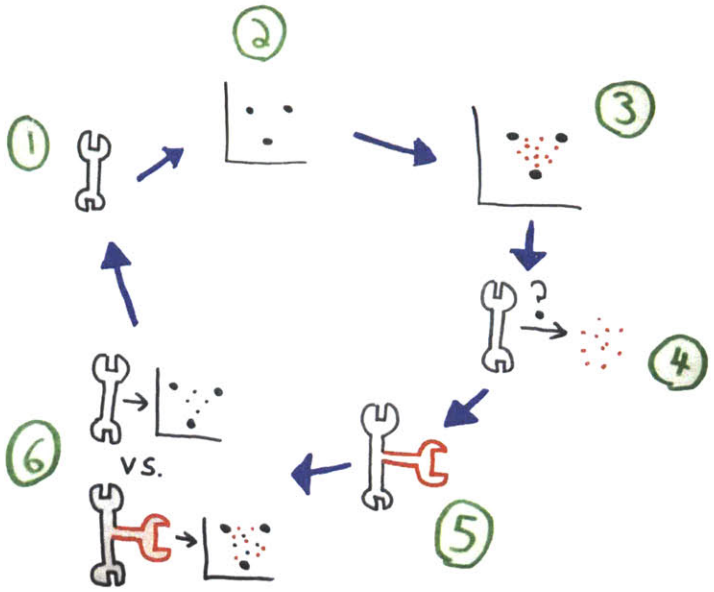


Figure 9.2. Sample Space creation by adding one sample project (left), two sample projects which create a line of possibilities interpolated between them (center), and three sample projects which create a space of possibilities interpolated between them (right).

You can then take the results of your sample projects (depicted above as big black dots) and the other projects that these projects in the project space that these help you imagine (depicted above as small red dots) and feed them back into the design of your Constructive Lens, or creative tool design in general.

Sample-Project-Space-Based Tool-Design Iteration-Guide



1. Create your Tool (see entire thesis for help with this)
2. Think of a few projects you could generate with the Tool as it is
3. Think of other projects that are like these projects, or that you wish you could make, regardless of whether you can make them with this tool
4. Are all these new projects possible with the existing tool?
5. If not, what would you need to add to the tool to make them possible? If so, great, maybe you are done or keep dreaming of new projects you wish you could do.
6. Is it worth adding the new tool feature in order to get the expanded Sample Project Space? What other projects would be made possible by adding these new features (repeat cycle with new tool to find out)? Is it powerful enough in its multiplying effect on your Sample Project Space to warrant adding the complexity of the new feature (money cost and attention cost)?

Figure 9.3. Sample-Project-Space-Based Tool-Design Iteration-Guide

Think In Sample Project Domain, optimize the tool for the User Experience

Look at step 6 from the Sample-Project-Space-Based Tool-Design Iteration-Guide. Note how there are two spaces, on the left there is a tool space, and on the right there is a Sample Project Space. Just like in Electrical Engineering, we look at audio signals in the time domain as well as in the frequency domain to get more information, and we often find the frequency domain tells us what we really want to know about sound, like which pitches it contains. It is the same with creative tool design. We must look at tools in the sample project domain in order to get a sense of what they make possible. A hammer doesn't tell you much about what it can do to a beginner. But show a beginner a house, a bench, and garden box, and say "Want to make these?" They may want to make one of those, in which case they will say "Yes how?", and then you give them the hammer (and nails, and wood). But if you start with the hammer, and "Want to use this?" then unless the person has experience with what a hammer can make it is pretty hard to imagine a house, bench, and garden box. So not only should you think in the Sample Project Domain so that you pick the right tool, but you also need to communicate about your tool to your participants using the Sample Project Domain.

So in the case of the Drawdio, the Drawdio Kit as displayed in Figure 5.30 which shows a picture of the tool and accessories, is not the important picture at all for explaining "Drawdio." It is important before someone buys one and is important to know it exists, but what matters is in the Project Domain, and so the Sample Project Space as shown in the video, which is depicted in Figure 5.31 and 5.32, is the real answer to "What is Drawdio." It's the substance of what the Drawdio makes possible.

Likewise the Makey Makey hardware shown in Figure 6.11 is less important in terms of explaining what Makey Makey is than the Sample Project Space shown in the video depicted in Figure 6.9.

I think of the end point as the Sample Project Space (and the processes and experiences evoked by the space) enabled by the Constructive Lens. In this way you end up with a spiraling design process where each change to your Creative Tool isn't just a change to the tool itself, but it is indirectly a change to your Sample Project Space. You can then evaluate the Sample Project Space and optimize your Constructive Lens for the most impact to a very evocative project space.

At the same time you can watch for low floors and wide walls and how they change when you make changes to the Constructive Lens. How does your Constructive Lens become more expressive, and how do different projects suggest other types of expression that would be interesting to explore? Now that you have a new Sample Project Space, go back into a new context and consider the projects for a particular population. Perhaps you should now consider a new modality for synesthesia. But how would that change the Sample Project Space? How will all these changes reflect on your presentation (e.g. your video) of the Sample Project Space to the creators in whom you hope to catalyze creative confidence? How will all this ultimately affect the way the tool is carried out in workshops and private use once it reaches the creators' hands?

Once your Creative Tool is in the hands of people in the wild, watch and see what they do with it by looking on the web or asking people who you meet. The only real measure of how someone will use something in the wild is to observe without direct interference. Take your observations and feed them back into the next iteration of your design.

Express Your Sample Project Space

Once you have a Sample Project Space, one of the most important things you can do for the success of your Constructive Lens is to communicate it clearly. In order to do so, in the past I have made videos that show what I currently understand to be the project space (any medium will work, video is not necessary, but try to use something that is easily digestible, and I think video is the coin of the realm for today's audience in 2014). I have examples in Figure 5.31 & 5.32, and 6.9. Based on my experience making these and other similar videos I have the following advice in general.

In your video (or other medium), show either the simplest or the most powerful idea right away. Don't talk about it, just show it in action. This idea should stand alone as either very simple / iconic, or very powerful. This is your "lead sample project" to open up the Sample Project Space. Then show a second example. Try to build in intensity and theme so the project space just keeps looking bigger and bigger. Spend less and less time on each new example because people have learned from the previous example. By the end you should be showing multiple projects in a very short amount of time. If you have to do explanation / talking heads, then save it for the end as much as possible.

Finally, be sure to show not just the end result of the project, but also the build-up. The reason is two-fold. First, it will help ensure the creator who is watching that they can do this too because they saw how it happened. Second, the process is part of the product, because what you are "advertising" here is creative process. You don't have to show the buildup for every project, just enough until the average viewer will follow. It's better to lose some people in small parts of the video than to bore lots of people, so lean more to lose than bore.

Sample Project Space Gold

Once you have your Sample Project Space video (or other media), then you are done with the Sample Project Space work right? I just can't emphasize enough how many places the Sample Project Space truly can be utilized. If it's a software product, ship the project space as executables with the product as Scratch, Arduino, and Processing do. If you have an instruction manual online or in the box, turn it into an opportunity to give instructions in the context of more sample projects. If you have a box or a cover page, show sample projects on it. You have a creative platform on your hands, and it exists to make projects with, show them off. This is both advertising for your project, explanation and instruction for what's going on to the user, and also artistic contribution to catalyzing the personal creative project space of people in the wild.

In 2013 I had the opportunity to design an instruction manual for Makey Makey with an intern, Sophie Diehl, the same woman who painted the World as a Construction Kit image on the front page of the thesis. We designed the instruction pamphlet shown in the Appendix Figure A.1 and A.2. The introduction column shown in FIgure A.1 does indeed show the Makey Makey and its parts. The bottom of that first column then shows a complete and most simple Makey Makey setup with no words. The next two columns are a detailed step by step walkthrough of a first-time setup, but done in the context of making Banana Bongos. So there is no lack of detail, even showing how to connect alligator clips and how to close popup windows. But the result is that you've just made a project by setting up your Makey Makey for the first time. The second half of the instructions in A.2 are labeled "Ideas to Get You Going." Even this title implies that we are heading you off in your own direction, and that these ideas are just

representative of a whole space of ideas which you will soon create yourself. Then there are three more instructional columns which are actually just sample projects: Fist Bump Remote Control, Cardboard Guitar Hero, and Veggie Piano. The three categories span the space of invention, game, and music, in that order, and use a diverse set of materials, human body, quarters and cardboard, and food, in that order. This diversity in genre and repurposed materials spans the space of possibilities so that people can imagine interpolating inbetween.

We also put the Sample Project Space right on the box. In our case we have an online order box and a retail shelf box. The online order box has a Sample Project Space on the back in the Appendix A.5. It shows a Cat Bowl Photo Booth, a Clay Game Controller, and a Musical Staircase. Again we highlight one example each from the categories invention, games, and music. And once again we show a diversity of materials, cats, clay, and staircases. On the retail box front in Appendix A.3 we show one single project example: a banana piano, without much explanation. When the user turns over to the back , we then show three more examples as seen in Appendix A.4, pencil game controller, water dance pads, and cat selfie cam. These four projects come from the categories of music, game, game/dance, and invention, to try to cover the diverse range of possibilities. The materials used are food, pencil, water, and cat. So in all of our packaging we make heavy use of sample projects. We do still show the tool as you can see the Makey Makey pictured in the front window of the retail box in Figure A.3 and on the back of the online box in Figure A.5.

In our case, once we put out our video, our box, our instructions, etc. essentially our entire sample space, we started to get videos of user projects emailed to us, or posted to Youtube, Twitter, etc. These projects influence our concept of the space of what is possible and allow us to output an even more diversely spanned Sample Project Space in our next round of media. Eric Rosenbaum's project page also allows you to submit your own projects, and a selection of these projects are shown in Appendix A.6. People who come to the website can then look at the user projects and that expands and densifies the Sample Project Space we have offered even more, putting more dots farther out, and adding more dots inbetween the dots we have already put in the space, and in some cases adding dots in new dimensions. All of this is gold from a creative catalyst point of view, and from the point of view of the tool's self-propagation.

Conclusions

Viewing the world permanently as a construction kit, as depicted in the cover picture, is a complex goal. Having the ability to selectively apply the viewpoint that the world is not fixed and that I can change it, is a basic requirement of civic action and is probably required to do any job well, be that raising a child, building a house, or pushing a field such as art or science. I find the number of tools and activities designed to incorporate the catalyzation of this viewpoint severely underrepresented in proportion to its importance. This thesis presents one approach to catalyzing the view that the world is a construction kit: designing tools and activity suggestions in the form of Sample Project Spaces, to form a Constructive Lens. When people in the examples I have presented use the Constructive Lenses, they exhibit repurposing behaviors that suggest they are seeing pieces of the world as components of a construction kit.

At the thesis proposal defense in 2012, one of the professors questioned the newness of the play

patterns inspired by the tools I presented. She compared the behaviors to those produced by old toys like string and a ball. Though I don't know if it was meant this way, I take this as a compliment. When someone is playing with a string or a ball, they are exploring the world they live in. What happens when I attach this string to this stick? What happens when I bounce this ball off of this wall? The play pattern that can emerge is one of playing with the rules of the world themselves rather than playing under the rules made by some other person. This beautiful form of play, playing with the designation of meaning itself, playing with the purposing of objects, situations, and activities, is the part of play/work/human-activity that is the representation of agency and original thought.

When playing with a ball, the game is not just "kickball," the game is "let's see how far we can kick the ball." But after a few kicks it is "Let's see how far we can kick the ball if it first bounces off this wall." Then it's "Let's see if we can kick the ball, bounce it off the wall, and then get it stuck in that tree." Which leads to, "How do we get the ball out of the tree?" Perhaps at this point string is brought into the scenario, and the invention process starts, "Quick tie the string to my flip flop and we can throw my shoe at the ball without getting the flipflop stuck," or maybe something else. But the playing is playing with the rules themselves, or outside of any specific rules. The "Construction kit" in this scenario is outside of any box, it is the tree, the wall, the flip flop, and didn't come delivered with any curriculum, and has no limits to what is "in" or "out" of the kit except those set by the imagination. Many people remember and treasure scenes like this from their childhood.

When the adoption of Drawdio and Makey Makey started getting serious, when I started seeing dads designing accessible controllers for their sons with cerebral palsy, or professional musicians performing with the tools, or when we sold more than 10,000 units in the first month of Makey Makey sales, I thought, [the following thoughts excerpted from Silver, 2012 TED Talk on Hacking Everyday Objects] "I better put a serious warning label on the box that this comes in…"

Figure 9.4. Warning from side of online Makey Makey box

I thought, "Because otherwise people are going to be getting this and turning into agents of creative change and corporations will be reinvented and governments will be crumbling and I wouldn't have told people so," I thought, "I'd better warn them. And I also put this little surprise when you open the lid of the box it says…"

Figure 9.5. Secret message revealed when first opening package of online Makey Makey box

I thought, "And as you start to kind of mess around with these tools I think that in some small ways you do start to see the landscape of your everyday life a little bit more like something you can express yourself

with, and a little bit more like you could participate in designing the future of the way the world works."

"So the next time you're on an escalator and you drop an M&M by accident, maybe that's an M&M surfboard not an escalator, so don't pick it up right away, maybe take some more stuff out of your pockets, throw it down, maybe some chapstick or whatever. You know I used to want to design like a utopic society or a perfect world or something like that, but as I'm kind of getting older and messing with all this stuff I'm realizing that..."

> "...my idea of a perfect world really can't be designed by one person, or 100 designers, or 1,000 scientists, or even by 1,000,000 experts. It's really going to be 7 billion pairs of hands..."

"...each following their own passions, and each — kind of like a mosaic — coming up, and creating this world in their backyards and in their kitchens and in their communities... that's the kind of world I want to live in."

Appendix

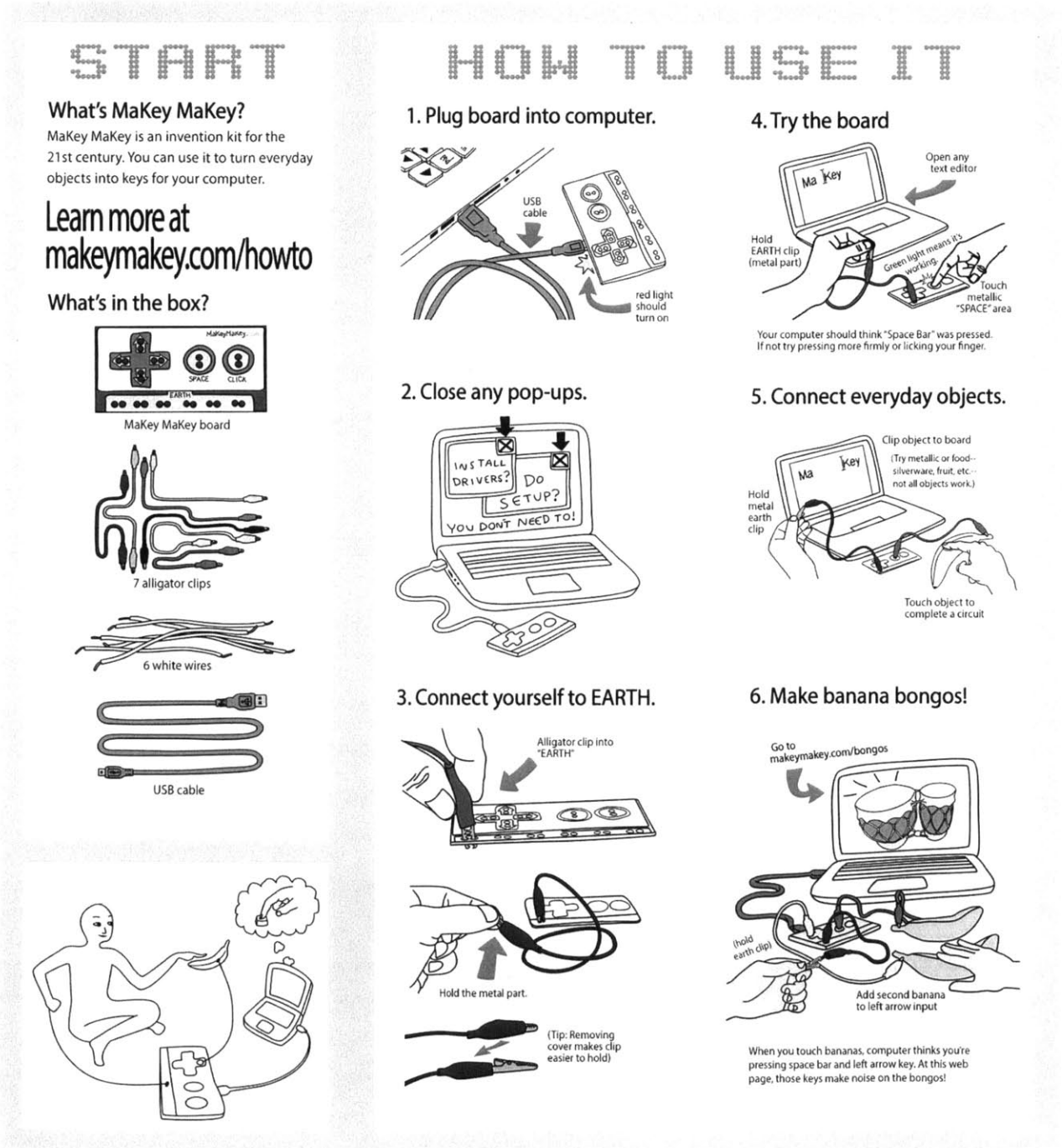


Figure A.1. Makey Makey Instruction Pamphlet Page 1. Getting Started.

Figure A.2. Makey Makey Instruction Pamphlet Page 2. Ideas to Get You Going.

Figure A.3. Makey Makey Mass Retail Box Front.

Figure A.4. Makey Makey Mass Retail Box Back.

Figure A.5. Makey Makey Online Box Back.

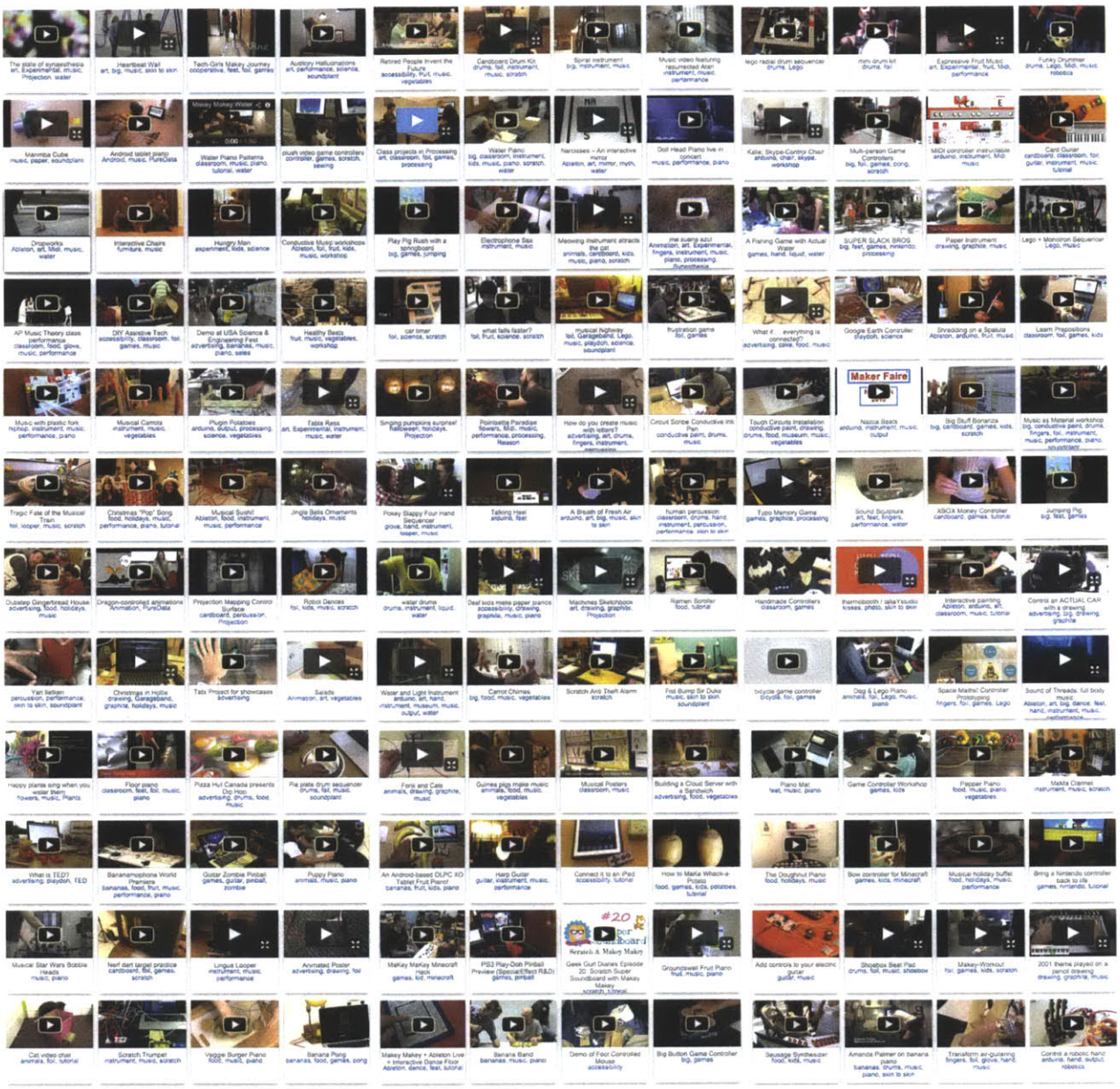


Figure A.6. Some of the projects submitted by creators to the Makey Makey website through Eric Rosenbaum's project-tool

Thanks and Gratitude

To truly do this section justice I would have to thank almost every person I have ever come into contact with. But let's give it a try. Please remind me if I forgot to add you.

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On Makey Makey Specifically

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Bio

Jay Silver is the Founder/CEO of JoyLabz and was the first ever Maker Research Scientist at Intel. He made many creative platforms such as Drawdio (Time's Top 15 Toys for Young Geniuses) and MaKey MaKey (Kickstarted for $500,000, Pop Sci Best of ToyFair). Jay has been a speaker at many TED events, exhibited artwork internationally, and been named a top 100 inspirational world changer by DELL. Jay has taught Yoga for ten years and practiced Reiki since the age of 12.

Jay has a:
Bachelors from Georgia Tech, Electrical Engineering, named Engineer of the Year
Master's from Cambridge University, Internet Technology, funded by Gates Scholarship
Master's from MIT Media Lab, Media Technology, funded by NSF Fellowship
PhD from MIT Media Lab Lifelong Kindergarten, Lemelson Prize for Inventiveness