A Kit-of-No-Parts

by Hannah Perner-Wilson

B.S. University of Art and Industrial Design Linz, 2007

Submitted to the Program in Media Arts and Sciences, School of Architecture and Planning, in partial fulfillment of the requirements for the degree of Masters of Science in Media Arts and Sciences at the Massachusetts Institute of Technology, June 2011

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ABSTRACT

I demonstrate a new approach to building electronics that emphasizes the expressive qualities of diverse materials as well as the skill and creativity of the builder. I believe that a more insightful and skilled process is also capable of producing more intelligible and personal results. Conventionally electronics that are built from a kit-of-parts have been optimized for speed, efficiency and repeatability of assembly. While this approach demonstrates the power of modular systems that have made many of the technologies we rely on possible, it also constrains us to particular styles of building, influencing what we build as well as impacting how we come to think about electronics. In order to promote a different approach I have developed a series of techniques that allow us to build electronics using a variety of craft materials and tools. A collection of electronic samples showcases the results and the potential of these techniques, and a public website documents these techniques in the form of “recipes”. Besides containing instructions on how to build electronics these recipes are also detailed accounts of my development process that aim to promote further exploration and material investigation, instead of straightforward replication. After developing this collection of new techniques, documenting and publishing them, I ran two workshops in order to observe how my approach fared in practice. Workshop participants were invited to build their own electronic projects from a new and diverse set of materials and tools. Observing participants’ process led me to reflect on their different styles of building and evaluate to what extent a Kit-of-No-Parts approach supports a building style that is more understandable, and allows individuals to work more freely and expressively with the materials and tools involved. Currently our approach to building electronics is shaped by industrial standards and discrete components. The Kit-of-No-Parts counters this approach by introducing the notion of craft and putting emphasis on skilled use of tools, intimate knowledge of materials, with the aim to produce more diverse and intelligible results.

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INTRODUCTION

The MIT Media Lab is a place to imagine, prototype and build technologies. Situated within this environment, the High-Low Tech research group looks at the processes, audiences and cultures surrounding technologies and at how these surrounding elements impact technology. We care about the kinds of people who are drawn to creating technology. We promote diverse, accessible and creative ways of approaching technology. Finally, we encourage and support the formation of communities and cultures around these new audiences and processes.

In my work, I look at how we build electronics and at the materials and tools we build with. The Kit-of-No-Parts is a new approach to building electronics that emphasizes the expressive qualities of diverse materials as well as the skill and creativity of the builder. This approach is represented through a set of techniques that include, among other things, ways to sculpt and plate electrical connections, cut paper speakers, carve wooden dials and paint color-changing pixels. I believe that this new approach to building will lead to a greater diversity of electronics that are more understandable and unique.

In industry, "kit-of-parts" describes an approach to designing discrete components that function as modular parts within a coherent system. These parts have been optimized for speed, efficiency, and repeatability of assembly. The Kit-of-No-Parts approach emphasizes building outside of these systems. While I incorporate a variety of parts in my techniques, I do not confine myself to working within their constraints.

I am not the first person to address some of these problems surrounding electronics. A whole range of electronic construction kits (picoCricket [picoCricket, w2011], Phidgets [Greenberg and Fitchett, 2001]) have been designed to make electronics more understandable, and accessible, making them appeal not only to children but also to artists and designers (Arduino [Arduino, w2011]). The LilyPad Arduino, a sewable microcontroller platform, is an example of how a new and more expressive approach to building electronics engages diverse communities and produces new kinds of technologies [Buechley and Hill, 2010]. A range of prototypes and projects from within the field of Interaction Design demonstrate some of the different kinds of technologies that could exist if we were to approach technology with a focus on more social, cultural and ethical implications [Dunne, 2005].

What differentiates my approach from toolkits and critical designs is that I am not introducing a new set of more understandable parts or examples of what technology might one day become. Instead I am developing new processes for creating technology by re-introducing the notion of craft. Taking a craft approach to building electronics introduces an insightful and skilled process that is also capable of producing more intelligible and more personal results. This process and its results appeal to individuals and communities who were previously not drawn to building electronics themselves.

Before the Kit-of-No-Parts approach, I had been working with textile crafts and electronics for several years. My previous work includes an online library of textile sensors [How To Get What You Want, w2011], a series of hands-on workshops [Perner-Wilson et al., 2011] on the topic of Do It Yourself (DIY) textile sensor interfaces as well as a series of projects that include a wearable game interface and a motion-capture costume.

In approaching my thesis, I selected and categorized electronic components, conductive materials and craft processes and mapped them into a collective space. Within this space I sketched connections between different categories and used these intersections to generate ideas. I proceeded to realize these ideas through making and testing samples. Making samples meant combining different materials and tooling processes in a systematic way in order to test what worked and what didn't. While I was systematic about my sample making, I also relied on my intuition. This process of producing samples forced me to think explicitly about my style of working and how to convey it as an approach. Through my thesis document I am interested in communicating not only the results of my experimentation, but also the experimental approach itself.

The results of my thesis work include a collection of examples and a website. The collection of examples demonstrates what one can build when craft skills and expressive materials become an inherent part of the building process. They showcase the results of the variety of techniques I developed such as copper-plated seashell speakers and ornamentally gilded gold circuits. The website documents the techniques used to create these examples as recipes, so that this approach can be applied by others. These recipes are not just straightforward step-by-step instructions one can follow to achieve the result; instead, they are detailed accounts of my process. They attempt to prompt others to build upon my work, rather than simply replicate it.

In order to get an understanding of how my work impacts how we currently build electronics, I discuss to what degree it supports a building style that is more understandable, and to what degree such transparency allows individuals to work more freely and expressively with the materials and tools involved. Through two workshops I look at others' ability to apply these techniques successfully, and at how the use of craft materials and tools influences their perception of electronics. I am interested to find out who is drawn to this building approach, what motivates them to engage with it, how they experience the process and what they want to build.

In the following chapters, I describe related work and background information relevant to my thesis. I detail my experimental process of building the Kit-of-No-Parts and document my techniques in the form of recipes. I introduce a collection of examples that showcase what kinds of electronics can be built with the techniques I've developed. Through summarizing and analyzing the workshops I've conducted, I reflect on my process as well as on the results of that process.

BACKGROUND

In this chapter, I introduce building processes as they relate to electronics and craft. I describe how electronics are designed and manufactured as discrete components and how we prototype and build electronics at an individual level. While this first section on electronics is focused on how we build within systems of parts. In a second section titled "Liberated Circuits" focuses on electronics outside their systems by exploring other forms of building with electronics that, for different reasons, build electronics in more unconventional and unintended ways. In a final section on craft, I describe what it means to craft and to what extents craft today incorporates technology.

Electronics

Industrial Production

Today the majority of electronic components are mass-manufactured. Standardization and a kit-of-parts approach to production have made large-scale manufacturing fast, efficient and affordable. An elaborate supply chain delivers materials that have been made workable, their flaws removed to render them uniform and predictable. Standardized production or "workmanship of certainty" as David Pye calls it [Pye, 1968], allows us to build technologies that are more complex than any one human could ever make himself or herself. The results of this process demonstrate the power of black boxing [Pugin, 1853] and division of labor, without which many of the technologies we rely on today would not exist. But these results also illustrate the influence that this standardized approach has on how technology looks, feels and functions.

"In particular there has been a pronounced development in the idea of a building as a kit of parts whose individual functions are tested and known, whose cost and performance has been set and whose use can be specified in one country and used in another and everyone concerned knows what to expect." [Craft and the Turing Test for practical thinking, Peter Dormer, The Culture of Craft, 1997]

The International Electrotechnical Commission (IEC), which was founded in 1906 and works towards developing industry standards, describes the goal of standards as allowing for the assembly of electronics that "perform, fit and work safely together" [IEC, w2011]. Some of these benefits of standardization can also become limitations. In first-world industrial societies we have already begun to think of electronics in terms of standardized parts and it is hard to break with these conventions. When we think of a transistor, we think of the specific component packages and not of the actual materials and material properties used to make the transistor itself. The way transistors are designed, their package and form-factor, have little to do with how they work. This way in which parts tend to black box functionality, hiding mechanisms and functional materials, makes them less intuitive and understandable and harder for individuals to use in unexpected or expressive ways. I believe that parts libraries and standardized industrial systems constrain how we build, what we build as well as how we think about electronics. Figure 2 shows an assortment of standardized electronics components.

Individual Prototyping and Building

The ways in which we currently sketch, prototype and build electronics, even as hobbyists within the vicinities of our own homes, rely on standardized parts. A range of tools exist that allow us to prototype and easily disassemble our designs built with these parts. This style of working, too, stands in contrast to the approach I am proposing.

I want to briefly introduce some of the ways in which we currently build electronics to better contrast it with the approach I'm proposing. Breadboarding is a common electronics term used to describe the process of prototyping circuits on a breadboard. The name "breadboard" comes from the way early radio enthusiasts used actual breadboards or pieces of wood as platforms to which they screwed and attached the individual parts of their radio circuits [Fig. 1, left]. Today breadboards are rectangular plastic construction bases with a grid of holes spaced to fit the leads of most through-hole components [Fig. 1, right]. Jumper wires are used to create additional connections on the breadboard.

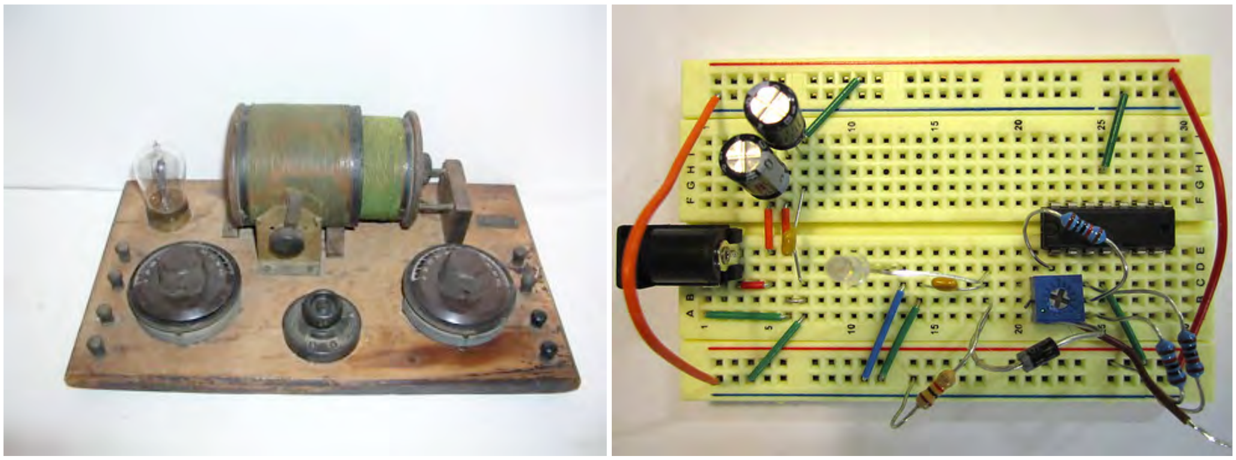


Figure 1. *Left: 1922 One tube breadboard radio by A.C Gilbert Erector (image taken from nwwone.org). Right: Modern breadboard with components and jumper wires.*

To design more durable and permanent printed circuit boards (PCBs), one can use software that allows for the selection of components from a library of standard parts to be laid out in a design. The software helps optimize the arrangement of individual parts and the connections between them. The final design can then be exported to create files for industrial or individual production through chemical etching or milling the circuit from a copper foil laminate.

Construction Kits

Construction kits make electronics accessible; they lower the entry bar to science, engineering and technology disciplines and allow more of us to build our own electronics. Similar to industrial production, the parts of a construction kit function inside modular systems, yet whereas in industry parts are optimized for engineers to build with and machines to mass-produce, the parts of a construction kit are designed with attention to how an individual uses them to build, understand, and learn.

A range of physical computing toolkits are aimed at bridging the gaps between programming and building electronics and their interactions with the physical world. Toolkits such as Phidgets [Greenberg and Fitchett, 2001] and Arduino [Arduino, w2011] have made programming and building interactive projects so accessible that artists, designers and students all over the world are integrating electronics in their work. PicoCrickets [Fig. 2] are physical computing modules for children designed to be easily integrated with the physical world to emphasize and promote artistic expression.

Figure 2. *Left: Electronics components (image taken from printedcircuit1.com). Right: PicoCrickets by PICO are based on research from the Lifelong Kindergarten group at the MIT Media Lab (photo from Smart Design).*

Liberated Circuits

Besides industry, individual prototyping and construction kits, there are other approaches to building electronics. Building outside of industrial production is often associated with building as a form of personal expression or aesthetic creation. The following paragraphs summarize some contemporary movements that represent independent, expressive and more materially diverse building processes related to electronics and technology.

Electronic Textiles

The field of Electronic Textiles (E-Textiles), the seamless integration of electronics and textiles, represents one of the more integrative material approaches to building electronics with and from fabrics as well as other soft, flexible and malleable materials. Research in this area [Buechley and Hill, 2010] has shown that introducing a new palette of materials and tools for building electronics attracts new audiences and generates a new diversity of electronic artifacts. These artifacts are not only aesthetically intriguing but also functionally novel and often the result of a personal encounter with technology.

A new set of toolkits such as the LilyPad Arduino [Buechley et al., 2008][Fig. 3], Fabrickit [Fabrickit, w2011] and the Schemer [Schemer, w2011] are designed to facilitate the integration and combination of electronics and textiles. While these toolkits support and enable a new community of builders to realize their own E-Textile projects they also introduce new processes and new styles of working that lie in between the plug and play world of electronics and the world of textile handicrafts.

Paper Crafts and Electronics

In 2007 and 2009 two conference workshops titled Transitive Materials [Transitive Materials, w2011] focused on integrating material technology and computation. The academic papers presented at these workshops included the work on Pulp-Based Computing [Coelho et al., 2009] that introduced electronics into the papermaking processes allowing for electrical connections, bend sensors and LED lights to be embedded within paper. Pulp computing also introduced a screen-printed flat speaker coil that inspired the paper and seashell speakers I introduce in my thesis. Another paper on Co-Designed Paper Devices [Saul et al., 2010] included documentation of a gilded circuit made from gold leaf that was used to actuate a paper robot.

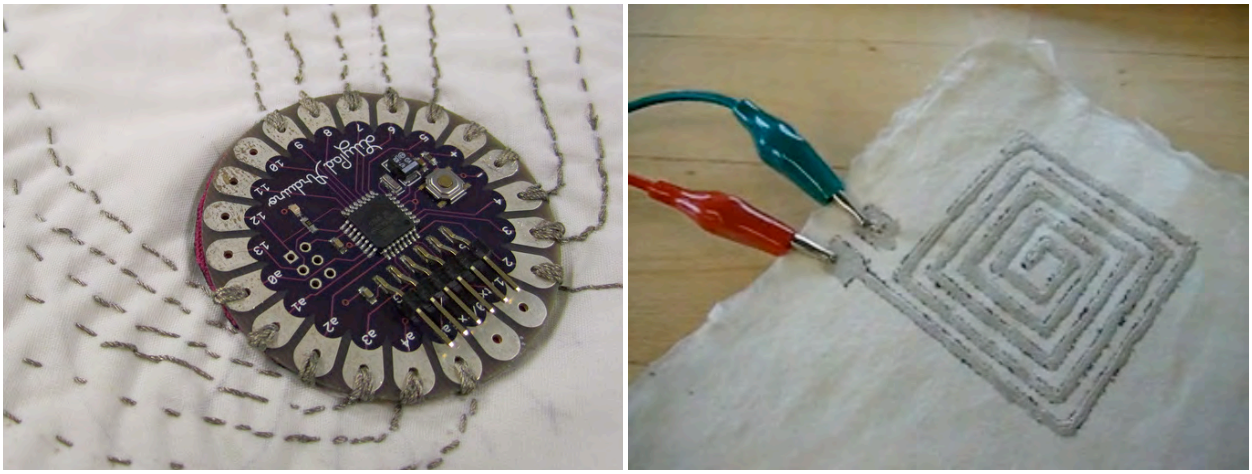


Figure 3. *Left: LilyPad Arduino embedded in an E-Textiles project. Right: Screen-printed speaker coil on handmade paper by Marcelo Coehlo (image taken from eyemotive.com).*

Combining paper, electronics and computation has also been one of the research directions of the High-Low Tech research group. Electronic Popables [Qi and Buechley, 2010] is an interactive pop-up book that showcases how electronics and pop-up mechanisms can be integrated to produce new results that combine artistic expression with craft and engineering skills. The Living Wall [Buechley et al., 2010] is a large-scale painted interactive circuit that appears as a decorative floral wallpaper pattern, integrating functional circuit layout and the electrical properties of conductive paint with appearance and aesthetics.

In many ways the Kit-of-No-Parts approach sprung from a realization that in attributing many of the novel and diverse results of E-Textiles and paper computing solely to the different materials they were made from, we are overlooking the impact that the shift in process was having on electronics - namely a shift from the established practice of assembling electronics from a kit-of-parts, to a process of crafting electronics.

Maker Cultures

In this subsection I introduce a variety of different building communities that, in my opinion, represent styles of building with electronics that take place “outside the box”. By this I mean that they make explicit efforts to work with electronics in unconventional ways, for a variety of reasons that include resourcefulness, customization and aesthetics.

Hacker spaces [Fig. 4] have established themselves in many places as a physical space to build and hack electronics together.

Circuit bending is a style of modifying mostly cheap toy circuits to illicit interesting electronic sounds. Bent circuits are often housed in custom-built containers from re-assembled parts and scraps, bringing together electronics components and household items.

Steampunk [Akah and Bardzell, 2010] is a subculture that, among other things, modifies and builds electronics to look like they originated from the Victorian area. While many Steampunk electronics are replicas of modern technology, they incorporate a range of materials and styles that are reminiscent of a past era in which steam power was widely used. The results are sometimes electronic artifacts that stand out because they look nothing like typical consumer electronics [Fig. 4].

Figure 4. *Left: Nosebridge hacker space, San Francisco (photo taken from mattleaf.com). Right: Rhombus Maximus by Alex Neretin - a steampunk computer mouse made of copper, brass and walnut wood (image from behance.net).*

The term Do It Yourself (DIY) has experienced recent popularity and media attention. O'Reilly's Make Magazine [Makezine, w2011] and Maker Faires [Maker Faire, w2011] are big supporters of this new maker movement. Maker culture has also very successfully leveraged the Internet as an international platform for communities to meet and exchange projects and information. Ravelry [Ravelry, w2011] and Instructables [Instructables, 2011] are examples of online communities based around sharing information, publishing projects and acknowledging others' work.

Cultures of making exist around materials, tools, and community spaces as well as around the artifacts that people make but the mindset of the individual maker is just as much an important part of these cultures. Jay Silver describes a Maker Methodology [Silver, 2009] that promotes making as a mindset, where the world is your palette and you and your body play a role in the way you build, learn create and interact with electronics.

Craft

Craft materials and crafted artifacts are often praised for their aesthetic, decorative and material qualities and yet we hardly consider them in terms of innovativeness or usefulness. We generally consider crafted artifacts to be shaped by the skilled "workmanship of risk" [Pye, 1968] and the personal knowledge [Dormer, 1997] of the individual craftsperson as well as by the materials and tools involved.

"A craft object often reveals much about the skill and the technology used to make it. The relationship between craft process and product is likely to be, if not quite transparent, then at least relatively accessible to most of us. There is pleasure from wearing or using something whose creation we can

both admire and understand. In a world where we have lost touch with the business of making things, the craft object restores for us the connection between making and using. By contrast, design conceals. Not only do we not understand how designed objects are made, we do not understand how they work." [Helen Rees, Patterns of making: thinking and making in industrial design, The Culture of Craft, 1997]

Craft Today

Looking at contemporary practices of craft, there seems to be a split between contemporary craft that leverages technologies in support of traditional practices, such as the online knitting community Ravelry [Ravelry, w2011], and contemporary craft that takes a more radical stance on establishing new forms of craft expression in modern society, such as Knitta [Knitta, w2011] and Hyperbolic Crochet [Hyperbolic Crochet Coral Reef, w2011]. Knitta is a collective of knitters who use knitting as a form of graffiti. Hyperbolic Crochet has become a world-wide movement that celebrates the craft of crochet to produce mathematical structures that represent coral reef structures in an attempt to draw attention to the threats that global warming is having on this natural wonder.

Figure 5. *Left: Knitta grafitti (image taken from hugznbitchez.com). Right: "Crochet Coral and Anemone Garden" with sea slug by Marianne Midelburg (photos copyright The IFF by Alyssa Gorelick).*

Craft emphasizes process, the materials and tools involved as well as the skill and joy in manual labor. Craft has become defined as other to industrial production and this comparison has emphasized more of the social and economical aspects of craft, craftsmanship and artisanal production. The result is that these aspects to have an impact on how we view craft and crafted artifacts.

The common image we conjure up of the craftsperson's workspace, while full of materials and tools, is outdated in terms of technology and innovation. The modern craft workspace exists. It includes computers and other high-tech electronics and yet when we think of craft we picture the nostalgic workspace that represents the birthplace of the kinds of artifacts we typically view as crafted. While craft has come to embrace technology for production [Ann Sutton quoted in Dormer, 1997, p145], community building and social networking [Torray, 2009][Rosner, 2010], there are few approaches that have brought us a framework in which to craft technology itself.

In the following chapters I detail my thesis work that explores the process and possibilities of building electronics by combining the skilled, material and personal qualities of craft, the expressive, tinkering and resourceful qualities of maker culture with established forms of building electronics from a set of discrete components. I describe the series of techniques that I have developed in order to promote what I believe is a more materially diverse, functionally transparent and expressive style of building electronics.

BUILDING A KIT-OF-NO-PARTS

Figure 6. *Snapshot of my workspace taken during the process of building a Kit-of-No-Parts.*

The introduction explained my motivation and described my approach and in the background section I painted a picture of how we build and craft with electronics today. In this chapter, I will detail the stages I went through in creating my thesis work. Figure 6 shows a snapshot taken of my workspace while I was building the Kit-of-No-Parts.

Throughout this description of my process of developing new techniques I talk about samples, examples and recipes, as shown in Figure X. While intimately related, these are three separate things. Samples are the experiments I produced to develop new techniques. Examples are the demonstrations I made to showcase these techniques. Finally, recipes are the instructions I wrote in order to share these techniques with others.

For organizational purposes I will describe the different stages of building a Kit-of-No-Parts in a linear order. But in practice there was much overlap and back and forth between stages that is better illustrated as shown in Figure 7.

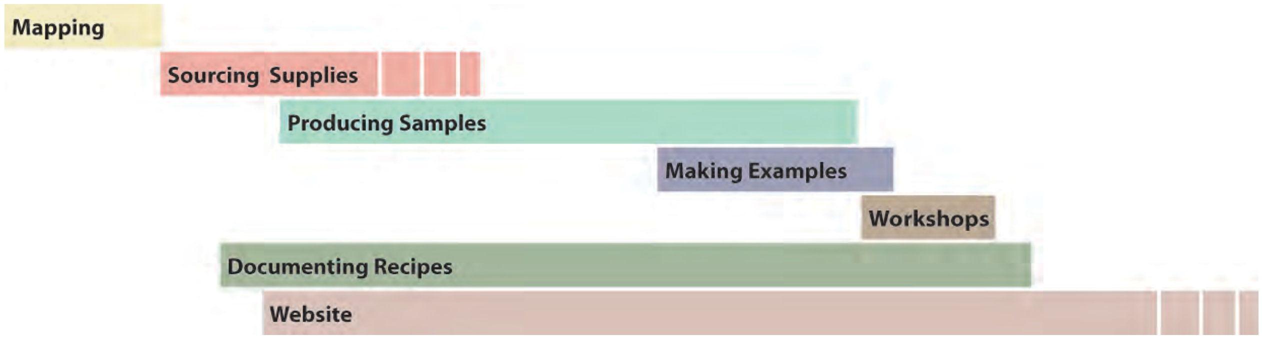


Figure 7. *Illustration of the process of building a Kit-of-No-Parts. Mapping Space: Visualizing the conceptual framework of my thesis to generate ideas. Sourcing Supplies and Instruction: Acquiring the necessary materials, tools and information to begin work. Producing Samples: Testing new techniques through a succession of samples. Making Examples: Designing a collection of examples that showcase my various techniques. Workshops: Holding two workshops to share techniques and gather feedback on how they are received. Documenting Recipes: Writing up my successes and failures for others to follow. Website: Launching the website and filling it with information.*

As I continue to talk about the techniques I developed, I want to be clear that I'm referring to a particular style of building that comes closer to craft than engineering, that is limited by skill and not by toolset and that is defined by risk and not by certainty. I began my exploration looking for tools that would allow me to work expressively with a wide range of materials; for techniques that require skill and emphasize material qualities. I was looking to achieve diverse and unique results. There isn't a clear line I can draw between the expressive process I'm trying to describe and the less expressive processes I'm trying to counter. The mindset and attitude of the maker play a large part in how expressive the building process is. This is why the Kit-of-No-Parts is as much about attitude as it is about concrete techniques and recipes.

Mapping A Space

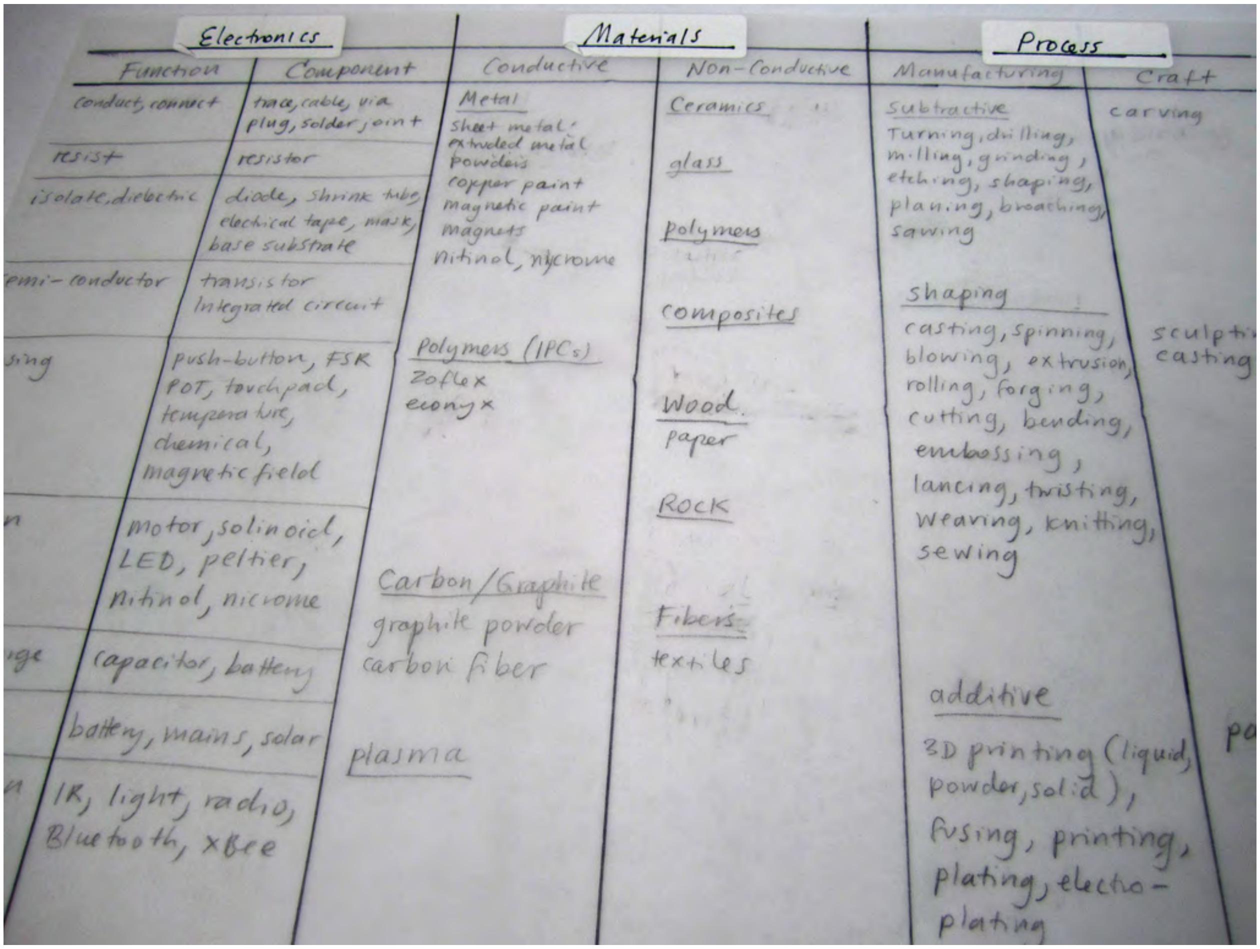


Figure 8. *Snapshot of categorizations made in the process of mapping space.*

The first step I took in exploring the intersections of craft and electronics was to look separately at the domains of electronics, materials and building processes. I was interested in how each of these three domains described and categorized themselves. I listed the different kinds of categorizations I could find for each domain and then selected the one that was most relevant for my intentions. Sometimes this involved mixing categorizations and even inventing my own. Figure 8 shows a detail of such a categorization.

Electronics can be categorized by electrical properties (conductive, resistive, piezoresistive, piezoelectric, dielectric/isolating…) or by package norms (surface mount, through-hole...), but conventionally they are categorized by discrete component (traces, resistors, capacitors, sensors, actuators, power, transistors, integrated circuits…) as listed in established literature such as The Art of Electronics [Horowitz and Hill, 1989]. While thinking of electronics in terms of electrical properties helped me to think of individual components from a new perspective, I decided to go with the common categorization. My reasoning for this was that it was not my immediate goal to change how we categorize electronics, but rather how we build them, which includes building *with* them.

Materials are conventionally categorized by chemical elements and compounds (metals, ceramics, wood, polymers...) but can also be categorized by form-factor (solid, liquid, powder, gas…) or by conductivity (conductive, resistive, piezoresistive, piezoelectric, dielectric/isolating…) I chose to pre-select conductive materials and then categorize them by form-factor. My reasoning for this was that such a majority of conductive materials fall into the metals category that this category would distinguish less differences and categorizing materials by form-factor allowed me to relate them more easily to processes and tools.

Building Processes are categorized differently, depending on domain. Industrial processes are sometimes listed by process type such as chemical process, heat process or physical process but more commonly they are categorized by similarity of function such as casting, molding, forming, machining, joining and polishing. Craft processes are traditionally categorized by material (metalwork, woodwork...) and by process (carving, weaving...) but this is not so much a categorization as a way of naming crafts. I decided to categorize crafts in modern manufacturing terms and to list them as additive, subtractive and deforming processes, another common categorization used in manufacturing handbooks such as Fundamentals of Modern Manufacturing [Groover, 2010].

It is interesting to note that each of these three categories describes itself differently through its choice of naming and categorization. Electronics are very much discrete components that have been categorized by industry and their manufacturing terms. Materials fall naturally into scientific categorizations, but could just as easily be described and categorized into more tactile or emotional categories such as rough, soft and cold. While crafts describe themselves through materials and tool processes such as woodwork or carving, industrial processes focus on how materials are worked into their final form, either through adding, removing or shaping the materials.

After trying out various combinations of the above domains and categorizations, I found the following combination most supportive of generating ideas for new techniques. I chose to list conductive materials by substance and then by form-factor on the left and processes by additive, subtractive and deforming on the right. I chose not to include electronic components as a category and instead have them result from the various material-process intersections. This mapping worked out very well for me and in the following I give a more detailed listing of what I included.

Conductive materials were listed as metal, metalized and non-metallic. Within the metal and metalized categories I listed metal types such as copper, silver, gold, nickel. Within the non-metallic category I listed carbon, intrinsically conducting polymers (ICPs), salt, plasma. The next subcategory was form-factor. In metals I included things like foil, sheet, rod, pipe, wire, mesh, leaf, bead, filing, powder, fiber, screw, nail and hinge. Metalized form factors included fabric, tape, thread and yarn. Non-metal form-factors included powder, fiber, liquid, solution, coating, gel, fabric, paper, tape, pencil lead and gas.

Craft processes were categorized as additive, subtractive and deforming. I divided additive into applying and fusing. Applying included printing, painting, coating, plating and drawing. Fusing included gluing and laminating. Subtractive processes were divided into cutting and removing. Technically, cutting is not always subtractive and can fall in the deforming category. Cutting included ripping, tearing and separating. Removing included carving, engraving and etching. And finally, the deforming category was subdivided into molding, casting, folding and interlocking. Molding and casting included throwing, sculpting, shaping and curing. Folding included creasing.

Interlocking included weaving, knitting, crochet and knotting. Many of the techniques in the interlocking category are prevalent in textile crafts and to some degree I explicitly tried to avoid these because I was looking to combine craft techniques that had not already been explored in E-Textiles.

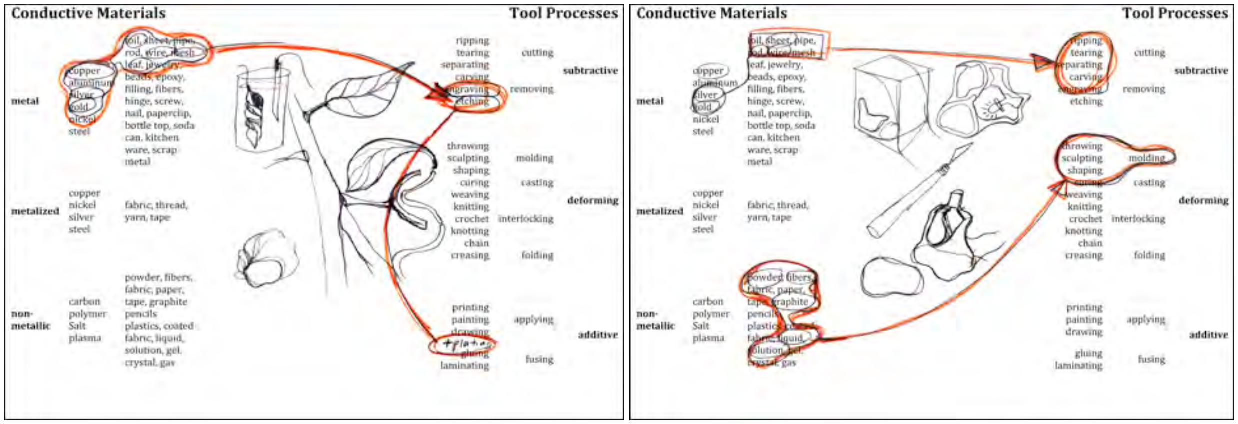


Figure 9. *Brainstorming sketches on top of categorization map that lead me to develop techniques.*

The sketches in Figure 9 show my brainstorming sketches for select components on top of the completed map that helped me draw intersections between materials and techniques. These sketches also depict concrete ideas for techniques that I went on to develop. The first sketch on the left describes a method for incorporating natural materials such as leaves and shells as base structures for electronics. This idea evolved into a recipe for electroplating seashell speakers. The second sketch on the right describes an approach to sculpting and carving electronics from conductive materials and this idea evolved into recipes for carving electrical connections out of wood as well as an attempt at sculpting precious metal clay to make tilt sensors and motors.

Having used my map to generate these concrete ideas I began the process of ordering supplies, finding instructions and developing new techniques.

Sourcing Supplies and Information

Figure 10. *Image taken of the spatchula tool display at the local art and craft supply store where I purchased several of my supplies.*

Having generated ideas for new techniques I was ready to begin sourcing and acquiring the necessary materials and tools [Fig. 10]. In this chapter I describe how I used different information sources to find supplies and instructions. Through select examples I share what I learnt about these new materials, tools and techniques through the process of obtaining them.

The types of media I found most useful included other peoples written accounts of their processes, especially when they included details not only regarding *what* but also *why* they chose a certain material or tool. Photos were extremely valuable because they captured more information than the person thought to write about. Sketches helped illustrate details that were otherwise hard to depict or describe. While videos were often tedious to watch at length, they were great sources of all kinds of implicit details that I had a hard time finding in explicit documentation.

I chose online media over other forms of instruction such as apprenticeships, classes and even printed literature. My reasoning for this was that I intended to use similar forms of documentation for my own work and it seemed like the perfect opportunity to experience learning from them first hand.

I drew most heavily upon the instructional resources both before and after, and less so during my process of making. Instructions are not only a source of how-to information but also a great place to look for information pertaining to the materials and tools involved in a process. Other places to look for this kind of information include the online and offline shops that manufacture and distribute these resources. These websites often make suggestions as to what collections of products belong together, giving you an idea of all the supplies involved in a particular craft or process.

Approaching a new field of practice can be an overwhelming experience in terms of the amounts of new information one encounters. This can make it hard to find the precise instructions or detailed information that one is looking for. Sometimes I give up on finding what I'm looking for relatively early in favor of a more hands-on learning experience. I find that even after a brief hands-on encounter with some of the materials and tools, I'm in a much better position to oversee and comprehend the masses of information available online. By figuring things out myself, my vocabulary grows, allowing me to better describe what I'm looking for and I become better at judging relevant from irrelevant information.

In order to illustrate some of the details of my sourcing process for materials I describe my search for conductive paints that I was looking to use for painting and casting conductors.

Sourcing: Conductive Paints

Figure 11. *Collection of conductive paints mixed at different ratios, with different mediums, and stray bottle of gilding size.*

Conductive paints are produced for variety of applications. Historically some paints were conductive because they contained metallic color pigments, but today there is a whole industry around the production of conductive paints for printing circuits as well as painting walls to shield entire rooms from electromagnetic frequencies (EMF).

My goal was to find conductive paints that could be applied to a variety of different surfaces and materials. I also wanted to combine them with base mediums such as screen-printing base, block-printing base and even latex so that I could cast stretchy conductors [Fig. 11]. I was looking to achieve a variety of conductive ranges that included: "Very conductive", less than 10 Ohm resistance across roughly a distance of 10cm and no wider than 1cm, "Resistive", in the K Ohm range across roughly that same length and distance, and "Piezoresistive", having electrical properties that change under physical influences such as pressure and stretch.

Being able to paint, print, stamp and cast electronics, as well as have them be stretchable and flexible, opens up many exciting possibilities.

One of the first trails of thought I follow when looking for a new material is whether I could possibly make it myself. In terms of conductive paint this could be something like grinding pencil lead and mixing it with a binder, and indeed if you search online you find a variety of instructions for mixing your own conductive paints and glues. Most of them mix graphite with a medium such as liquid tape or two-component epoxy, a medium that will shrink rather than expand during drying or curing so that the non-conductive medium will not separate or encapsulate the conductive powder particles but instead to compress them. I had experimented with this in the past and while it was possible to make my own conductive paints I was looking for something more conductive than I had been able to achieve previously.

I often begin my search for a specific material, not online, but by thinking if the material is contained in or a part of any commercial product. Often times finding a commonly available variant of what one is looking for can save time as well as cost. Silver paint, for example, is contained in conductive pens that are sold for fixing electrical connections on circuits. I have had little luck getting these pens to work well and dispense their conductive ink nice and smoothly, but they can easily be cut open and the silver paint extracted to be used in other ways. While metallic markers and magnetic wall paint seem like they might be conductive, neither of them are. Metallic markers either contain only minimal amounts of metal particles, not enough to conduct, and often they don't contain any conductive materials. Iron filings in magnetic wall paint are too dispersed in their medium to conduct electricity.

Another way to find materials in odd places is to consider all the different forms and form factors it might be sold as. Conductive paints are also sold in spray cans both for shielding your home as well as for shielding boxes that contain sensitive circuits.

There are countless manufacturers and distributors of conductive paints online and because conductive paint is used in a variety of applications it is sold in different packaging and amounts. Conductive paint for EMF shielding purposes, where customers might be painting the walls of their house, comes in buckets, while the same paint for jewelry plating processes comes in small jars.

When making samples one often only wants small quantities of any material to test before placing a large order. It is always worth while to contact the company directly and ask for samples of their product(s). Often times the samples amounts are extremely generous and free. Other times you will pay. Before purchasing amounts of a specific product it is great to have access to smaller quantities to make sure it will work for your purposes. In looking for conductive paints online I found numerous manufacturers and suppliers and was surprised to find quite a number of them that were "local", or rather based in New England. While it can be convenient and helpful to order from a local supplier sometimes I did not restrict myself as I began by browsing websites.

Browsing some of these websites can be overwhelming due to the amounts of products and datasheets filled with new kinds of information. I find it helps to take notes and sketch charts in which I can compare the properties and prices of the items I come across. I then begin formulating emails to the supplies of the companies I'm interested in. In the emails I often request more information on specific products and inquire about samples. I also briefly described what I am working on. The Kit-of-No-Parts website was not quite setup at that point but as soon as it was, I linked to it in order to reference my work and help explain what I was doing. I heard back from two or three companies, one of which asked me to more precisely specify my purpose. It turned out that they mix their paints for each order after clients specify what they want. At that point I was looking for a conductive paint that would conduct even when stretched. The company sent me a sample of one of their paints screen-printed on a piece of fabric to demonstrate its flexibility and ability to work on porous materials. While the paint looked interesting I did not end up purchasing it for two reasons: it was a solvent based paint that required thinning and it needed to be dried and cured for up to 15 minutes at temperatures above 100 °C. While unfortunate, our lab space is not setup with good ventilation or a curing oven, making work with some materials more tedious than others. But thinking that I also want my techniques to be available to a wide audience, choosing not to work with higher-maintenance materials such as this one, often make my work more accessible.

The conductive silver paint I did end up purchasing from another supplier was water-based and dries extremely quickly at room temperature, WB-101 from conductive compounds [Conductive Compounds, w2011]. Unfortunately silver paints are not cheap and this one cost $1.25 per gram. They did not offer samples, but they did sell sample amounts at this price. Some companies have relatively large minimum orders, which meant I could purchase 100g for $125. Compared to many of the other materials and tools I was using in my process, this was definitely among the most expensive purchases. 100g of the paint was less than 100ml and at first did not seem like much at all, but it ended up lasting me throughout my process as well as throughout the workshops.

One of the most valuable things I have learned through requesting sample amounts of materials is that the people who manufacture the products are often just as interested in my project as I am in their product. They want to know what I am using their product for and even if it is working well or not. The people who engineer and make the materials know a lot about them and one just has to get in contact with the right person and not be afraid to explain what it is one is working on. I have found some people extremely understanding of unusual sounding applications and actively helping me find good solutions.

Smaller companies may have a smaller product range but they might also be more flexible and able to produce something for you specifically. Even the fact that you can contact them and get a personal response from the person in the right position gives you better access to their expertise. Large companies often produce large amounts to meet industrial orders. They tend to be less interested in one-off projects because their revenue comes from big sales. Even if your project is successful, the amounts you might end up purchasing from them are nothing on the scale of their returns. Also, if their machines are set up to run large orders, then it is not easy for them to make anything in small amounts. It is not that large companies as such don't care about your project, it is just that their business model does not always scale to your project.

The Internet is a vast and intriguing landscape of resources. Instead of walking into a store you browse an online shop and it is hard to not let a website's design influence the impression you have of their products. Some industrial websites are especially hard to navigate and can appear dodgy. After getting used to these sites you become more adapt at looking past what is often just poor design. Many companies don't have a designer or simply don't care as much about their online presence because it is not their main interface with their clients. Instead orders are placed directly over the phone.

It is interesting to look at the different audiences some industries cater their products to, especially when these are niche markets one wouldn't immediately consider having anything in common with one another. Conductive fabrics are a nice example of how the Electro Magnetic Field (EMF) shielding industry produces products that are being sourced by individuals sewing interactive light-up garments and people shielding their homes from EMF. Often times these different communities are not even aware of each other.

As these observations accumulate, they make up a large part of this process. These details are what make this process more diverse, transparent and individual than placing your order for pre-assembled parts with a company like DigiKey [DigiKey, w2011] and being able to assemble everything the next day.

Producing Samples

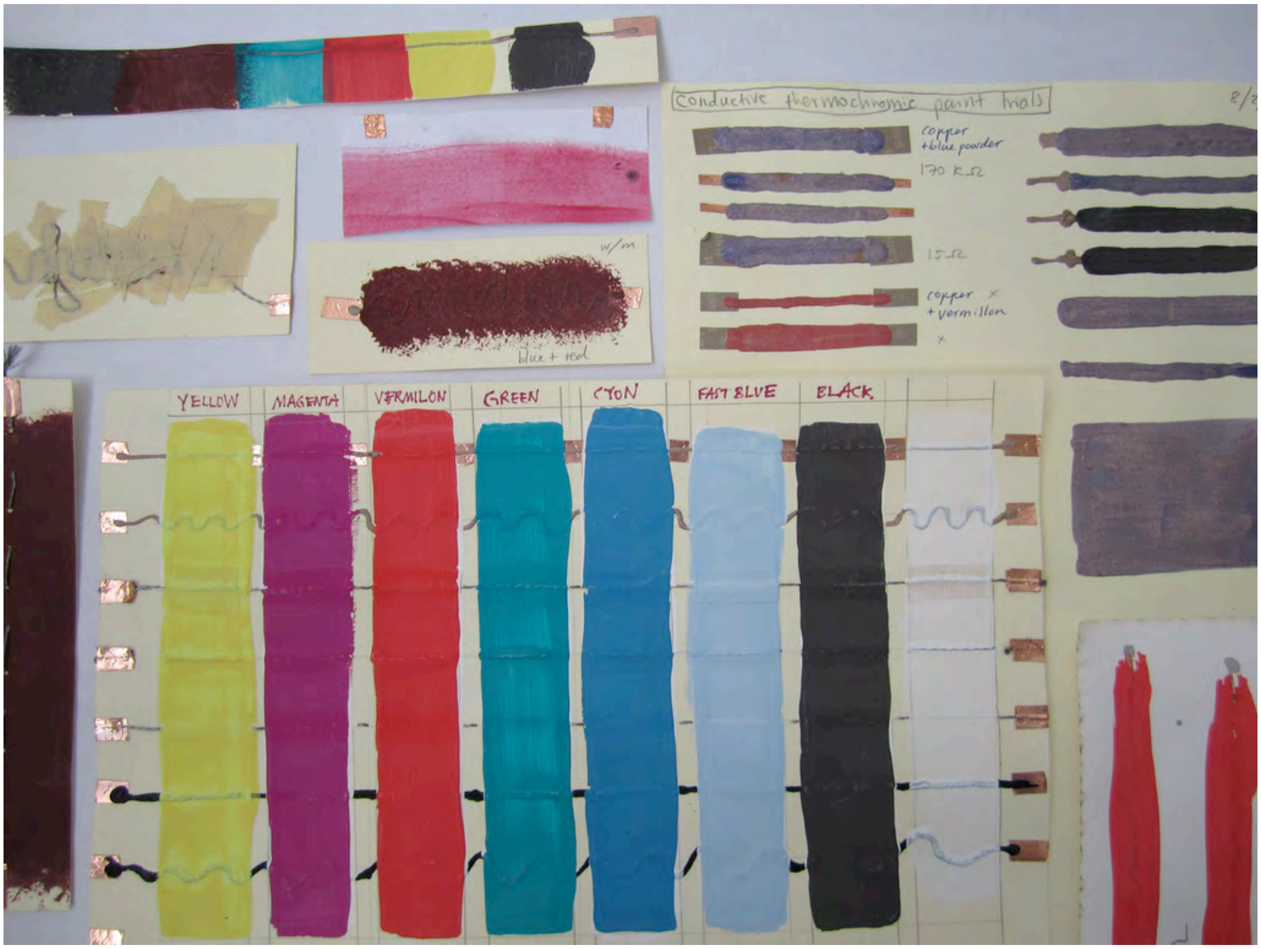


Figure 12. *Samples of different color thermochromic paints on different heating elements that include steel thread, copper paint, carbon paint, silver paint and copper tape.*

This section describes the process of producing samples, of trying things out through systematic making and testing [Fig. 12,13]. While it is a methodological process it also benefits from intuition. Especially as you gain experience working with materials and tools, one develops a feeling for what works and what doesn't. I've found that balancing method and intuition works well, so long as I keep track of everything I do.

While sample making thrives on the freedom to branch out and explore new possibilities, one also needs to know what one is looking for. Ideally one already knew what one was looking for when sourcing the materials and tools, as described in the previous chapter. In the process of building a Kit-of-No-Parts I established a routine of making samples that went something like this:

(1) Try to make a conductor, a continuous and reliable electrically conductive surface or solid that can be controlled in terms of dimensions and spread (the equivalent of a wire). (2) Connect this conductor, for example to the lead of an electrical component. (3) If 1 and 2 are successful, then try to isolate the conductor and "jump" over it with another one, creating an intersection of two

overlapping conductors that are not electrically connected. (4) Connect one of the conductors you have made to another, this can be seen as part of step 3 as part of jumping a trace is to connect two existing traces. (5) Based on experience from the previous samples, think of possibilities for resistors, capacitors, input and output. For example: switches, pressure sensors, heating elements, motion, and color change.

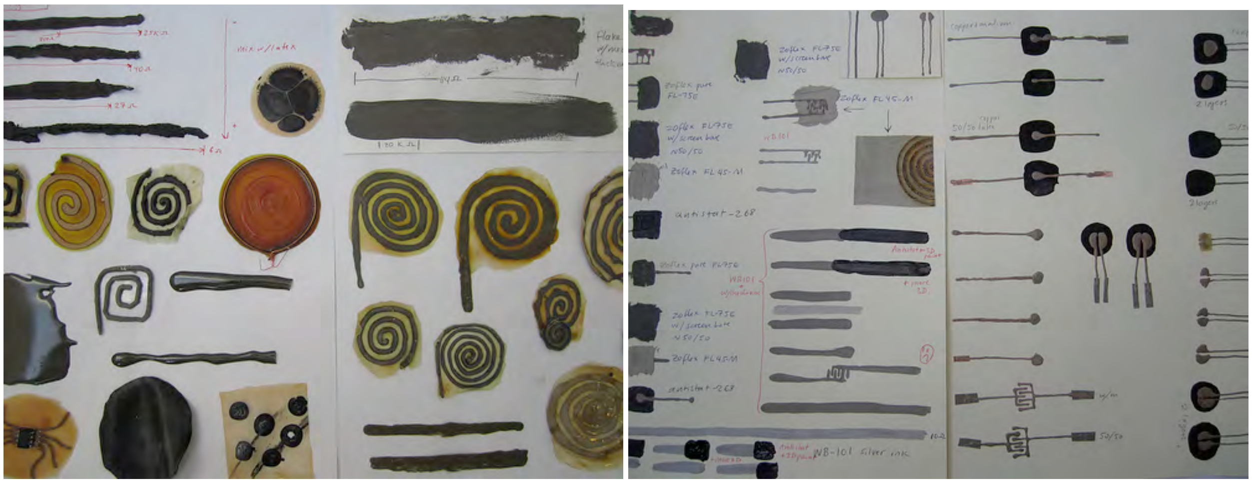


Figure 13. *Left: Samples of conductive paints and powders mixed with latex in an attempt to make a stretchy conductor that can be cast. Right: Samples of conductive paints and rubbers mixed with various mediums such as matte acrylic medium, fabric medium, latex and puffy fabric paint in an attempt to create paintable substance with piezoresistive properties.*

For roughly two months I spent every day trying to demonstrate how the selection of materials and tools I had chosen could be worked into functional electronic circuits. Each time, I roughly followed the succession of samples listed above. Of all the work that went into this thesis, this stage took the longest, was the most challenging and fun, yet remains the least complete. The process of trying things out never really ends, there is always something left to try.

Whatever samples I made, I always kept track of what I did and how I did it. I noted the materials I used, how I combined them, sometimes even when I combined them – so that I could compare results over time. As experiments accumulate, these notes become invaluable. They allow one to go back and reference any prior experiment and pick up from there. Sometimes experiments led full circle and I found myself trying something I had done before. Well-organized notes allowed me to check back and reference my previous results. Sometimes it paid off to make extra samples that could be used in further experiments. While working on a project, never throw anything away. Especially not failed experiments or excess samples, one never knows when one might need them.

During the actual process of producing samples I found a good balance between browsing instructions and figuring things out for myself. This also helped me concentrate on the tangible materials at hand to not go back and forth between reading and making. Often, the conclusions I reached were inline with existing documentation but having figured it out for myself, even if it took me longer than following instructions would have, gave me an insight to the materials and tools that I wouldn't have gotten otherwise.

To better illustrate some of the details of the sample making process, I describe how this played out for carving wood circuits.

Samples: Carving

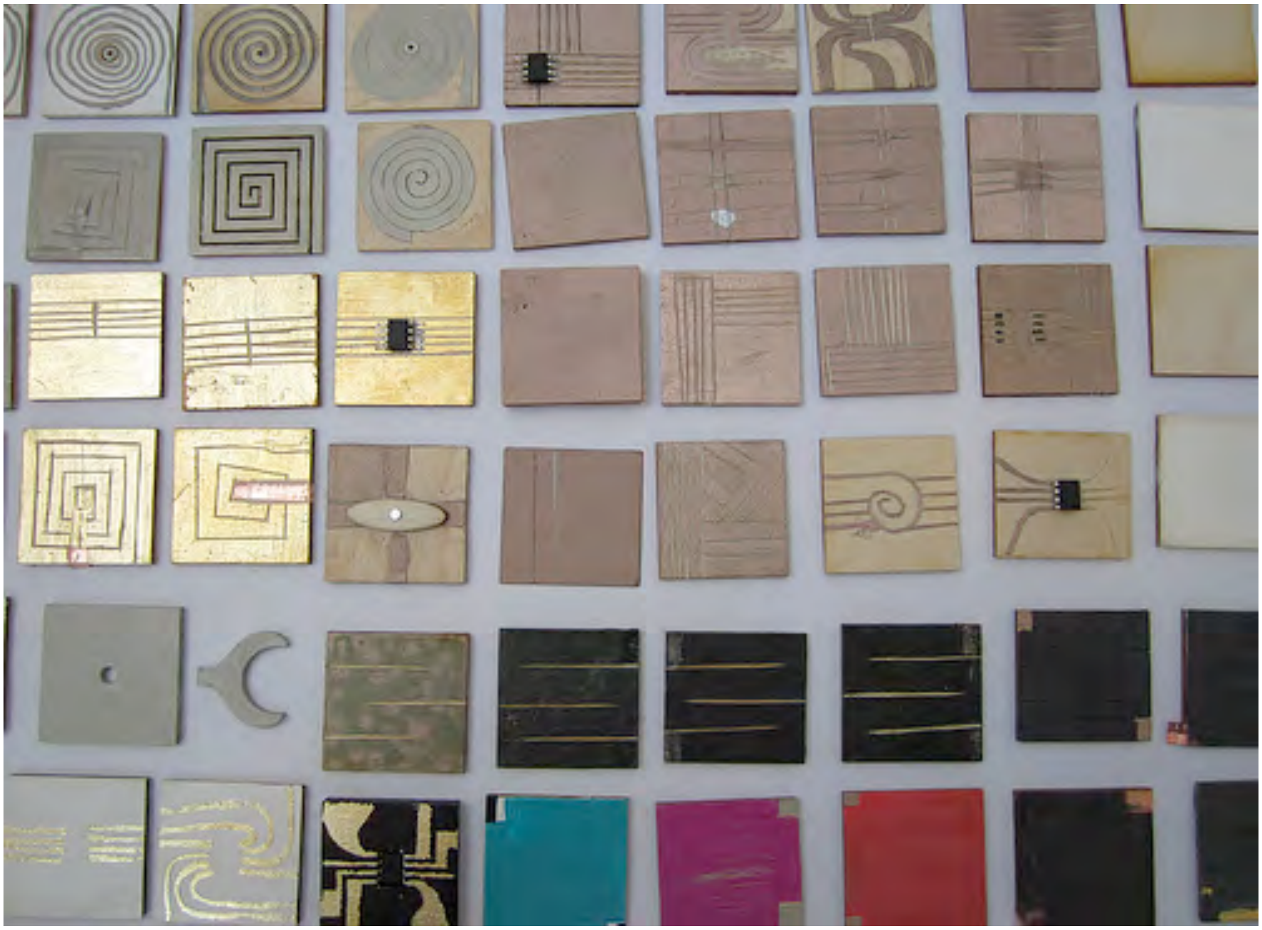


Figure 14. *Samples of carved wood circuitry that include a variety of conductive materials such as copper and silver paints and imitation gold leaf. In an attempt to create elements such as conductive connections, dials, thermochromic heating elements and speaker coils.*

The term "carving" can mean many different kinds of carving, depending on the materials involved. Even woodcarving encompasses a range of different techniques. In this chapter I describe the process of developing techniques for carving wood circuitry and explain my series of samples [Fig. 14] that I made to explore and experiment with what would work and what didn't.

What appealed to me most about carving wood as a technique was that it would allow me to work sculpturally in three dimensions as well as incorporate some of the aesthetic and tactile qualities of wood. Knowing what I wanted to achieve was key in figuring out where to start as well as how to move forward through the sample making process. My goal was to develop a process that allowed me to carve circuits out of wood, leveraging and exposing its material qualities.

One day at the craft store I picked up my first carving tool. I had done no research on carving, any knowledge I had on carving came from glimpsing other people carve and from examining carved objects. It is interesting to pay attention to all the places one encounters relevant information. Even at the craft store, just by looking through the variety of tools for sale. Sometimes tools come packaged with elaborate information, and even instructions. Other times there is nothing. These carving instruments had very little information attached to them but still, from the variety of different kinds of tools I could already gather some useful information. Carving tools come with different blades, shaped in variations of a V or U shapes and various flatness of angles from a sharp V to a perfectly flat line. Another form of information I was able to obtain then and there was through comparing different qualities of the same tool. I could distinguish this by comparing the quality of the blades, some of which already had notches in them. And the design of the handles, some of which were not shaped ergonomically. I could confirm my intuitions by comparing prices. That day I purchased a single very small V-shaped carving tool.

Figure 15. *Left: Carving supplies. Conductive silver paint, paintbrush, wood, acrylic paint, sandpaper, carving tools and superglue. Right: Carving copper painted wood using a flat carving tool.*

I'm not sure if the idea came to me when I picked up the tool or if I had already been thinking of it prior to that. My plan for carving wood circuits was to create a conductive layer on top of wood that could then be selectively carved away. Leaving conductive areas behind where I wanted them. This concrete idea of what I wanted to achieve determined what samples I started making. Figure 15 shows a selection of some of the carving supplies I worked with as well as a demonstration of carving with one of the carving tools.

The first set of samples I made was aimed at achieving a highly conductive surface on wood. For this I mixed a water-based copper paint from LessEMF [LessEMF, w2011] with different mediums at different ratios. The mediums I chose were acrylic medium and latex and the medium to copper ratios I chose were, 1:1 and 1:2. My choice of mediums and ratios were based on intuition and on previous experience working with the paint on paper. From this I knew that the paint was brittle and I wanted to mix it with something that would hold the copper particles together better than just water. I also made samples using copper paint with some water to thin it, but without any medium. I applied single coats of all my mixtures to individual 4 x 4 cm wood squares using a soft paintbrush so as to minimize visible brushstrokes. When the paint was dry I measured surface conductivity. All of the acrylic and latex mixes were good, except the 1:2 copper to latex mix which was seemingly not conductive. The samples of pure paint thinned to various degrees with water were not consistently continuously conductive, in other words flakey.

Since three of these first samples were successful (and I had made extra), I began carving traces using my new tool. I carved traces of various thicknesses both with and against the grain of the wood. I discovered that if I carved a too narrow trace against (perpendicular to) the grain of the wood then this would not conduct, while a trace of the same thickness that ran inline with the grain of the wood was conductive.

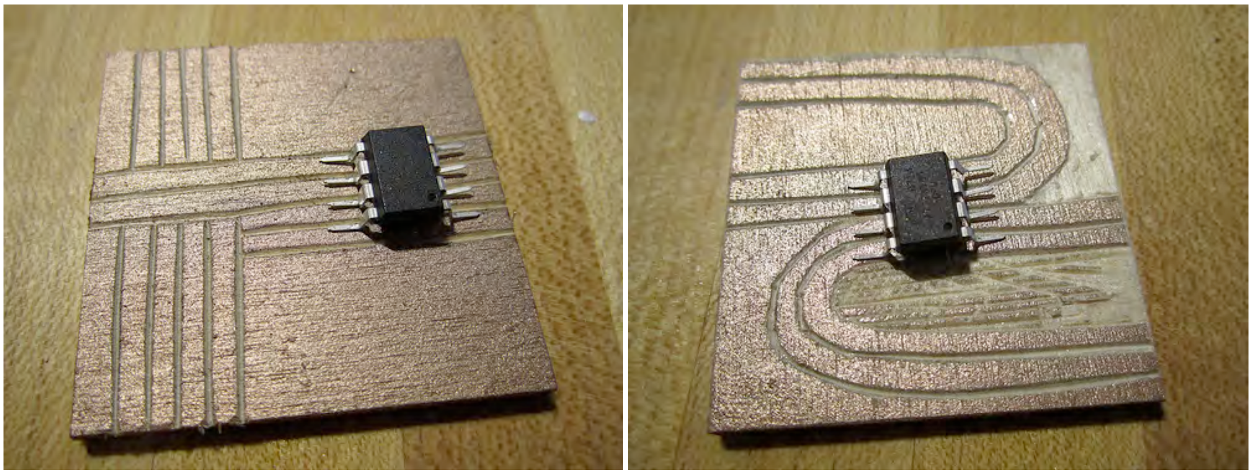


Figure 16. *Copper paint mixed with medium and painted on wood. Traces carved to match the spacing between leads on through-hole microcontroller.*

My intuition was that the grain of the wood was too rough and the paint was cracking across the hills and valley of the grain. Also, the carving process of moving the tool perpendicular to the grain damaged the surface along the edges where the tool removed material. When cutting very slim traces this meant that these damages might disrupt the full trace. One reaction was to think of accepting this, in which case all thin traces simply must run inline with the grain of the wood. There is something nice about how the properties of a material can dictate how you work with it and what it is capable of. At the same time, there were so many ways of solving this problem. I could sand the surface of the wood making it smooth and more uniform to reduce the unevenness that might have been causing the conductive paint to crack. In addition to this I could also apply a layer of primer, again sanding this down to create an even smoother surface. Both of these options worked, allowing me to carve narrow traces any which way I liked across the surface of the wood without having to worry about disrupting conductive connections [Fig. 16].

While I was happy with this result because I felt good about overcoming a hurdle, sanding down the surface and priming it disguised the wood's surface structure, which is what had initially appealed to me. In a further attempt to maintain more of the wood qualities of this technique I went and bought another tool that I had seen when purchasing the first. A flat version of the V shaped tool I was using. With the flat version I could easily remove all the areas of paint that were no longer valuable as functional conductive surfaces in my circuit. This exposed the wood underneath the paint. It also gave a sculptural quality to the surface, as it was no longer flat with ridges, it now showed more contrast. Depending on how deep I carved I exposed different layers of wood and binding material that were differently colored.

At this point I had also received a new conductive silver paint, WB-101 from Conductive Compounds [Conductive Compounds, w2011], that was much more conductive than the copper I was using previously. I could apply it without medium to achieve a very smooth and highly conductive surface and, because the silver particles were smaller, it had a lower viscosity letting more of the wood structure show through. Figure 17 shows images of a speaker coil being carved from a layer of silver paint on wood. The image also shows the use of the two different carving tools that I had acquired.

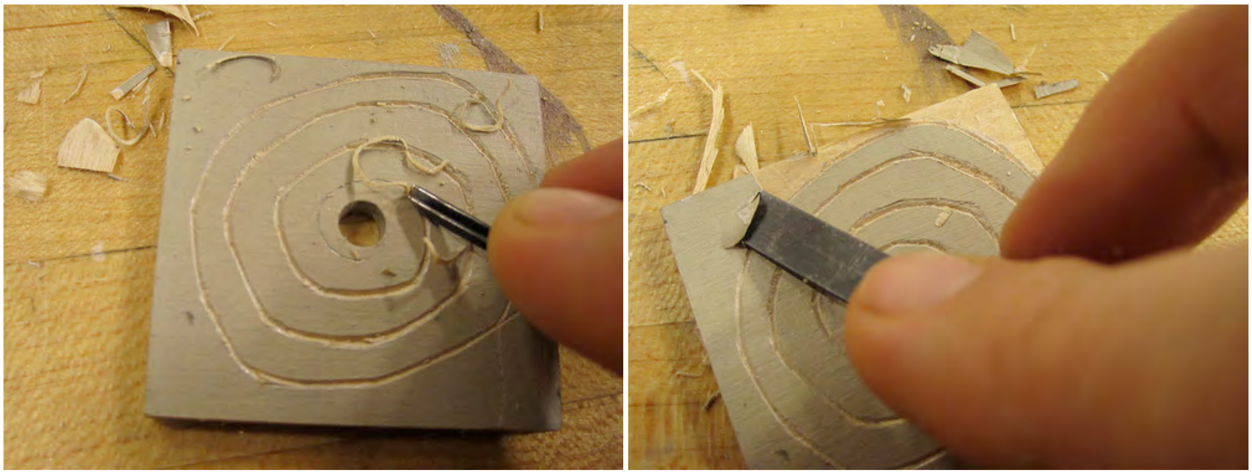


Figure 17. *Carving speaker coils using different tools.*

Before I go on to describe the next step in this sample process, I'd like to go back to the very first set of samples and note an observation that I made, that relates to why the one copper paint and latex sample on wood did not conduct.

When mixing conductive paints and powders with latex to be able to cast a conductor I tried a lot of different ratios and many of them were not conducting, but I discovered some interesting facts. The conductive materials were heavier than the latex and because the latex took time to cure, these would settle to the bottom of the mixture, creating an isolating latex layer on top but exposing conductivity on the bottom. My procedure for measuring conductivity was to poke the probes of the multimeter into the cured latex and check for continuity. I wasn't getting a reading on some of my samples, but at some point I realized what was happening. Figure 18 shows an upside-down (from the way it was cast) speaker coil that that is conductive underneath but not when measuring from above. The latex does an excellent job at isolating, even against pointy millimeter probes.

When a sample does not do what one expects of it, it is important not to give up on it too easily. Some of the steps I take to insure this is first to double-check and make sure the sample is what I thinks it is, especially if I was certain it would work. Without going back and re-doing the experiment, I check that I didn't accidentally use a wrong ingredient or miss-measure a ratio. Sometimes just thinking back over the process or looking at photos of the process helps jump my memory. Then I check that my test setup isn't faulty and try to think of another way to test the sample as well as testing it for other interesting properties, sometimes not the ones I was originally looking for. Getting to know the sample, developing a theory of why it isn't working, describing what properties it does have and spend some time thinking about what it might be good for are all helpful things to do in order to get the most out of this process.

Another example of a failed attempt related to my casting samples is of mixing latex with carbon paint. I first spread out a thin layer of latex and then with the tip of a toothpick dripped carbon paint/latex mixture into the uncured layer of latex. The result was not conductive at all, not even highly resistive or stretch sensitive. But what happened as the pure latex and carbon paint blend cured was that at the edges the carbon expanded into the latex forming very geometrical patterns. Although electrically uninteresting, they were extremely beautiful [Fig. 18].

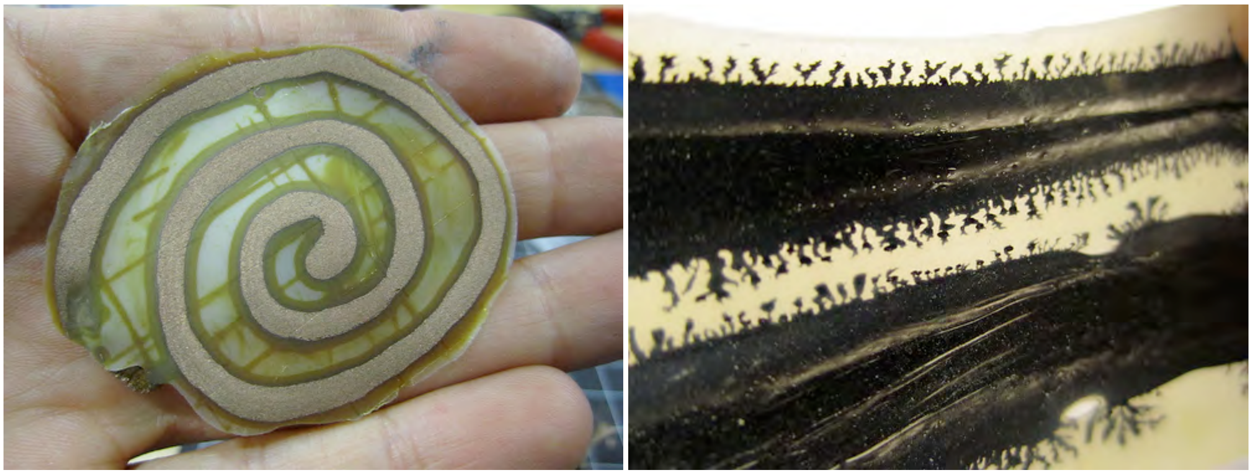


Figure 18. *Left: Example of a cast speaker coil from conductive copper paint and latex. The copper particles have sunk to the bottom (side shown) of the latex, creating an isolating layer on top and exposing them on the bottom. Right: Carbon paint mixed with latex and cast in uncured latex. Not conductive but the black carbon paint trickled out into the latex at the edges creating an interesting pattern.*

Back to carving wood. The next step in making samples was to find ways of connecting my carved traces to component leads. Since wood is stiff and will not bend or flex too easily or too much, a simple and immediate way of doing this was to superglue the components down to the wood and then paint additional conductive paint between the lead and the carved trace. If the wood were flexible and would bend at this joint, the paint would probably crack and the connection would not be reliable. When gluing the component down by its leads be careful not to coat the lead entirely in glue otherwise the glue encapsulates them in an isolating layer, intercepting the connection you are trying to make. The images in Figure 19 were taken with a USB microscope of the connections I just described, they also show the surface mount LED lights inset into the wood. This was done by carving out a small hole that could fit the LED before gluing it down. These painted connections were very reliable.

Another way of making the connection between the component lead and the carved trace was to push the leads of a through-hole component into the wood and again apply additional paint around the lead to connect it to the paint on the wood. This worked well if the wood was soft enough.

Now that I was able to carve connections and connect to connections, I wanted to be able to jump connections. I used some of my earlier samples to test different non-conductive materials as isolators for jumping carved traces. I tried acrylic paint, primer paint, wood glue, acrylic sealer and nail varnish. Two layers, with drying in between layers, of all of these samples worked fine. Pieces of masking tape or transparent tape also worked. I found nail varnish to be one of the most convenient because it dries fast and comes in many different colors including transparent which makes it almost invisible, especially if you coat the entire circuit in a protective sealant at the very end. The left image in Figure 20 shows an example of the nail varnish applied to the traces before jumping over them with an additional layer of conductive paint.

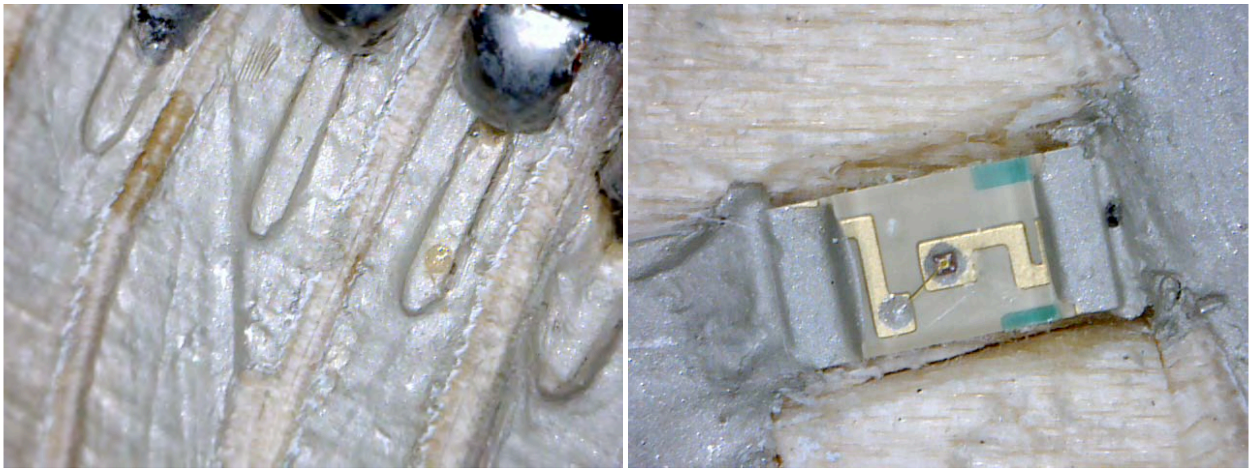


Figure 19. *Images taken with a USB microscope of the (left) the leads of a microcontroller and (right) a surface mount LED painted over with silver paint to make electrical connections to the rest of the circuit.*

In the next step of sample making I ran into a problem. I had successfully isolated my trace against the probes of my multimeter, but when I painted across the isolated trace with more conductive silver paint, my two traces, that should have been isolated from one another, were electrically connected. As far as I could tell it was not that the nail varnish was affected by the conductive paint and let it seep though, but rather at the very edges of the trace the nail varnish had not properly sealed it. The silver paint was extremely viscous and very conductive, it could get into even the smallest hole and even the smallest amount of paint could make a good electrical connection. I was able to solve this problem by re-doing my sample and being extra careful in applying the nail varnish and paying attention that it sealed over the edges of the carved trace and into the valley.

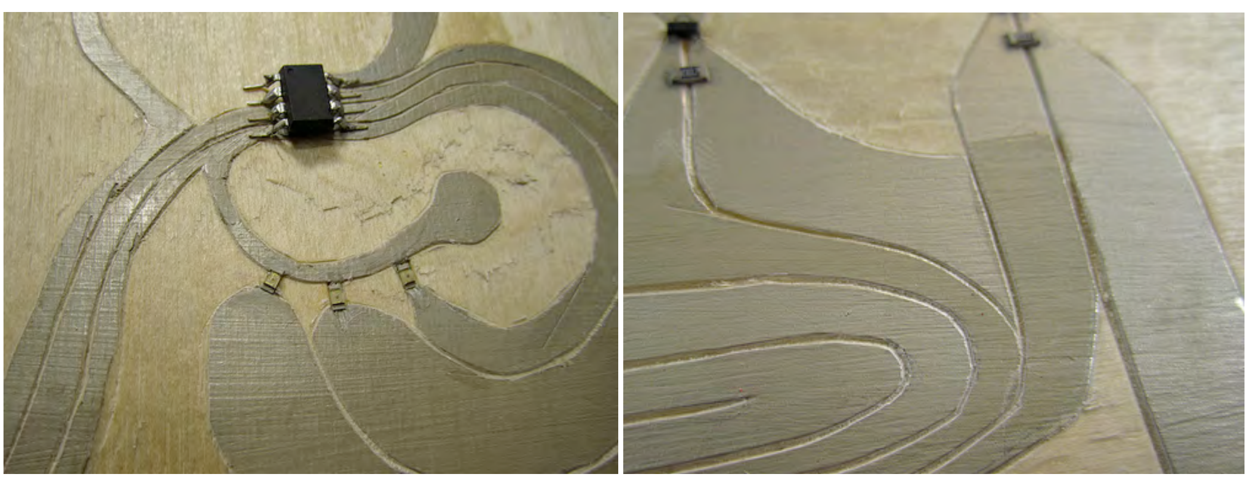


Figure 20. *Left: Carved wood circuit containing a microcontroller and three surface mount LED lights. Right: Carved wood circuit traces coated in two layers of nail varnish to isolate them.*

Before I continue to describe some the next samples in this process, I want to mention that I also tried out different ways of carving traces in wood. These included carving first and then saturating the carved trace with paint as seen in Figure 21. In this case I could submerge the component leads into the conductive paint while it was still wet to make the connections.

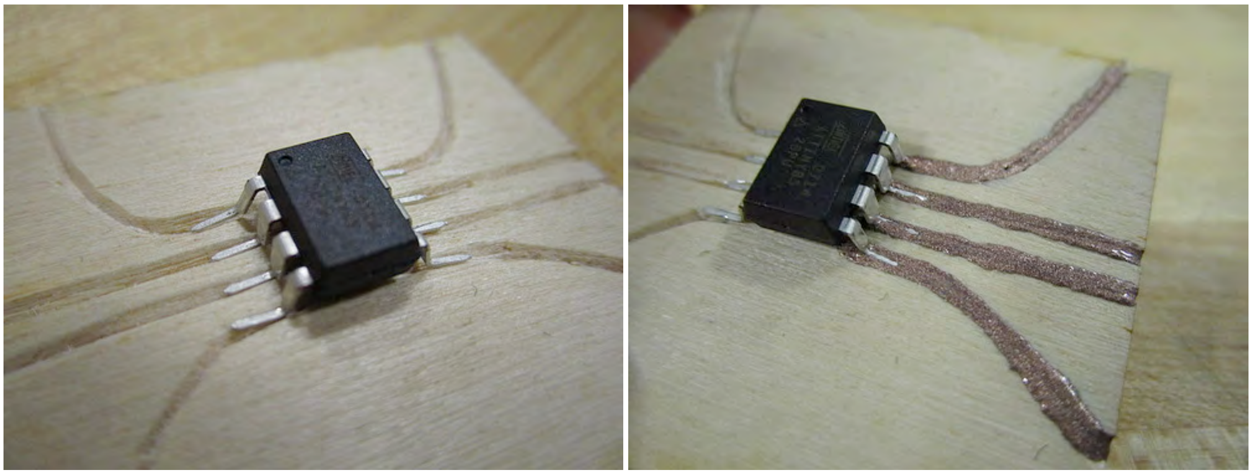


Figure 21. *Left: Carved traces for microcontroller leads. Right: Carved traces filled with copper paint.*

A variation on this technique used the lasercutter to engrave the traces instead of carving them by hand. Images of this can be seen in Figure 22.

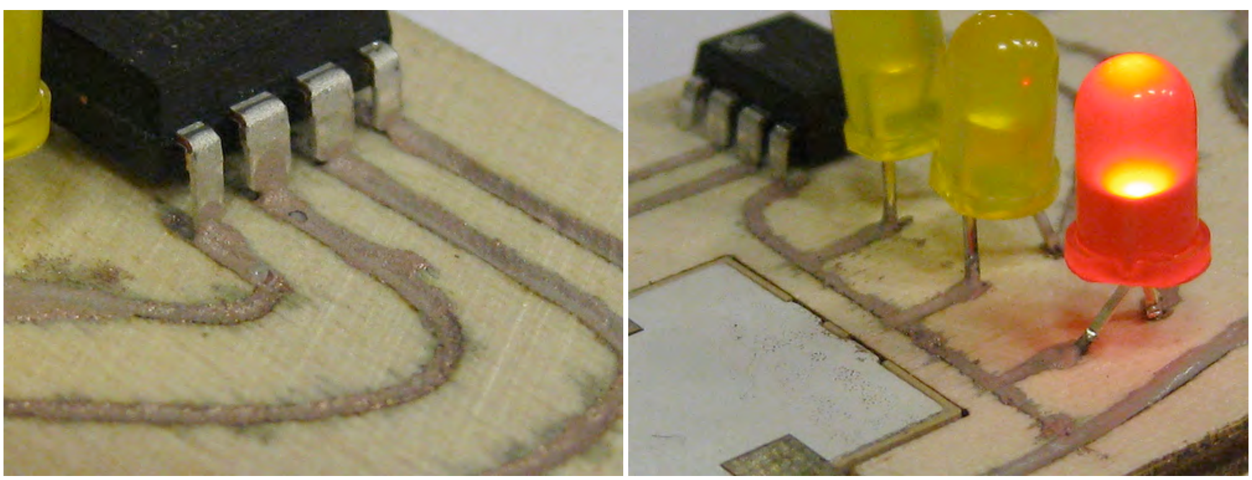


Figure 22. *Images of laser-engraved traces saturated with copper paint. Through-hole components have been pressed into the wood for electrical contact and stability. Left: Close-up of microcontroller. Right: Close-up of LEDs, speaker and microcontroller.*

The next step in the process was to begin thinking of elements that could be integrated and used in a circuit in meaningful and useful ways. I began lasercutting press-fit coin-cell holders like the one shown in Figure 23 and the dial switch that has a press-fit hole in it for a toothpick to fit as a peg around which it can rotate [Fig.23].

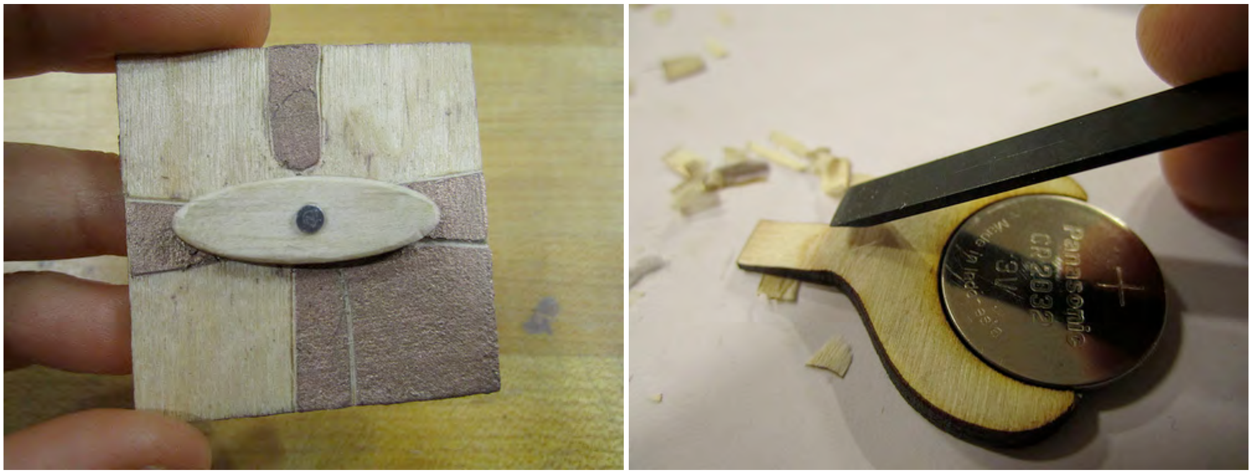


Figure 23. *Left: Carved dial with press-fit peg joint. Right: Lasercut press-fit coin-cell battery holder being carved to create a sloped surface.*

As well as another press-fit coin-cell holder made by screwing two small screws into the conductive paint [Fig.24].

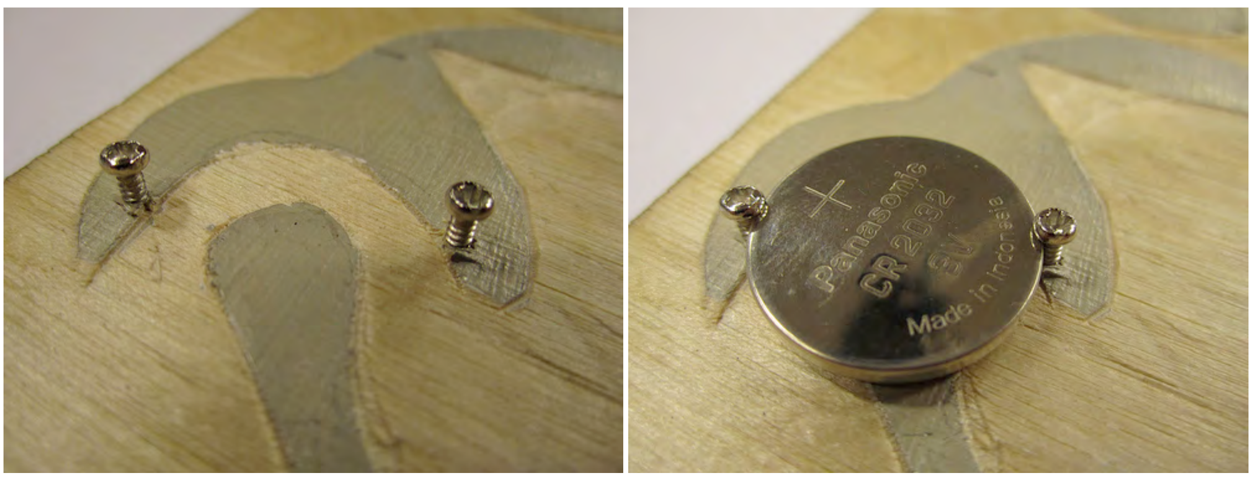


Figure 24. *Images of the metal screw press-fit battery holder without (left) and with (right) the coin-cell battery.*

I also tried carving painting and then plating wood successfully [Fig. 25]. The following images show some close-ups of a pair of headphones that I worked on. The structure of the headphones was lasercut out of plywood and the electrical connections were explicitly made visible as an integral part of the design.

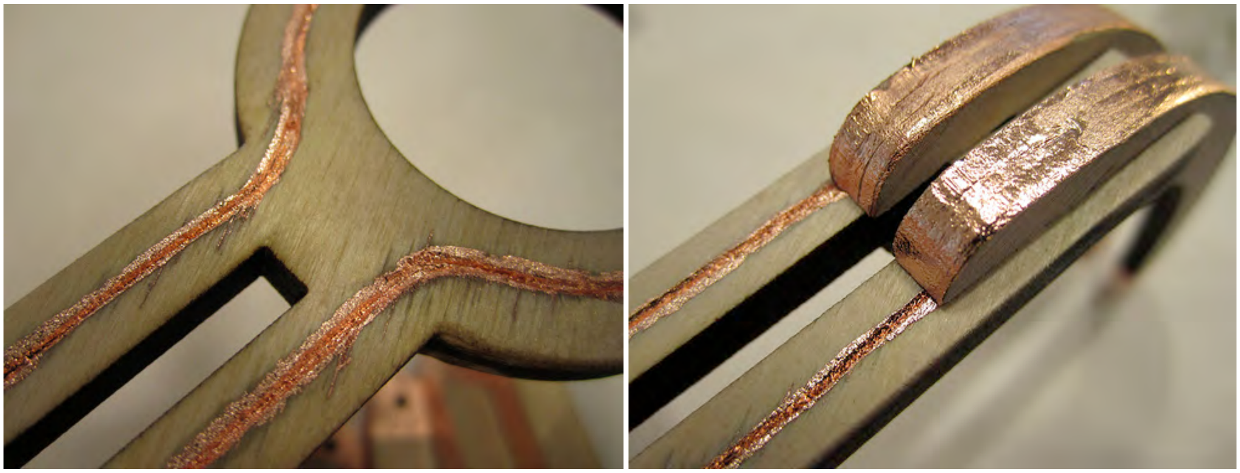


Figure 25. *Carved, painted and then electroplated copper traces in wood.*

In the end I was very pleased with this technique I developed for carving circuits and some basic circuit elements from wood. But, as I mentioned in the very beginning of this chapter, the process of experimenting and trying things out never really ends. If anything, it continuously spawns new ideas. Even writing about this process and recalling the details generated new ideas and thoughts on improvements.

The next chapter is about documenting recipes. Recipes are an opportunity for reflection as well as for refining techniques, through choosing how to convey them and what information to include.

Documenting Recipes

Figure 26. *Sketches of the craft techniques and electronics components as used on the website.*

In the previous two chapters I described the processes of sourcing supplies and making samples to refine good techniques and throughout these processes I documented everything I was doing. In this chapter I now describe the procedure of translating these processes and the documentation into recipes and publishing them on the website. Figure 26 shows sketches that I drew of the different craft techniques and electronic components that are featured in the variety of recipes on the website.

When writing up my work as recipes I try to convey two things. First, I try to include the breadth of documentation covering a specific technique and to include every related detail. Having thorough documentation makes it easier for me to insure that I'm not forgetting anything because I can use the documentation as a reference and guide to jog my own memory. Second, I want the recipes not only to describe how to do something right and get things to work, I also want to convey my experimental approach of sample making and material investigation. To achieve this I try to write very honestly and straightforward about *what* I did, *how* I did it and *why* I did it. I write equally about what worked and what didn't. To this end some recipes might feature more failures than successes. And some recipes might be just an initial idea that I have not yet set out to realize. It is important for me to emphasize this point that my recipes are different from what one usually expects a recipe to be. My recipes are not straightforward step-by-step instructions, they are documentation of the knowledge I acquired during my process and a means for me to convey my approach.

In thinking about how I formulate my recipes for others to read I was inspired by Richard Sennett's book chapter on "Expressive Instructions" [Sennett, 2009]. Sennett details three recipes on how to prepare a boned, stuffed chicken and points out differences in the instructions as they were written with the cook, the food and gastronomy in mind. Where the cook is the person following the instructions, the food are the ingredients or the materials and tools involved in the recipe, and gastronomy is the bigger picture. When writing my recipes I try to focus on all three points. I consider the cook in my writing by describing my own experiences, hoping to make it more accessible for others to relate to. I am thinking of the food when I include details and use analogies to explain how things feel and behave. Gastronomy for me is the bigger picture of sample making and I consider this throughout each recipe by constantly promoting an experimental approach where "just try it" is always an option.

To show the details and scope of my documentation I have included my recipe for sculpting and electroplating copper conductors. Figure 27 bellow shows screen-shots of this recipe as it appears on the Kit-of-No-parts website.

Figure 27. *Screenshots of the electroplating recipe as it appears on the website.*

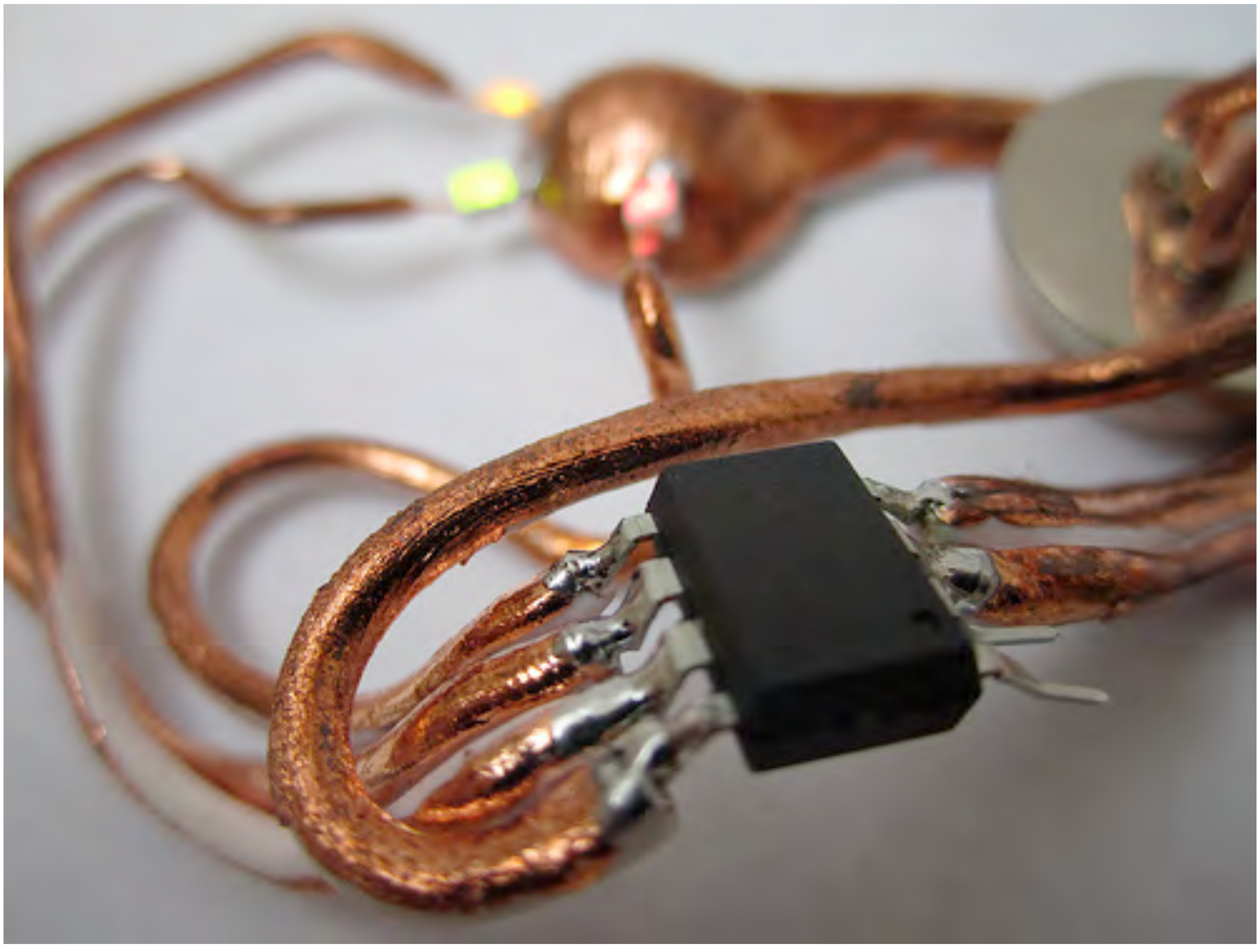


Figure 28. *Electroplated Fimo sculpted circuit with microcontroller, LED lights and coin-cell battery.*

Introduction

Electroplating is a technique for coating a conductive object in a thin layer of metal. It uses electrodepositing to transfer metal ions in a solution from one electrode to another, depositing a thin layer of metal on the conductive material attached to the negative electrode of your direct power supply. This technique is used in jewelry making to plate natural objects such as leaves, flowers and seashells. Once one gets the hang of it, electroplating is a very straightforward and relatively simple process. It took me some time to get a feeling for the process and all the materials involved, but now it allows me to sculpt three-dimensional circuits as well as include found objects such as seashells in my circuit designs.

This recipe describes the process of sculpting acrylic clay, firing it and then electroplating it with copper metal to form fully functioning circuit connections, create a magnetic battery holder, shape a skin resistive switch and embed some electronic components; in my case an Atmega ATtiny85 microcontroller and some LED lights [Fig. 28].

Materials and Tools

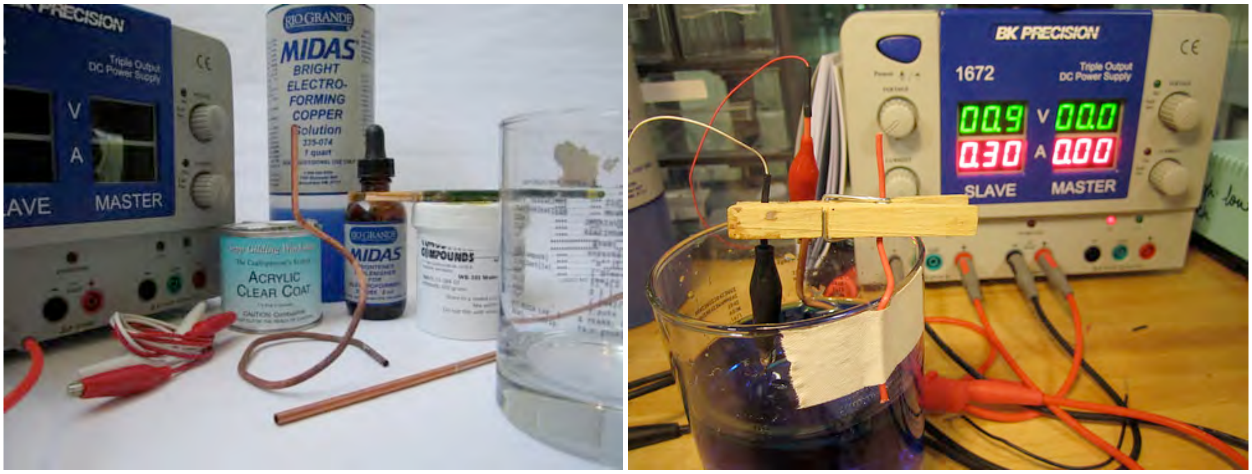


Figure 29. Left: *Electroplating supplies: Rectifier, copper sulfate, replenishing brightener, copper rods, silver paint, paint brush, glass container and alligator clips. Right: Snapshot of my electroplating setup.*

The materials and tools used in this process can be sourced from a combination of local craft, hardware and online shops. To begin electroplating and sculpting circuits you will need the following materials and tools, some of which are depicted in Figure 29.

- *A rectifier:* A direct power supply that allows you to control the amount of voltage and current you supply. Rectifiers cost from $100 upwards. Some models are sold specifically for plating and include Sherri Haab's E3 kit [Sherri Haab, w2011].
- *Copper sulfate:* Commonly sold as a root killer and can be purchased from local hardware stores. It can also be purchased through a variety of online electroplating supply stores such as Rio Grande.
- *Replenishing brightener:* Midas also sells a replenishing brightener solution can be added to the plating bath to maintain the bath's ability to produce a bright finish.
- *Some copper metal:* The positive lead from your DC power supply connects to a piece of copper metal that is submerged in the plating bath, this can be a solid piece of sheet copper or a rod that can be bent in a spiral to fit the shape of your plating container.
- *A container:* Depending on the shape and size of the objects you plan to plate you'll want to select a container for plating in. This container should be of a material that will not contaminate the solution, nor be affected by the solution's corrosive properties. Transparent glass containers work well since they also allow you to better see the object you are plating.
- *Alligator clips:* You will need alligator clips or similar to connect from the leads of your power supply to the copper rod as well as to the object you are plating.
- *Conductive paint:* some other recipes I read said that they were plating objects coated in carbon paint but I could not get it to work well for me. Silver paint is not as cheap as carbon, but the water-based silver paint WB-101 from Conductive Compounds worked best for me.
- *Some Fimo: or another kind of* polymer clay.
- *An oven:* a toaster oven will work too.
- *Some electronics components:* to include in your circuit.

Sculpting your Circuit

For sculpting you circuitry you can choose from a variety of polymer clays and their firing or hardening methods. The following steps describe in detail the process of molding Fimo, an acrylic clay that can be fired at a low temperature in an oven or toaster oven for half an hour. Benefits of the low firing temperature are that you can fire your sculpted circuit containing certain electronics components without destroying the electronics, and also it cools quickly and you can continue to work with it as soon as it has cooled down. After firing, the clay is firm, yet flexible and can withstand the etching properties of the plating bath. Other, more porous clays need to be sealed before plating them if their substance is affected either by liquid or the acid of the plating bath. For shaping your circuitry you might also like to keep a selection of common sculpting tools at hand, such as ribs, needles, knives and rolling pins as well as a surface to working on.

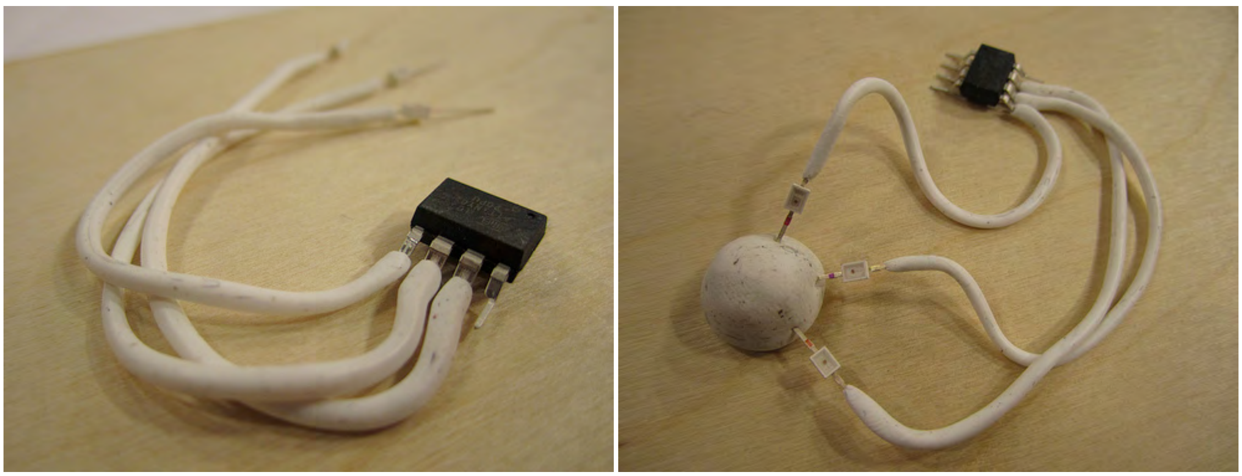
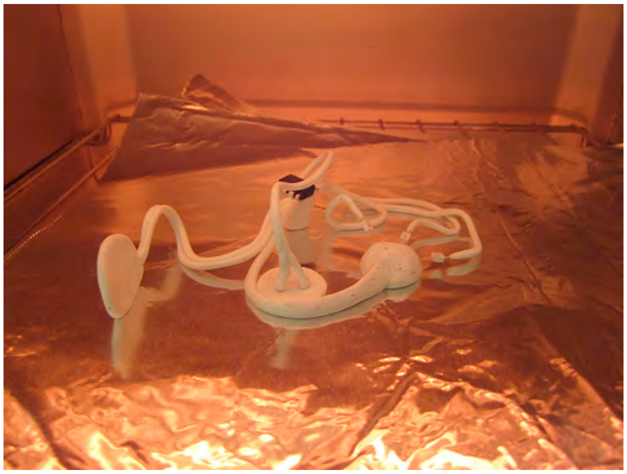


Figure 30. *Left: Microcontroller with legs bent outwards and pressed into the long pieces of acrylic clay. Right: Addition of three LED lights that all connect to the same ball that will be the ground connection.*

To begin sculpting the Fimo start by rolling and kneading your clay in your hands, warming it up to make it more workable. As you shape the material you can incorporate various electronics as you go [Fig. 30]. You can do this by sculpting clay around them or by pressing them into the clay. As you work the clay into it's final form you need to plan where the connections between your electronics will run so that they match the connections in your circuit diagram.

Firing

When your Fimo sculpture is finished it can be fired in your oven or even in a toaster oven [Fig. 31]. Check the packaging for precise instructions on what temperature and for how long you should fire your piece. The Fimo that I used could be fired at 110°C for 30 minutes, at this temperature you can fire most electronics with the clay and not damage them. Fimo softens as it heats up in the firing process and this might affect the structure of your piece. Depending on what you have sculpted you might need to create some support structures out of toothpicks or similar materials that can withstand the heat of the firing process. Right after firing the Fimo is hot and still soft, leave it to cool before proceeding.



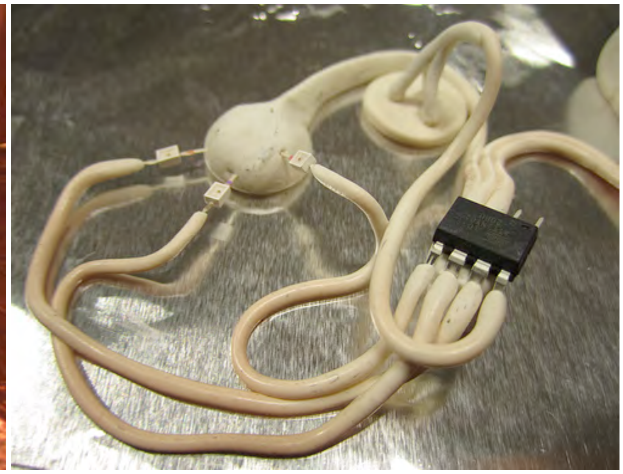


Figure 31. *Left: Fimo sculpture in toaster oven. Right: Fimo sculpture after being fired.*

Applying Conductive Paint

The copper sulfate plating bath is also an etchant. If the object you want to plate is of a material that might be affected by the etching properties then you first want to seal it with a layer of varnish. For this you can use a whole range of products, for smaller objects one of the most convenient options is to use nail varnish, since it also dries relatively quickly.

In order for the copper to selectively plate to areas that you would like it to, you first need to make the surface of your object electrically conductive in these areas. While there are a variety of different conductive paints that can be applied to various surfaces, I had the most success using a water based silver paint WB-101 from Conductive Compounds [Conductive Compounds, w2011]. You can thin the paint with water and with a paintbrush apply a single layer to the areas of the object you wish to plate [Fig. 32]. Paint selectively, but keep in mind that when you go on to plate these areas, if they are not interconnected then you need to connect separately to each of them.

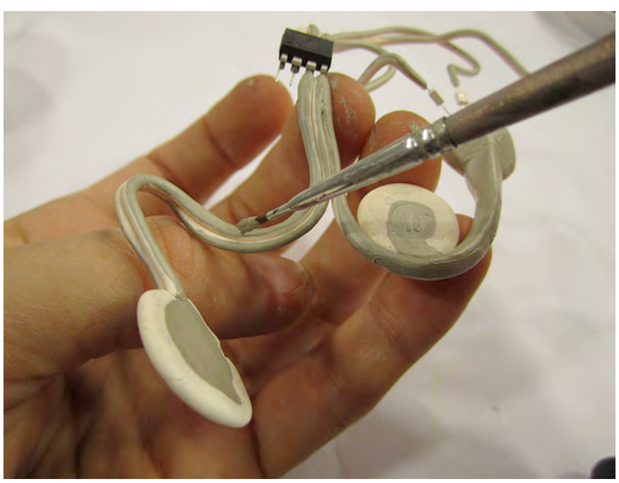


Figure 32. *Left: Applying silver paint with paintbrush. Right: Disassembled circuit.*

There are some things you can do to get around having to make multiple connections or to plate each separate conductive area one at a time. One solution is to have all your conductors meet in an area that you can later cut away or remove. A trick for this shown in Figure 44 is to use a piece of copper tape that you can stick to the surface of the object and have the conductive paint connect to it by painting on top of it. After the plating is done you can score the copper metal buildup around the tape and then peel it off. Another variation of this approach is shown in Figure 33, where a wire has been superglued to the seashell and then silver paint has been painted on top of it. Be careful not to completely coat the wire in superglue, otherwise you create an isolating layer and the wire and the paint will not be electrically connected.

Another solution is to use multiple alligator clips to interconnect all your separate conductors to the cathode of your rectifier. Beware that alligator clips and any other metal items that get in contact with the plating solution will corrode over time unless you rinse and dry them after use.

Figure 33. *Left: Seashell with silver paint and wire super glued to surface as a point of connection. Right: Seashells that were accidentally left in plating solution over night. The shells were etched by the solution but protected where the conductive paint had been applied.*

The following images in Figure 34 show a seashell coated in carbon paint. The plating attempts were less successful than with the silver paint. While in the image on the left the homemade plating bath did not achieve a nice layer of copper, it did coat almost the entire shell. In the image on the right the shell only plated close to where the alligators clips were attached, even after being left in the plating bath for longer periods of time. Most likely the copper paint that I was using had too high a resistance.

Figure 34. *Plating using black carbon paint instead of silver. I did not have much luck with this. Left: Carbon painted seashell in homemade plating bath would only plate at higher voltage and copper buildup would happen fast, be contaminated and wash away. Right: Same shell after rinsing plated in commercial plating solution worked better but copper buildup would only happen in select areas, even when left in for longer periods, up to half an hour.*

Plating Bath

You want your plating bath to be in a container suitable to the size of the object you are plating as well as the piece of copper metal that will be your anode in the plating process. If you are using a rod then you can bend it in the shape of your container so that it surrounds the object you are plating as shown in Figure 36.

When I first started electroplating I was set on making my own plating bath. I had read on various online tutorials that it is possible to create the plating solution yourself. When etching copper fabric in salt and vinegar the solution turns green and crystallizes as it is left to dry. I had been saving these crystals because they are poisonous and should not be poured down the drain. Reading up on copper sulfate it sounded like these crystals were a form of copper sulfate that I could dilute in water to make a plating bath. The images in Figure 35 show my attempt at diluting the crystals and plating a coin. This was not successful, though I am not sure of the exact reasons, I suspect is might have to do with the purity of the solution.

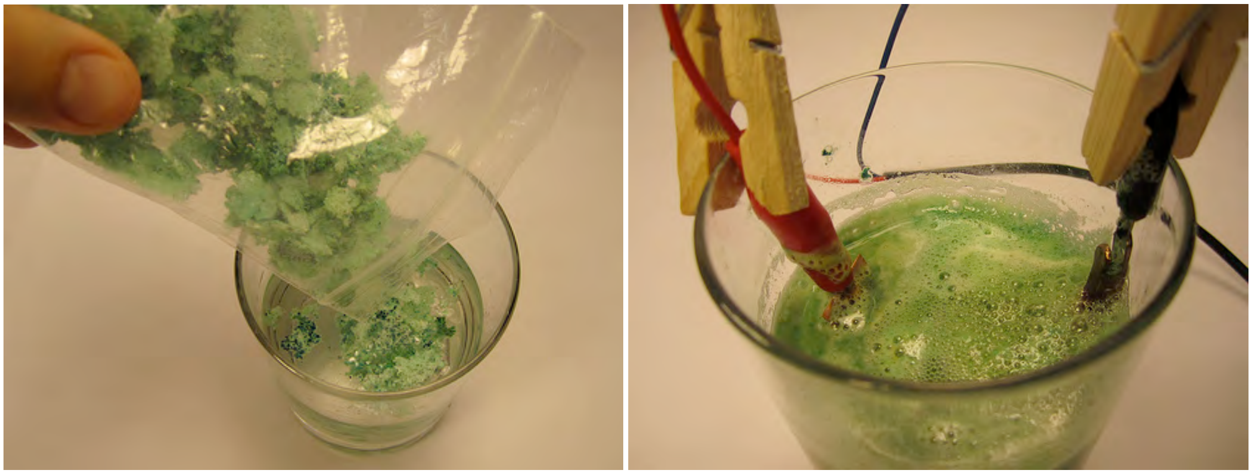


Figure 35. *Preparing my own plating bath from the crystallized remains from etching copper fabric in salt and vinegar.*

The second homemade solution I tried making was to dissolve citric acid in distilled water. After noticing that it did not work [Fig. 36, left], I ran low voltage across two copper electrodes for awhile until the solution turned turquoise.

Figure 36. *Left: Preparing my own etching solution from salt and vinegar. After some time the solution begins to turn light blue. Right: My own etching bath prepared by dissolving citric acid in distilled water. After awhile the solution turns blue, as the picture shows.*

I proceeded to plate in this turquoise bath and my attempts were finally somewhat successful. The problem was that the copper buildup was very rough and looked like it was rusting as it was plating as seen in Figure 37. Whatever copper buildup I achieved would wash away under running water.

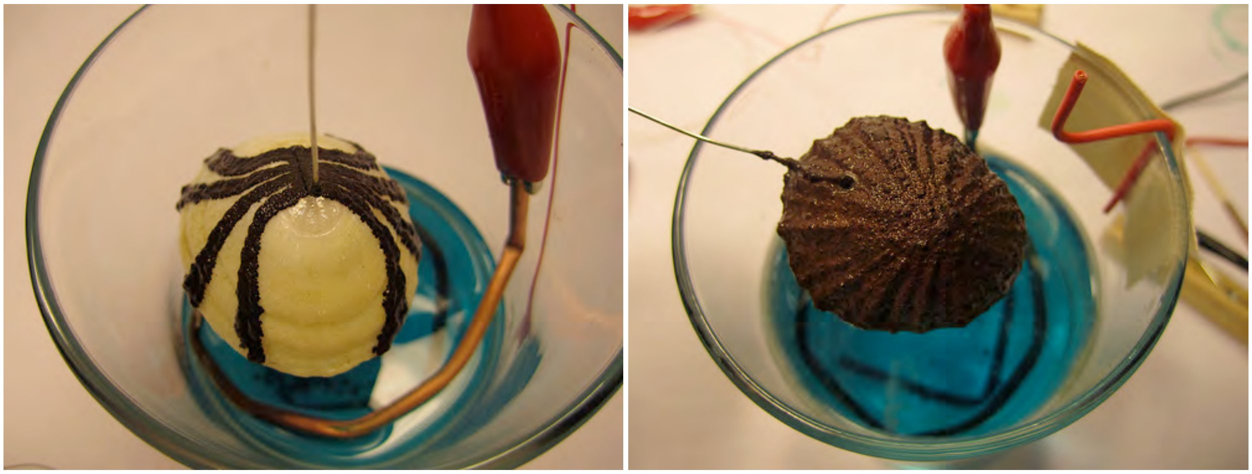


Figure 37. *Images of plating process in a homemade plating bath. The copper buildup looks rough and rusty and rinsed off with water.*

After all these unsuccessful attempts at creating my own plating solution I finally ordered some professional Midas copper sulfate jewelry plating solution from Rio Grande [Rio Grande, w2011] as well as a bottle of replenishing brightener and these worked wonderfully. The following procedures were all done with this commercial plating solution.

Power Settings and Connections

Set your rectifier to supply a very low voltage, less than 1 Volt and do not limit the current. Connect the copper metal (Anode) to the positive pole of your rectifier. And the object you are plating (Cathode) to the negative pole of your power supply. If you look up the copper plating process online [Sherri Haab, w2011] you will find lots of illustrations that indicate what to connect to what as well as what exactly is happening with the copper electrodes in the plating bath.

Submerge the object completely in the plating bath and make sure the areas coated in silver paint do not touch the copper anode. When the plating process begins it will draw current and if your rectifier has a display then you can watch the amount of current it draws increase. Check the object within the first minute to ensure it is plating, if all is going well then you should see a tint of copper forming on top of the silver paint as shown in Figure 38, right.

Continue to plate the object until you're satisfied with the copper layer. This might take anywhere from a few minutes to much longer, depending on the size and conductive surface area of your object. If the copper does not look shiny, you can add a few drops of the brightener solution to the bath.

Figure 38. *Left: painting seashell with conductive silver paint. Right: Seashell during plating process. After the first few seconds you can already see a fine buildup of copper.*

When the plating is complete, remove the object and rinse thoroughly with water to remove all of the copper sulfate solution. Copper sulfate is poisonous so make sure not to get it in your mouth or in contact with any utensils that you use for food!

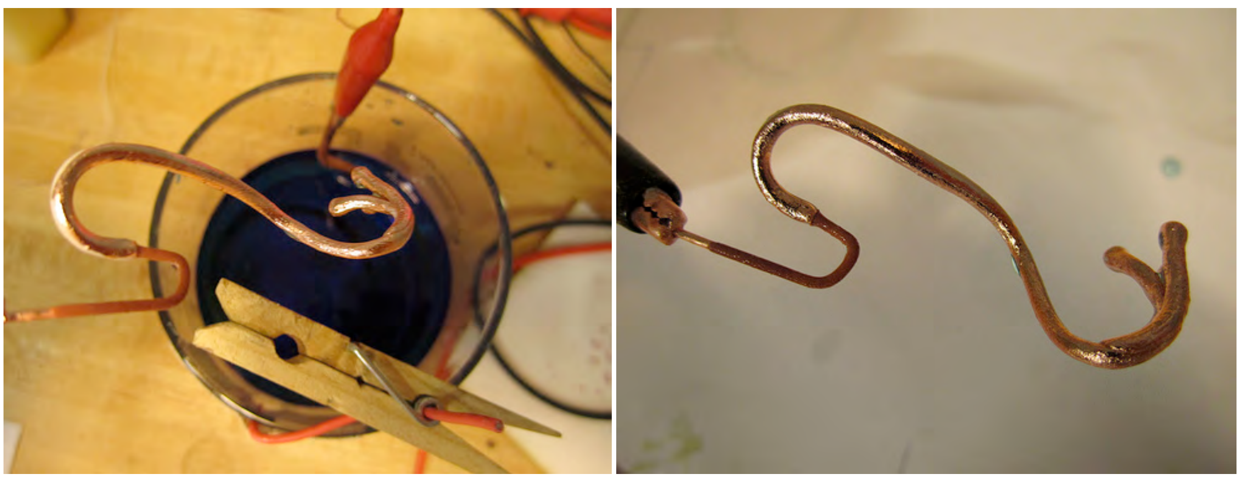


Figure 39. *Left: Removing plated object from bath. Right: Rinsing after removing from plating bath to remove copper sulfate solution.*

Re-Assembling the Circuit

You can begin to reassemble the plated pieces of your circuit [Fig. 40]. The great thing about plating is that you build up a layer of copper metal that you can then solder to, creating extremely robust connections.

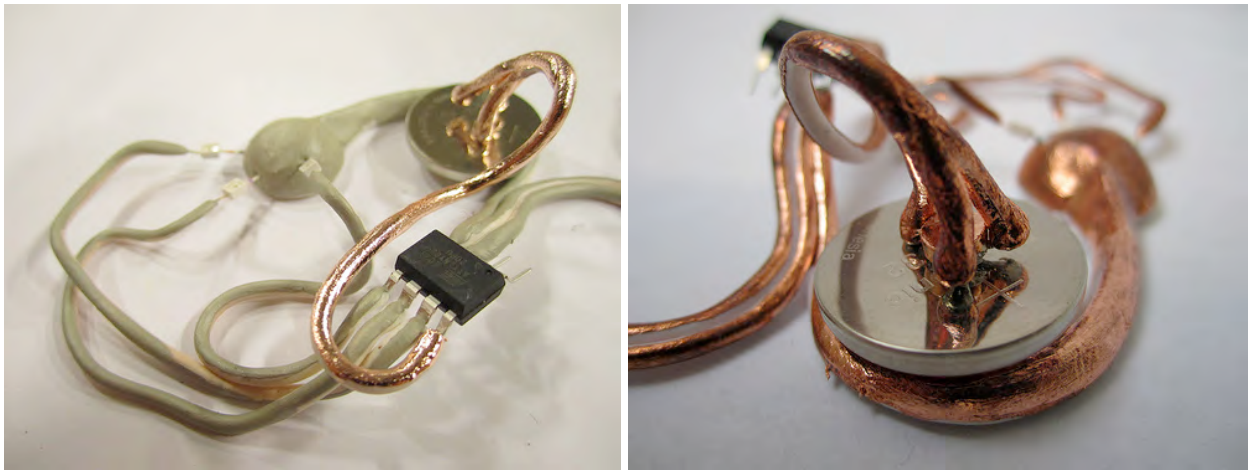


Figure 40. *Left: Partially plated and assembled circuit. Right: Close-up of the magnetic battery holder.*

Figure 41 shows close up images taken with a USB microscope. While the connections to the microcontroller were soldered, the connections to the LED lights were painted and then plated. You can see how to the right side of the LED the plated copper seamlessly covers the Fimo as well as the right led of the LED.

Figure 41. *USB microscope images of the soldered and plated connections.*

The Final Result

The following Figures 42 and 43 show images of the final plated circuit.

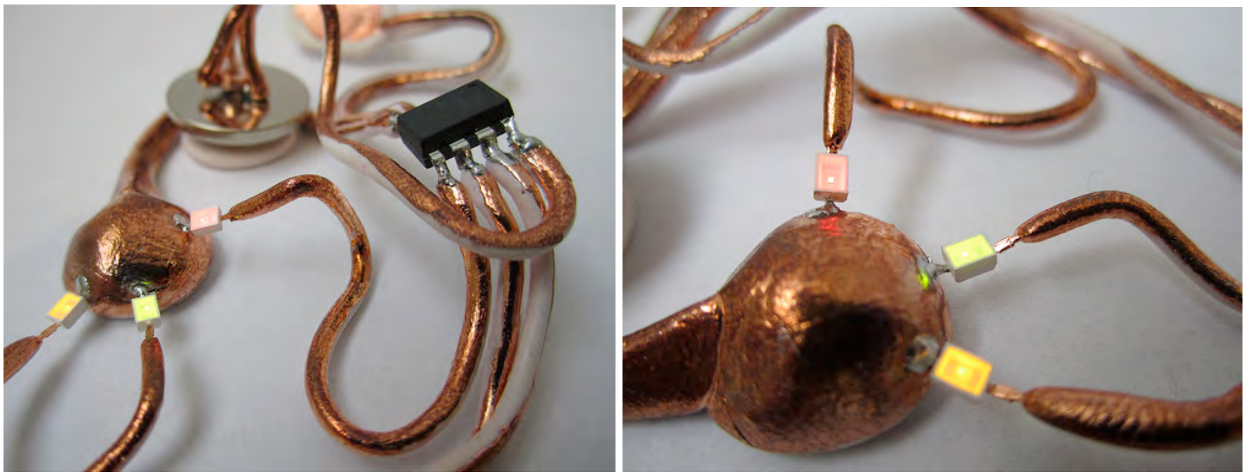


Figure 42. *Images of the finished copper plated circuit with the three different colored LED lights lit-up.*

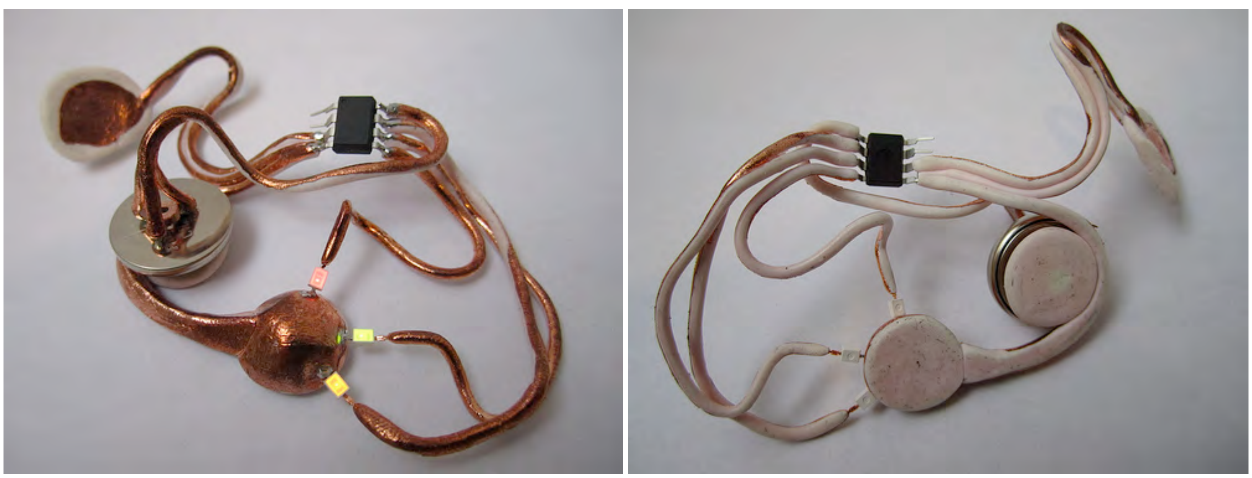


Figure 43. *Images of the front (left) and back (right) of the copper plated circuit.*

Comments and Reflections

Besides sculpting and plating acrylic clay you can also plate a variety of other objects. Including seashells, and even flexible and porous materials such as paper and fabric [Fig. 44,45]. When plating on slick surfaces copper traces will easily come off the surface. Though I have not done this (yet), you could use this feature to cast circuit elements off of existing structures. A process in which the electroplated metal is self-supporting and can be removed for the base structure is called electroforming.

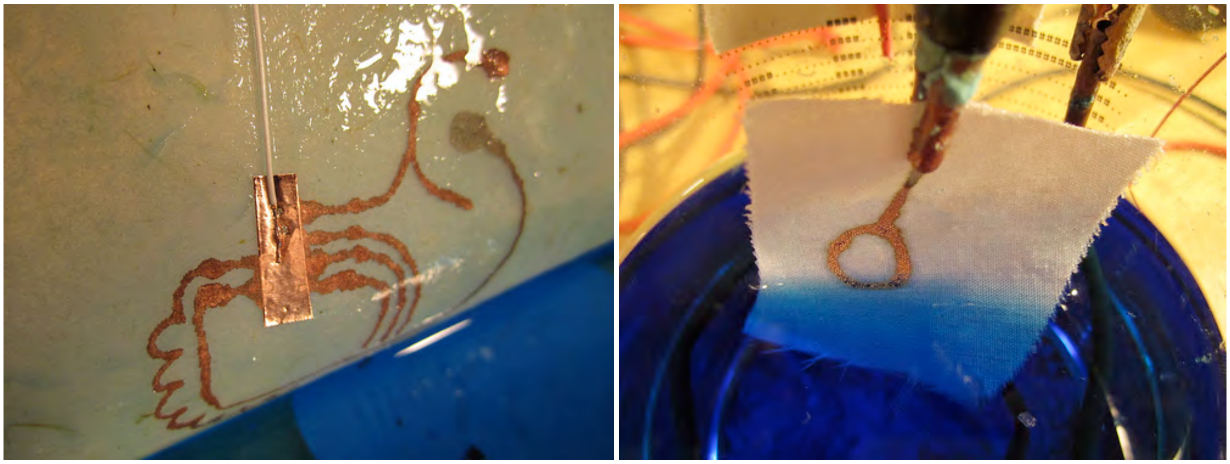


Figure 44. *Other, flexible materials you can plate: paper and fabric. Even though plating instructions recommend that you seal porous materials before submerging them in the plating bath to prevent the etching properties of the bath to affect the object, I successfully plated paper and fabric. After plating rinse the materials with clean water to get rid of all the copper sulfate.*

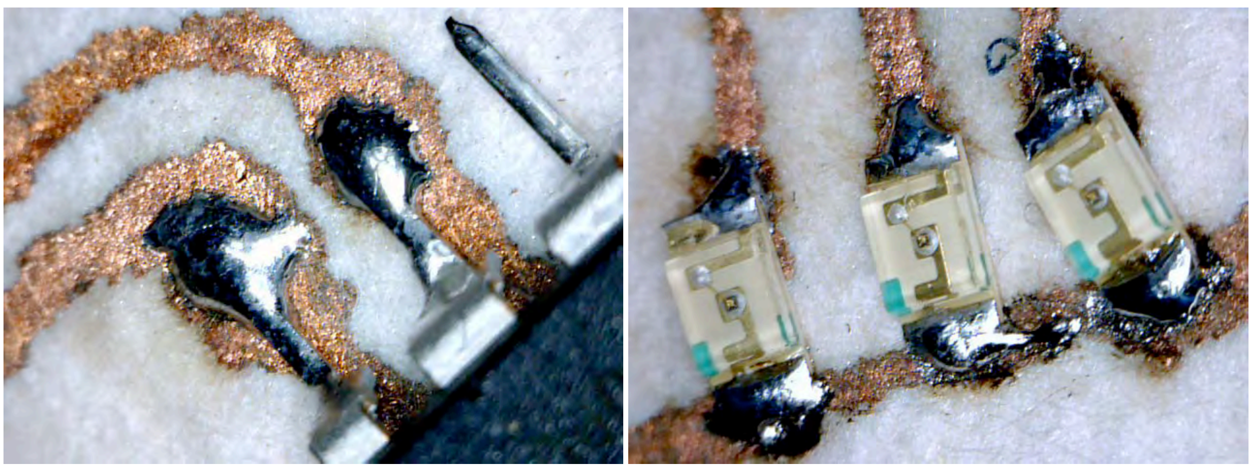


Figure 45. *USB microscope images of the copper plated paper. Left: Legs of a microcontroller soldered to the copper. Right: Surface mount LEDs soldered to the copper traces.*

Links

In learning how to successfully plate copper circuits I found Sherri Haab's tutorials extremely helpful. Sherri Haab is a jewelry making instructor and also develops her own techniques and equipment that she shares with others. Her website [Sherri Haab, w2011] contains, among other things, extensive and well-prepared PDFs on how to plate natural materials for jewelry. She also sells kits and supplies that include her own electroplating regulated direct power supply.

The publication "Jewelry: Concepts and Technology" by Oppi Untracht [Untracht, 1982] contains detailed information about all the materials and tools involved in electroplating. You can view parts of the books online through Google books.

The Website

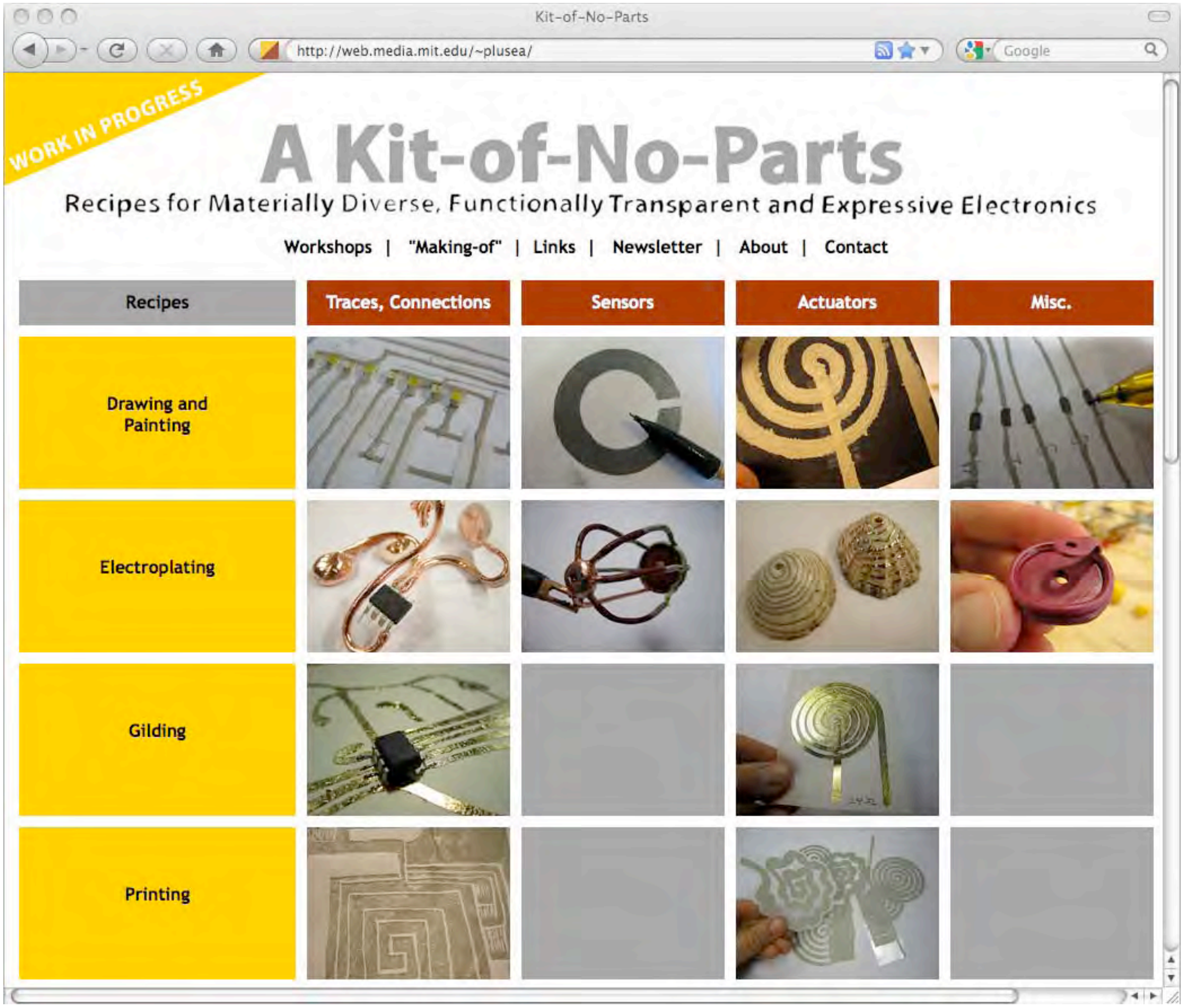


Figure 46a. *Kit-of-No-Parts website front page displaying select recipes in a grid organized by electronics and crafts.*

In this chapter I introduce how the website [A Kit-of-No-Parts, w2011] came to be and explain its current structure and contents. I will also detail some of the more technical aspects. Figure 46a shows a screenshot of the website's front page that displays select recipes listed in a grid organized by electronics (columns) and craft techniques (rows).

The website went online early on in the processes of making samples and documenting recipes. It was intended as a database that could grow and expend alongside the process. It also offered me a way to visually organize my thoughts to help me structure my approach. It is the place where I would compile notes, post results and share techniques.

The structure of the website developed over time but was always based on the initial categorizations I chose when mapping the space I used to generate ideas. The current selection of categories is based on the kinds of techniques and resulting recipes I ended up developing and documenting. Whereas in the beginning I had three categories that were electronics, materials and processes, I ultimately narrowed this down to two main categories: electronics components and craft techniques. I wanted it to be an easy and intuitive structure to navigate and to accommodate the content I had created and was continuing to create. While I feel that the current structure lacks some of the potential that less conventional categorizations might offer, I have also become used to it and find it convenient for my own purposes.

The recipes on the website are organized as individual posts. These can be browsed by two main categories, Crafts and Electronics. Within each of these categories are the following subcategories. *Craft:* Additive - drawing and painting, gilding, plating; Subtractive -carving, etching, cutting and engraving; Deforming - molding and casting and sculpting. And *Electronics:* Traces and connections, resistors, sensors, actuators, capacitors and power options.

Figure 46b shows screenshots of the website listing recipes in the electronics category "Traces and Connections" (left) and in the craft technique category "Molding and Casting" (right). The website also features categories for "Ingredients" [Fig. 46c], "Equipment" and "Examples".

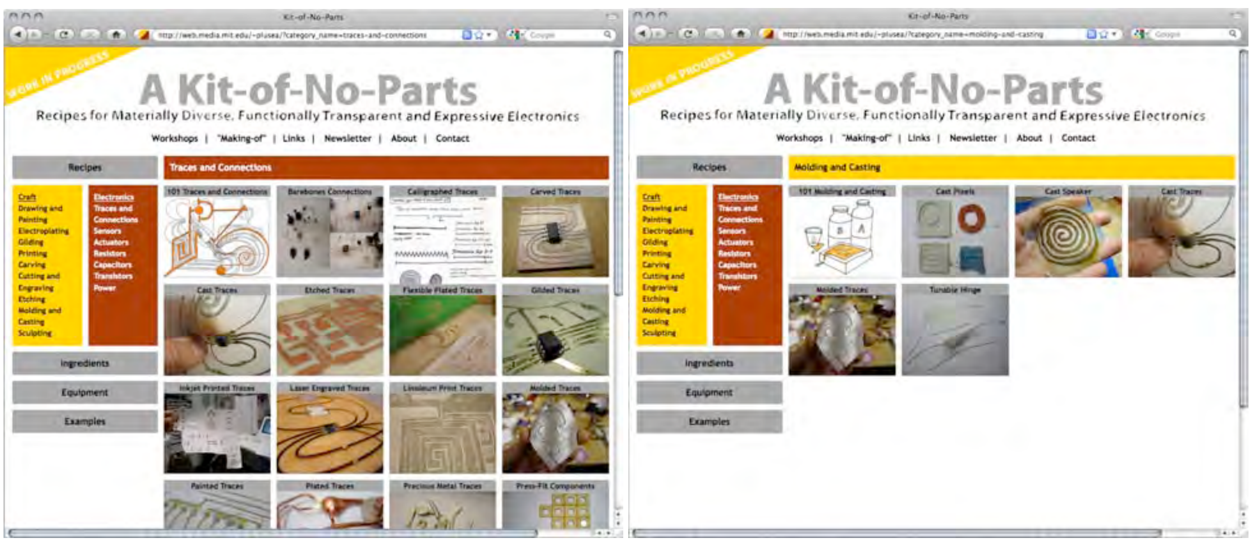


Figure 46b. *Kit-of-No-Parts website. Left: Listing all recipes in the "Traces and Connections" category. Right: Website showing all recipes listed in the "Molding and Casting" category.*

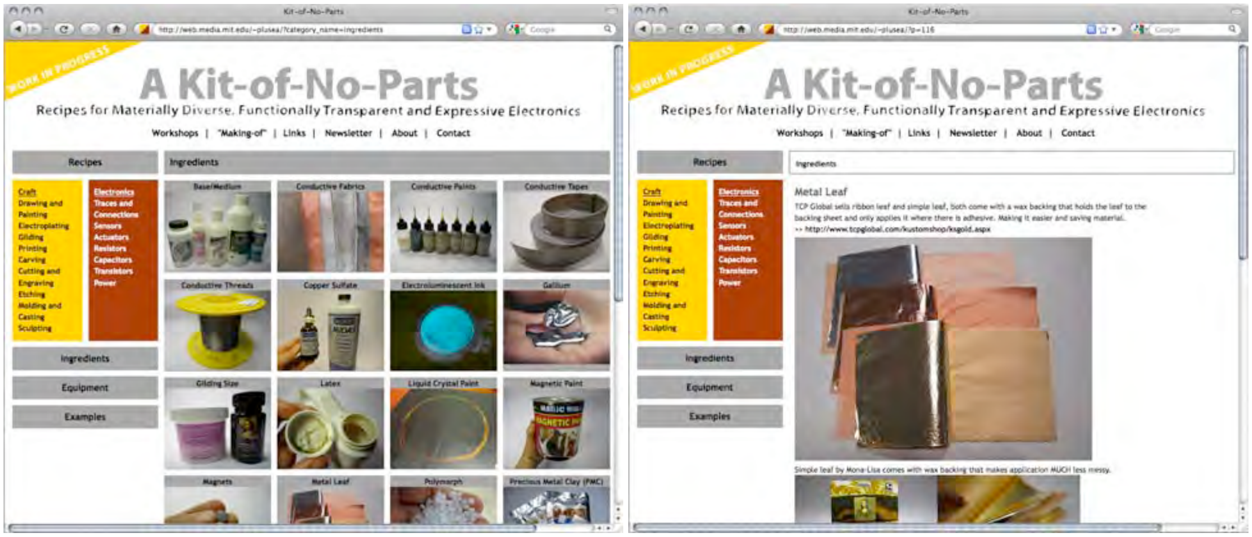


Figure 46c. *Kit-of-No-Parts website. Left: Listing "Ingredients". Right: Showing the listing for "Metal Leaf".*

The website was built using Wordpress [Wordpress, w2011], a free and open source software for creating blogs and websites that uses a MySql database structure. The site is currently hosted on my MIT student server space with the URL: "http://web.media.mit.edu/~plusea/" it can also be accessed through the domain: "www.kit-of-no-parts.at".

COLLECTION OF EXAMPLES

Figure 47. *Collection of Examples mounted on a wall. They represent the techniques developed in building a Kit-of-No-Parts.*

The examples that I introduce in this section were designed to each represent one of the different techniques I developed. When viewed together they function as a sort of library or an exhibition of the circuits, materials and techniques representing the Kit-of-No-Parts approach [Fig. 47]. Besides showcasing materials and techniques each example also demonstrates the possibilities of this approach.

Some of the examples are interactive, others are intentionally left incomplete and some unfortunately do not work. Videos of each of the examples can be viewed in the examples section on the Kit-of-No-Parts website [Kit-of-No-Parts, w2011]. The interactive examples include a microcontroller that runs a very basic program. When the, in most cases spiral, contact between ground and input is touched, the microcontroller toggles between three LEDs that are connected to its outputs. The touch sensing is done through a set threshold based on skin-resistance.

Carved Pixels

This example demonstrates how thermochromic paints can be used to paint colorful displays that are actuated through an underlying carved circuit [Fig. 48]. A dial in the center of the pixels directs the current to different parts of the circuit, revealing the carved pixels one by one.

The plywood on which the circuit was created was first coated with primer and then sanded down to create a smooth and less absorbent surface. An even layer of silver paint was applied to this surface and left to dry. The circuit was first sketched out in pencil and then carved out using the narrow headed carving tool depicted in Figure 17, left. After carving the circuit, stripes of thermochromic paint were painted on top in an attempt to defer from the maze-like design of the carved traces. Different colors of thermochromic paint and pigment were mixed with a range of colors of acrylic paint to create a variety of colors. The thermochromic colors become transparent when heated and reveal the regular acrylic paint colors they were mixed with. Different color thermochromic pigments react at different temperatures causing an uneven visual effect. In the center a wooden dial with a conductive underside connects one side of the battery to different parts of the circuit, depending on the direction it is pointing. The part of the circuit underneath the tip of the dial begins to heat up because the 9V battery is shorted across the conductive paint.

Figure 48. *Thermochromic Pixels. Left: Photo of full example. Right: Close-up of dial pointing in the direction that the current is being directed. The path of the current causes the thermochromic paint to heat up and change color.*

Carved Traces

This circuit has been carved out of plywood and silver paint [Fig. 49]. When you touch the spiral to the bottom left of the square the LED lights toggle on and off, one by one.

The plywood base was sanded down to smooth the surface but no filler was applied in order to maintain as much of the wood's natural surface structure as possible. Then a coat of silver paint was applied and let dry. The microcontroller, LED lights and coin-cell battery were laid out on the conductive surface and, with pencil, the circuit connections were sketched out. When the design was ready the excess silver paint was carved away using a narrow carving tool to make the narrow lines and a flat tool to remove larger areas as shown in Figure 49. Small grooves were carved out for the tiny surface mount LEDs to recede into.

Once the circuit was carved, the components were super glued to the surface and additional silver paint was applied with a small tipped brush to bridge the connections between the painted wood traces and the component leads. Details of these painted contacts can be seen in Figure 19. The coin-cell battery holder was made by screwing two small screws into the wood, penetrating through the silver paint that connects them to the positive lead of the circuit. The screws are spaced so that the battery press-fits between them. Details of this battery holder can be see in Figure 24.

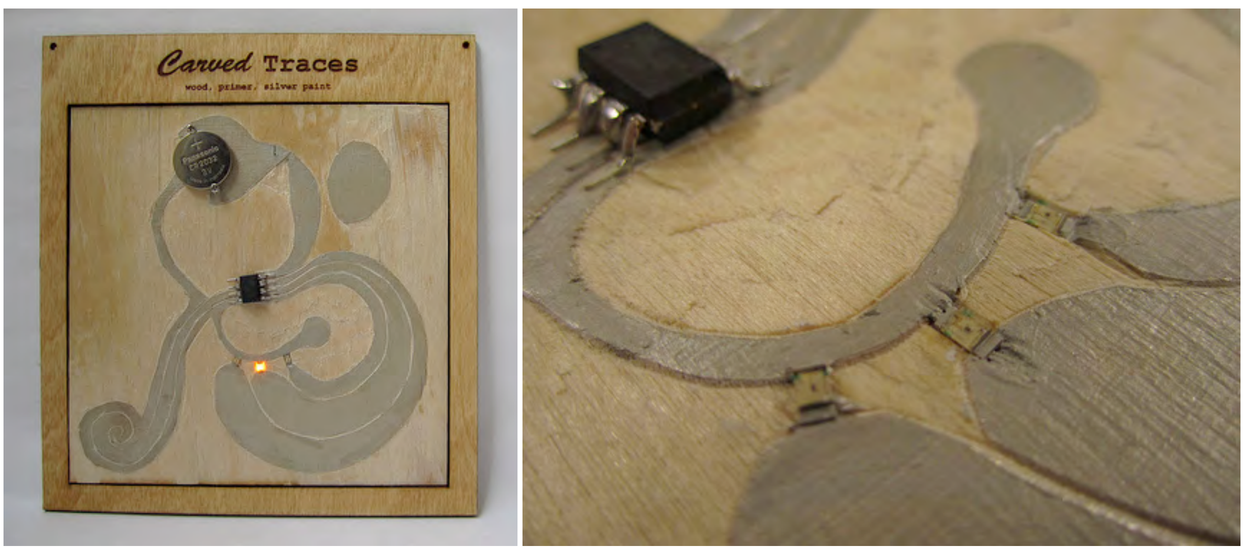


Figure 49. *Carved Traces. Left: Example. Right: Close-up of microcontroller and LED lights in their carved out groves.*

Cast Traces

The circuitry in this example is cast from a silver paint and latex blend that, unfortunately does not conduct electricity [50]. But never the less, this example demonstrates the possibilities of cast stretchy conductors.

First a thin layer of latex was spread out on a piece of acrylic and left to cure. Once cured, the microcontroller, LED lights and battery were all placed on top of this surface. Silver paint mixed in a 3:1 ratio with latex was then applied through the tip of a squeeze bottle to create the connections seen in Figure 50. Finally, additional latex was used to coat the components and keep them in place.

Unfortunately this example does not work. In all my molding and casting attempts I was not yet able to achieve a good conductor to latex mix that maintains the stretchy properties of the latex as well as the conductive properties of the conductor be it a powder, paint or fiber. I was able to cast conductors that had high resistances (in the Kilo Ohm range) but these could not be stretched, otherwise the conductive contacts would be broken.

Figure 50. *Cast Traces. Left: Example. Right: Close-up of microcontroller, demonstrating the stretchiness and flexibility of this circuit.*

Etched Traces

This example demonstrates the process of selectively etching copper fabric to create conductive fabric circuits [Fig. 51]. The components for this circuit have not been attached to the fabric in an attempt to draw attention to the delicate and aesthetic properties that can result from this technique.

To etch this circuit, first a mask was cut from masking tape and transferred to a square of copper rip-stop fabric. Vaseline was applied to the cutouts of the stencil and the masking tape removed [Fig. 51]. The water repellent properties of the Vaseline work as a resist in the etching bath, protecting the copper fabric in the places where the resist was applied. The fabric was then submerged in a bath of one tablespoon of salt and one cup of distilled vinegar. Within four hours, most of the copper, except for that protected by the Vaseline, had been etched away. The fabric was then thoroughly rinsed to remove the salt and vinegar etchant and ironed between tissue paper towels to remove the Vaseline.

The missing components can be attached to the circuit by sewing them on with conductive thread. The leads of most electronics can be curled to create a loop that can then be stitched down similarly to how one sews on a snap or loop fastener. In the case that a component does not have a long enough lead, additional wire or crimp beads can be soldered to the component's leads to make them "sewable". This is a common E-Textile technique.

Figure 51. *Etched Traces. Left: Example of circuit etched from copper rip-stop fabric. Right: Removing the masking tape stencil after applying Vaseline to the copper fabric as a resist.*

Gilded Traces

This example demonstrates the ornamental and decorative properties of gold leaf and how they can simultaneously function as an electronic circuit [Fig. 52]. This interactive example toggles on and off between three LED lights that are mounted at the bottom of the vertical gold traces.

First the wood surface is prepared through sanding and applying black acrylic paint to create a nice smooth black surface. After the circuit has been sketched out on this surface with pencil, size is applied where the gold leaf should go [Fig. 52, right]. Size is an adhesive used in gilding; it is applied to a surface and let dry for several minutes. When it has become tacky, metal leaf is then applied and the excess brushed away. The circuit in this example was made from imitation gold leaf, which is made from brass, a combination of copper and zinc.

The microcontroller and LED lights can be super-glued to the wood for stability, and then their leads can be soldered with care and flux to the gold leaf. Working with gold leaf is finicky and this circuit has ceased to work. Tiny cracks in the gold leaf surface can be the cause of an electrical disconnection that is not visible to the human eye. With the help of the USB microscope used in previous examples, some of these cracks can be spotted. The process of bridging a cracked connection is not straightforward since the layer of size that needs to be applied for the metal leaf to adhere also creates an isolating layer. Applying uneven dabs of size to create an inconsistent cover is one way to re-connect to underlying circuitry.

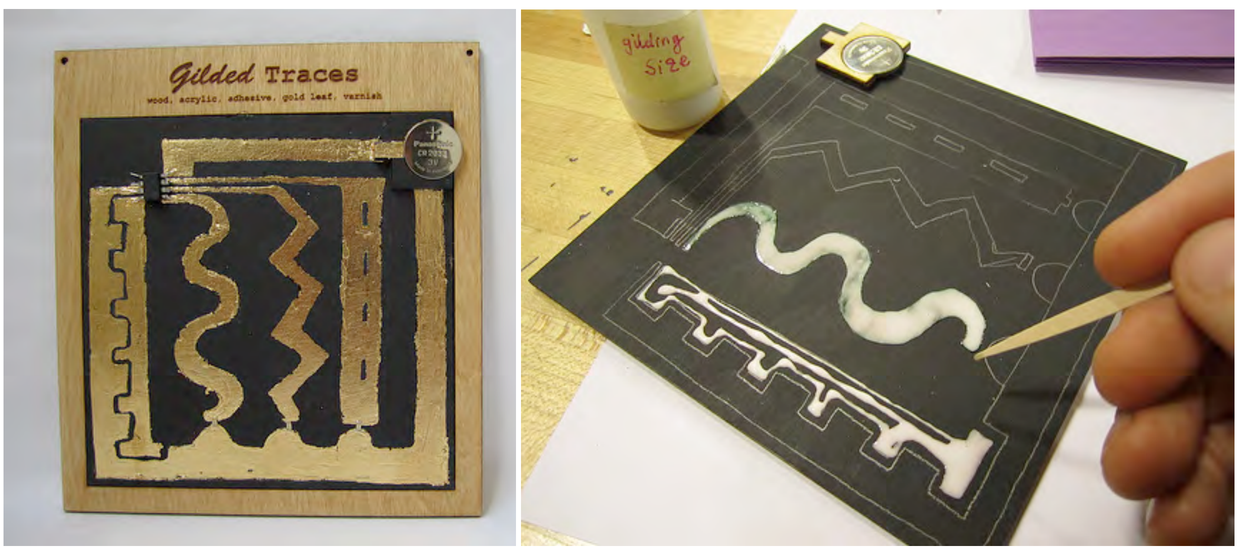


Figure 52. *Gilded Traces. Left: Example showing gilded circuit with pres-fit battery holder in top right corner. Right: Applying size with a squeeze bottle and toothpick to create a tacky surface on which the sheets of imitation gold leaf will stick.*

Laser-Engraved Traces (and Press-Fit Components)

This example showcases how a lasercutter can be used to cut holes for various components such as a coin-cell battery, a microcontroller and a speaker that are just the right size so that the parts press-fit into them and do not fall out [Fig. 53]. The lasercutter can also be used to engrave channels that connect the different components. This example has not been completed, but the next step would be to saturate or flood the engraved channels with a conductive paint to make all the electrical connections.

In the case of this circuit the press-fit holes as well as the engraved traces were created in the software Adobe Illustrator. This design was imported into the lasercutting software and different elements were assigned different power and speed values as well as specified whether they should be cut or engraved.

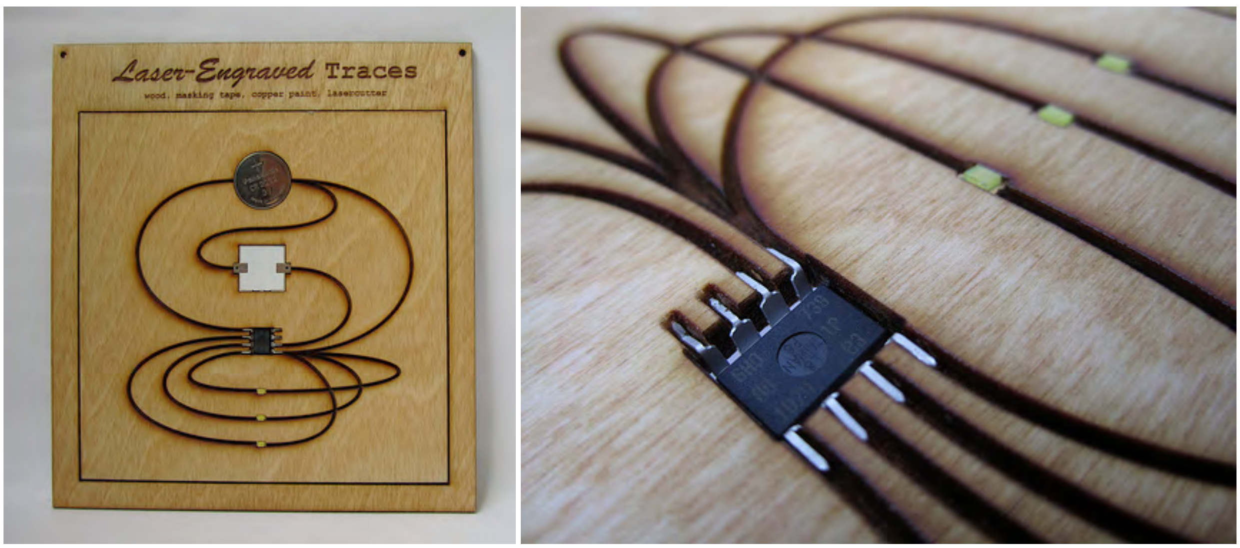


Figure 53. *Laser-Engraved Trace. Left: Example of circuit made by laser-engraving the connections between the components that have been press-fit into holes cutout holes. Right: Close-up of upside-down microcontroller in a press-fit hole with leads recessed in the engraved traces.*

Linocut and Lino-Printed Traces

Carved from a sheet of linoleum this circuit can be coated in conductive paint and stamped to create multiple prints. I have not yet been able to find a good mix of conductive paint and transfer medium that allows me to make prints that conduct well.

To make the linoleum print, first the components used in the circuit were laid out on top of the linoleum and then the circuit was sketched. With a linoleum carving tool the excess linoleum was carved away, leaving the original linoleum surface as the circuit as seen in Figure 54, left. Conductive silver paint and a linoleum print base were mixed and applied to the surface of the carved linoleum with a roller. The paint only applied to the areas that had not been carved away. Then a piece of paper was laid on top of the painted linoleum and with the back of a spoon the paper was rubbed down carefully. Then the paper was peeled away, revealing the print shown in Figure 54, right.

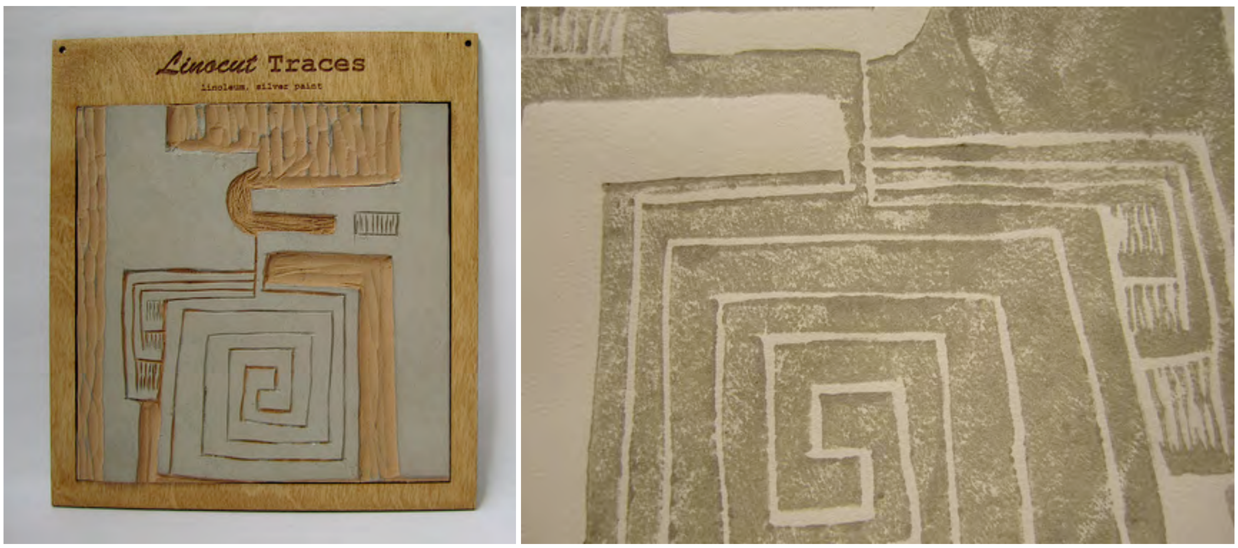


Figure 54. *Linocut and Lino-Printed Traces. Left: Example of circuit carved from linoleum with a silver paint and linoleum transfer base mix applied to its surface. Right: Print made from the linoleum cut featured on the left. Unfortunately the silver paint did not transfer well to the paper and so the traces of this circuit are not conductive.*

Painted Traces

This little circuit was painted on a piece of store-bought handmade paper. Then the whole circuit was electroplated so that a thin layer of copper formed on top of the paint and paper [Fig. 55]. The plated copper makes the traces much more resilient to cracking when the paper is flexed and it also means that the leads of the microcontroller and LEDs can be soldered to the circuit. The coin-cell battery is held in place by a tiny neodymium magnet taped to the back of the paper. The positive lead of the microcontroller connects to the positive side of the battery with another such magnet soldered to the end of a flexible wire.

In Figure 41 as part of the electroplating recipe you can see images taken with the USB microscope of the plated traces and solder joints.

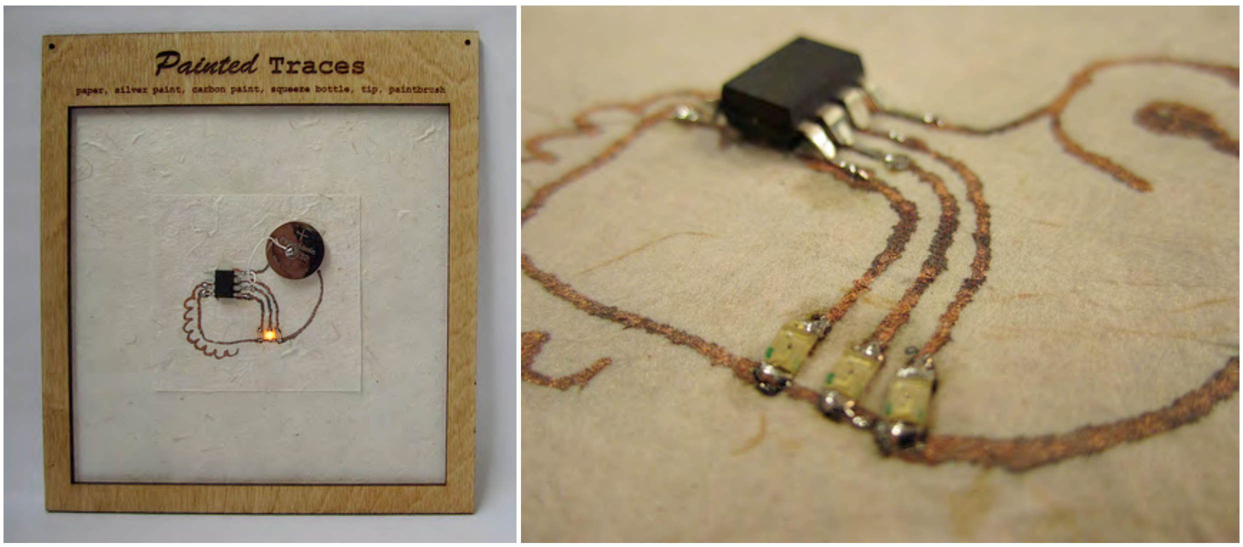


Figure 55. *Painted Traces. Left: Example of small circuit painted on paper and then plated with copper. Right: Close-up of plated paper circuit. LED lights and the microcontroller leads have been soldered to the copper buildup, creating extremely robust connections.*

Paper Speakers

This example, based on the Pulp-Based Computing paper speaker [Coelho et al., 2009], showcases a speaker that has been made on tissue paper, by taping a vinylcut copper coil on top of it [Fig. 56, right].

The copper coil was drawn in Adobe Illustrator and cut out using a Craft Robo vinylcutter. Behind the piece of tissue paper a small neodymium magnet is glued to the larger square of yellow paper [Fig. 56, left]. In the lower left corner a small circuit taken from a Hallmark greeting card has been mounted and a transistor added so that the audio signal coming from the sound circuit can be amplified with an external power source.

When a 9V battery is connected to the two leads at the bottom right of the example and the switch on the sound card is pressed, the speaker plays music. Whereas normally the coil inside a speaker is wrapped cylindrically, in this case the coil is a spiral on a plane. As the current modulated by the audio signal flows through the coil, it turns it into an electromagnet with a fluctuating magnetic field so that the coil, and with it the tissue paper membrane, are repelled and attracted to the permanent magnet mounted behind it. These fluctuations of the membrane cause air to be moved creating the sound waves that we hear.

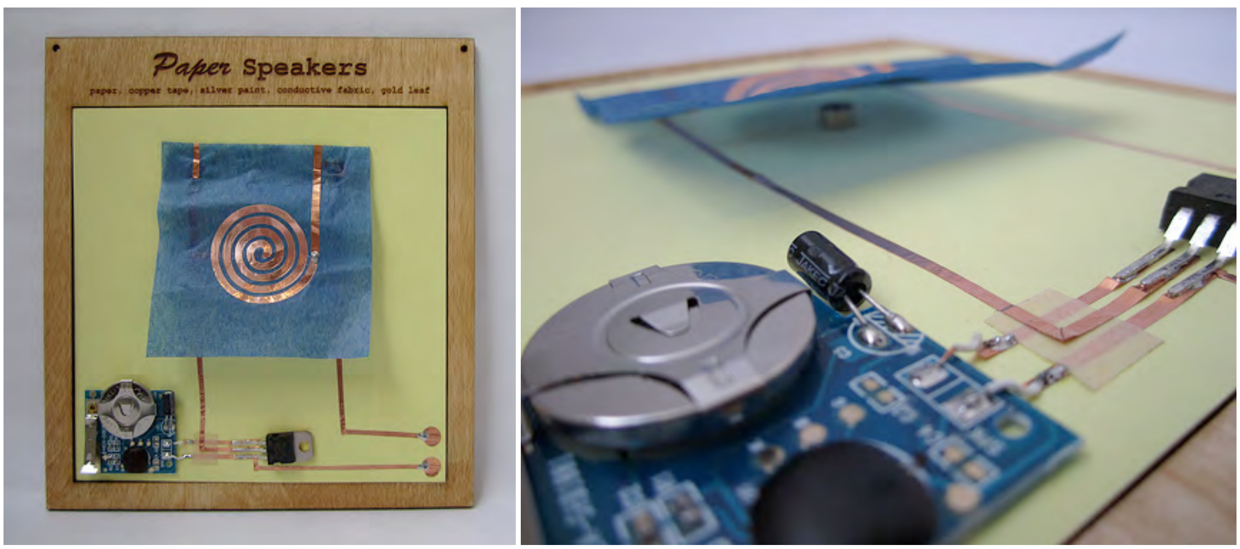


Figure 56. *Paper Speakers. Left: Paper speaker example with greeting card circuit. Right: Close-up of example in which you can see the neodymium magnet mounted underneath the paper speaker.*

Plated Seashell Speaker

This example demonstrates how a limpet seashell can be made into a speaker by plating a copper coil around its interior and exterior with a hole in the tip, that connects the two. Because the shell is a much thicker membrane than the tissue paper described in the previous example, it vibrates less given the same amount of current as the paper speaker, and so plays much quieter sound. But if one holds the seashell up to one's ear, one can hear it play music.

The example of the plated speaker pictured in Figure 57, left also shows the sound circuit, taken from a Hallmark product, and the amplification circuit that includes a TIP 122 transistor and connections for a 9V power supply.

The speaker coil was plated onto the seashell [Fig. 57, right], by first painting the coil with conductive silver paint and then submerging it in the plating bath. Thin flexible wires were soldered to either end of the coil making the connection from the speaker to the amplified sound source coming from the circuit.

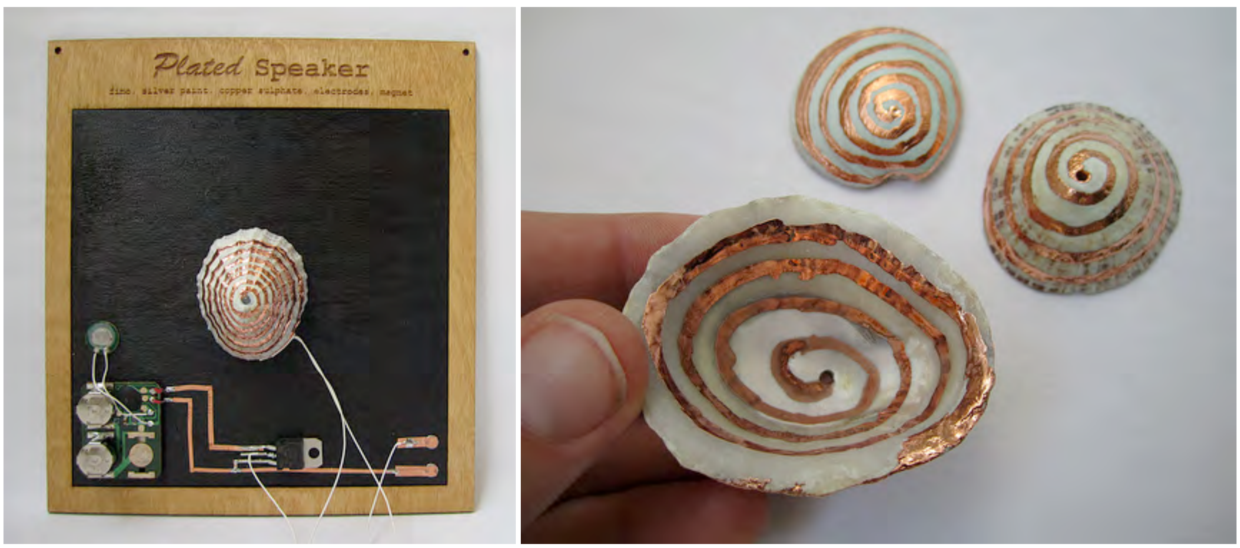


Figure 57. *Plated Speaker. Left: Example of plated speaker and circuit that plays and amplifies sound. Right: Three seashells with speaker coid plated to them.*

Plated Traces

This circuit is sculpted from acrylic clay and then selectively electroplated to build a robust conductive coating that will not crack when the traces of the sculpture are flexed or played with [Fig. 58]. The components of this circuit include a microcontroller, three LED lights and a coin-cell battery holder.

In making the sculpted circuit the acrylic clay was sculpted right around the leads of the various components and everything was fired in a toaster oven, without damaging the components. Then conductive silver paint was selectively applied to make the connections between certain components. When the paint had dried, the circuit was disassembled and the traces plated individually. For details on this process, see the electroplating recipe featured in the "Recipe" chapter.

After plating, the circuit was re-assembled and the connections to the leads could now be soldered. A skin-resistance switch, situated in the upper left hand corner of the circuit, toggles between the three LED lights each time it is pinched. The battery holder includes two magnets to ensure a good electrical connection between the sculpture and the coin-cell battery.

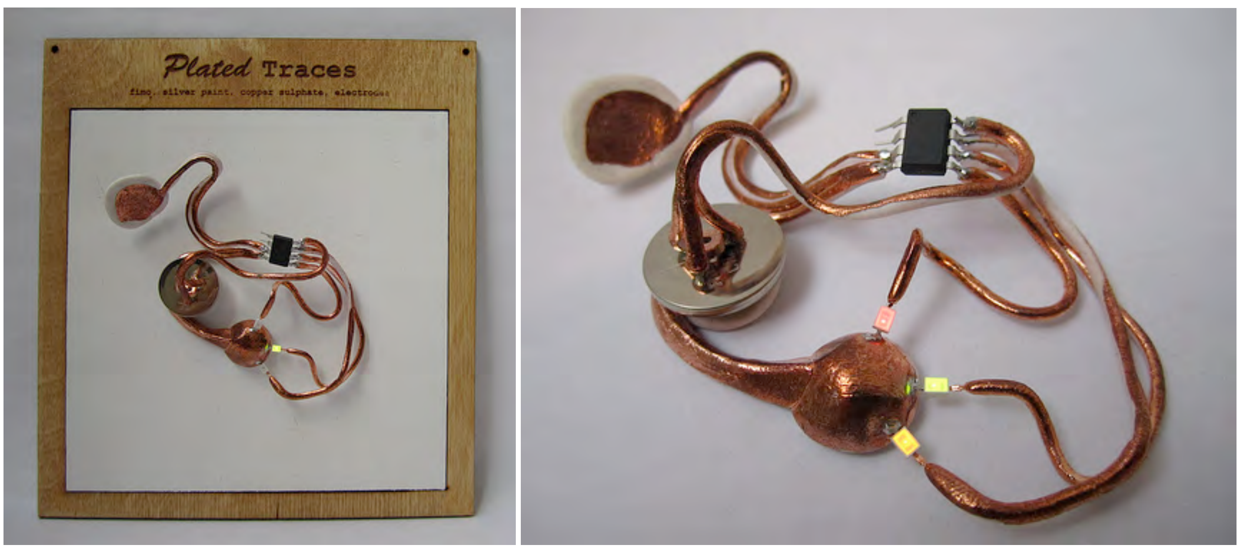


Figure 58. *Plated Traces. Left: Example of plated traces as it appears in the example collection. Right: Close-up of the example with all three LED lights lit up.*

Screen-Printed Traces

This example of screen-printed traces shows how you can use traditional silk-screen printing to create circuitry on a variety of flat media [Fig. 59].

The circuit in the example was hand-drawn and then scanned into the computer and translated into vector graphics. The mask for the screen was cut out of masking tape with the lasercutter, using the file created from the scan. The masking layer was then applied to the back of the screen and additional areas were taped off with more masking tape. Copper paint was mixed roughly 1:1 with a transparent screen-printing base and then applied along the edge of the masked screen. With a squeegee the paint was evenly distributed into the pores of the silk screen before laying the screen down on a piece of paper and using the squeegee to pressure the conductive paint from the screen onto the paper. Two to three layers of paint were necessary to create good electrical connections. In this example only the microcontroller had been glued to the surface of the paper. The other components could be attached in a similar manner and additional paint would need to be applied between the printed traces on the paper and the leads of the components to make the electrical connections.

The circuit in this example, though not fully assembled, includes connections for three LED lights, one resistive input as well as a transistor for triggering a thermochromic pixel (see the first example in this chapter). Many of the leads from the microcontroller connect to the lower right hand side of the example square, these connection are for programming the microcontroller using a six-connection ISP programmer.

Figure 59. *Screen-Printed Traces. Left: Screen printed circuit on paper. Right: Screen printing using conductive copper paint and masked silk screen.*

Sculpted Motor

This extremely basic motor design has been assembled from a variety of materials such as toothpicks and custom shaped Fimo fixtures [Fig. 60]. The assembly has then been electroplated, forming a conductive layer of copper metal. When a 9 Volt battery is shorted across the two connections, forcing the current through the wire wrap coil that is suspended between the two poles, it creates a magnetic field around the coil that repels itself from a stack of magnets mounted beneath. The motor begins to spin and the images of the bird and the cage merge into one.

Figure 60. *Sculpted Motor. Left: Example of a motor assembled from toothpicks and parts sculpted from acrylic clay. The assembly was then electroplated with copper. When powered, the coil begins to spin, merging the image of the bird and the cage.*

Vinylcut Traces

In this example, a circuit cut from copper adhesive tape has been transferred to a piece of clear acrylic. A hole in the acrylic holds the coin-cell battery in place and additional components have been soldered into place [Fig. 61].

The design for the circuit was hand-drawn and scanned. The scan was then translated into vectors and sent to a Craft Robo vinylcutter which then cut it out from a sheet of adhesive copper tape. The cutout circuit was transferred to the acrylic using masking tape, to ensure that all the traces stayed in place. A hole for the coin-cell battery was lasercut out of the acrylic and the connections to the positive side of the battery extend over the edges of this hole. The negative side of the battery is connected simply by sticking the negative lead of copper tape to the bottom of the battery as shown in Figure 61. The microcontroller and LEDs were soldered onto the vinylcut traces to hold them in place. The coil in the lower left corner is a skin resistive input that toggles between the three LED lights every time you touch it with your finger.

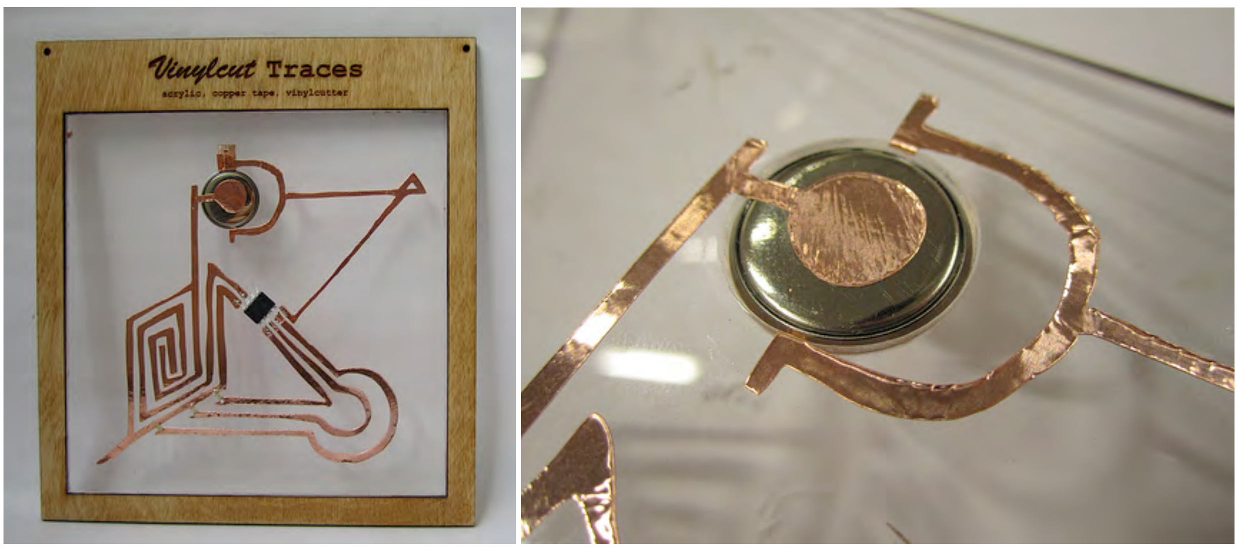


***Figure 61.** Vinylcut Traces. Left: Copper traces mounted on clear acrylic. Right: Press-fit hole containing coin-cell battery and copper traces making power connections to the battery along its sides and bottom.*

WORKSHOPS

Figure 62. *Picture taken during the second workshop of a participant painting a conductor that will then be used as a heating element to change the color of thermochromic paint, causing the outline of the tree to appear.*

After building, documenting and sharing the Kit-of-No-Parts online, workshops were the next step in disseminating this new approach. Workshops were also the ideal platform to interact with individuals who were interested in learning these new techniques. I wanted to observe how other people would take to the techniques, how they would experience the building process and what they would want to build. Figure 62 shows a workshop participant painting a circuit on wood.

I organized two workshops that were held on consecutive Saturdays in the High-Low Tech group space at the MIT Media Lab. Both workshops were advertised under the same description, with the exception that the first workshop was open to anybody while the second workshop was specifically for individuals who had experience with craft. The calls for participants were published on the website and sent out to the Kit-of-No-Parts newsletter as well as to the High-Low Tech newsletter. I took the first 10 people who responded for either workshop and both workshops filled up within the first week of advertising them.

The workshops were advertised as opportunities to learn the range of techniques documented on the Kit-of-No-Parts website. The following workshop description was included in the email that was sent out as well as on the posters used to advertise the workshop that are included in the Appendix.

Have you ever wondered what kinds of electronics we would be using if we had crafted them ourselves? What kind of interface would you have built to interact with your music? What would your alarm clock look like? How would your doorbell feel? What shapes, sizes, colors, textures and functionality would a craft approach to building electronics offer?

The Kit-of-No-Parts workshop introduces participants to a craft approach to building electronics. Imagine you could sculpt a switch, carve a circuit or plate your own speakers. This workshop will cover a range of traditional and contemporary craft techniques including gilding, carving, casting, sculpting and plating, and demonstrate how a variety of craft materials can be formed into functioning electronic artifacts.

The workshops started at 11 am on a Saturday and went until 6 pm, with a lunch break from 1-2pm. Each workshop began with a presentation that briefly introduced the Kit-of-No-Parts approach and went on to demonstrate the selection of techniques that would be possible during the workshop.

In structuring the workshops I had to decide on what to introduce, how to introduce it and how to frame it so that participants had a clear idea of what to do and what they could expect to achieve. My goal was to introduce a range of techniques so that I could see which ones participants wanted to engage with. I imagined participants would develop an idea based on the available materials and the kinds of output I presented in each workshop. Depending on the scope of their ideas, I did not necessarily imagine all participants would complete their projects during the workshop, but I did anticipate that they would be able to begin building and get a good introduction to the craft style of working with electronics.

To collect feedback from the participants I prepared two surveys. Participants were emailed roughly a day or two in advance of either workshop with a link to an optional online survey that asked questions about their prior experience with art, craft, electronics and programming. The day following the workshop participants received another email with a link to a post workshop survey asking questions about their workshop experience as well as asking them to rate things such as workshop duration, difficulty and speed.

Although there was much room for improving the clarity, structure and focus of the workshops, they both went well. An overwhelming majority of participants stated that they enjoyed being introduced to the full variety of new techniques. It was exciting that both workshops filled up so fast. I knew that there was a keen interest in the E-Textiles and paper computing work from our research group, but I wasn't sure how popular a more general craft approach to electronics would be. Throughout the workshops most participants were able to work fairly independently and nobody was at a loss for an idea of what they wanted to build.

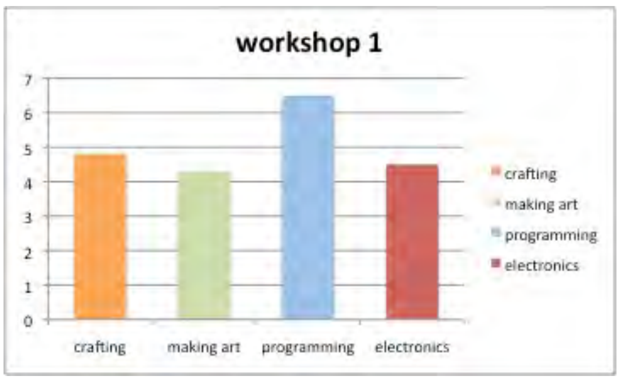
From my part, I thoroughly enjoyed watching everybody work with the materials and techniques I had prepared, but both times it became apparent early on that in my planning I had expected too much of a one day workshop. I crammed too much choice and newness and too little focus into the flow of activities. Making it hard for participants to concentrate on learning and mastering a technique. Not only was I introducing participants to eight different techniques and the materials to go with them, I was also presenting electronics in a craft context. I underestimated how confusing it can be to receive so much new information at once. Even though I prepared illustrated information on the electronics I introduced in each workshop, I did a bad job of selecting and introducing electronics in a basic and straight forward way that would have allowed participants more creative freedom. Overall it was simply hard for them to immerse themselves and create something new in such a short amount of time.

In the following two subsections I summarize the outcome of both workshops and focus on how the Kit-of-No-Parts approach was conveyed and received.

First Workshop

Of the eight participants that attended the first workshop five were female and three male. Six people filled out the pre-workshop questionnaire and 5 the post-workshop questionnaire. Of the people that filled out the questionnaires all were between the age of 20 and 35.

The charts in Figure 63 illustrate some of the following observations. Everybody had at least a little programming and art experience but roughly half the participants had no craft experience. This first workshop contained more people with electronics experience than the second workshop. The majority of participants considered themselves designers, electronics hobbyists and artists. Their individual art experience included painting, photography and illustration. And their experience with electronics included Arduino and E-Textiles projects. The participants that had experience with craft had worked with casting, papermaking, ceramics and jewelry as well as a range of textile crafts.



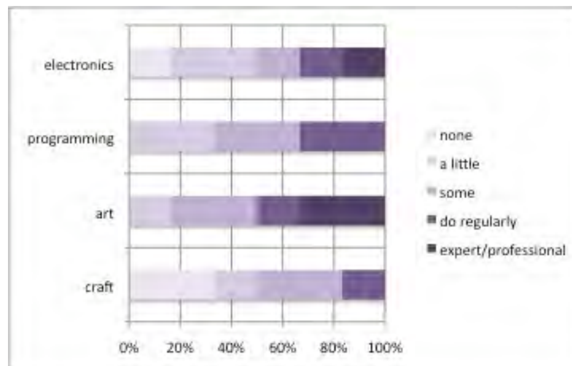


Figure 63. *Workshop 1. Graphs showing participants' responses to the pre-workshop survey. Left: On a scale from 1 to 7, how comfortable do you feel crafting, making art, programming and building electronics? Right: How much experience do you have with craft, art, programming and electronics? None, a little, some, do regularly, expert/professional.*

In the questionnaire I explicitly asked whether people had previous experience combining crafts and electronics and everybody responded that they had heard or read about it prior to the workshop. Many of them had also already worked on concrete projects. It was interesting that so many of the participants were already involved in combining art and electronics, but this was probably tied to the fact that they found out about the workshop through the High-Low Tech newsletter.

When asked about their motivation for attending the workshop, I found the following two quotes representative of two different reasons that participants stated for coming to the workshop that day.

"I don't have a lot of experience with electronics and find it very empowering to learn about technology in a hands on/craft way."

"I am working on an art project that integrates electronics with sculptural objects. I would like for the circuit to be not only functional but an aesthetic part of the piece."

This first workshop focused on making the speaker coils described in the previous "Example" chapter. Participants were shown a variety of speakers made from various techniques and materials. The challenge in introducing the speaker was that I needed to include a source of sound. An easy solution was to provide a selection of Hallmark greeting cards that participants gutted for the circuit. Some of the cards played pre-recorded songs, others were recordable so that participants could record and playback their own sounds. For the audio signal of the greeting card circuit to make sound through the speakers, the signal needed to be amplified with a transistor and a 9 Volt battery. These extra components were bulky and somewhat distracting from the techniques I was trying to focus on. Since I was not focusing the workshop on a specific technique and needed to focus it somehow, I was set on having the speaker and the speaker required these extra parts.

After the initial introductions and demonstration of the techniques, participants proceeded to sketch and think about what they wanted to build. This is when it became most apparent to me that while I had made sure to organize all the materials and tools required for the techniques, there were not enough "other" craft materials around to inspire the kind of building I had envisioned.

Figure 64. *Copying an existing design is a great way to get started as well as learn some things in the process of building.*

While I encouraged participants to focus first on building a conductive speaker coil, I did not enforce it as an introductory activity. While some participants went about making the coil before anything else others hesitated. In retrospect I should have considered this situation more. Having an extremely structured introductory activity can be a great starting point that allows participants to get to working with the materials and learning about them even if they are copying an example design. Figure 64 shows participant's speaker coils based off some of the examples I showed in the introduction.

It is always a hard decision how many and what kind of examples to introduce in a workshop. Everything you show has an impact on how participants come to think, especially because workshops are often held in such short amounts of time these influences can really impact the outcome of a workshop, both for good and for bad.

While roughly half the participants build variations of the paper speaker, the other half became interested in the use of thermochromic paints that change color when heated. This interest sprung from two participants in particular who had seen the thermochromic paints featured on the Kit-of-No-Parts website. They were looking to incorporate thermochromic paints in their own work as painters and illustrators. Although these paints were not initially planned for the workshop, it was not difficult to introduce them on the spot.

As participants began building their designs, one of the first things I noticed was that they lent towards using materials and techniques they were already familiar with. Figure 65 shows some of the works that participants created with materials they were familiar with. At first I thought I had failed to introduce some of the other techniques clearly enough and participants were unsure of them. On the other hand, this response made total sense. When you come to a new activity, even if you are all set to try out everything you don't already know, as you begin to work you naturally fall back into thinking with and manipulating familiar materials and tools. Despite this being a natural process, I could have done more to support participants in engaging with some of the more unusual techniques such as sculpting and plating the polymer clay, and carving from wood. Introducing these techniques as short and simple hands-on introductory activities would have been one way to do this.

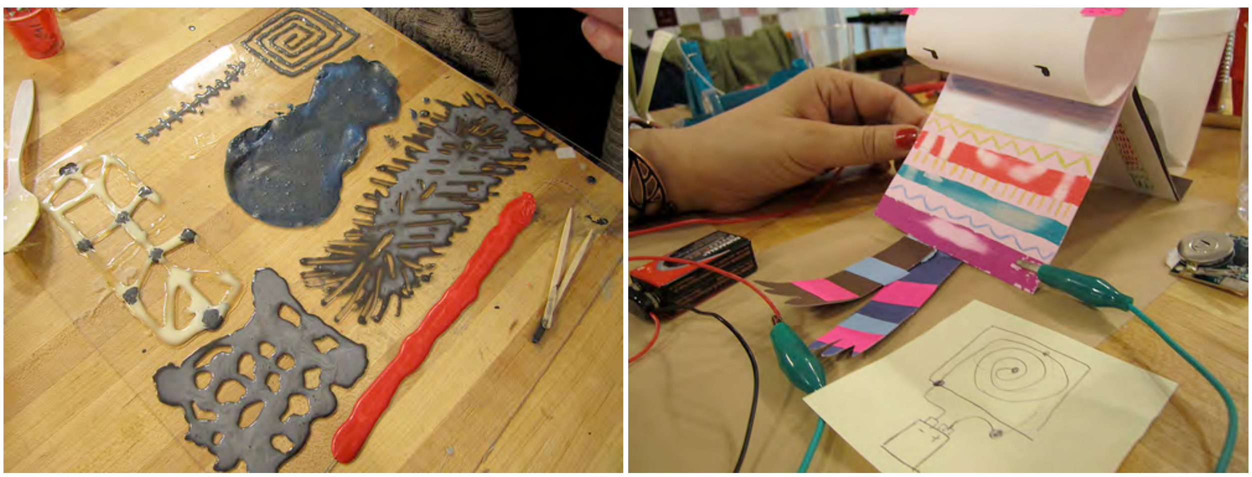


Figure 65. *Participants explored the use of thermochromic paints. Left: One participant experimented with casting both thermochromic paints as well as conductive powders in latex to create materials that could simultaneously conduct and change color. Right: Another participant explored the combination of thermochromic paint with the speaker coil in order to animate her own paintings and illustrations.*

One of the most essential tools in working with electronics is the multimeter, which can be used to measure electrical resistance, check for continuity and also for capacitance. In the workshop participants all used the multimeter to check their circuits for both good and bad connections [Fig. 66]. Besides being an extremely useful tool the multimeter also has a strong effect on supporting explorative and more experimental approaches to electronics. In many ways it bares similarity to Jay Silver's Drawdio [Silver, 2009] tool, which supports and enables a playful exploration of conductive everyday objects.

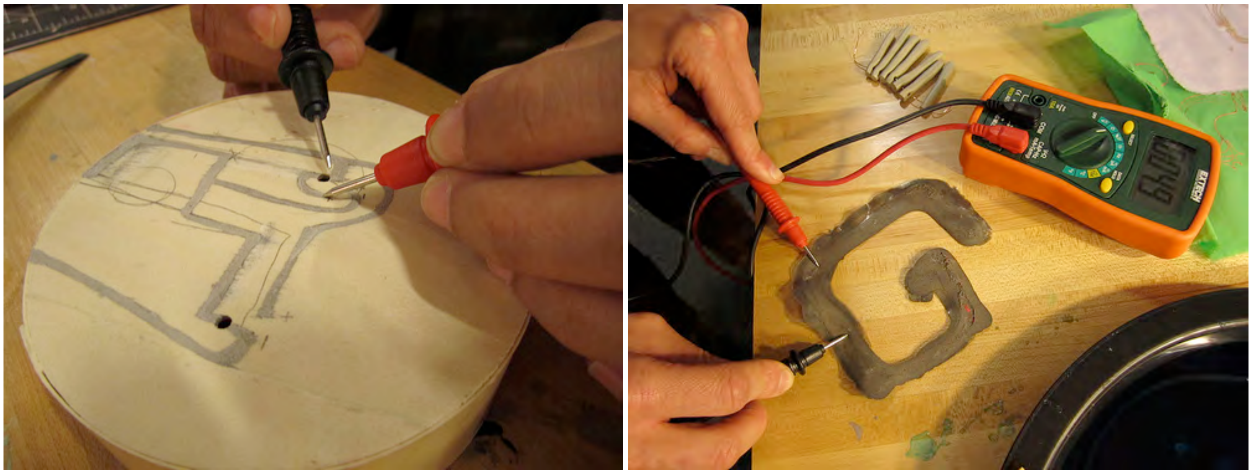


Figure 66. *The multimeter is an essential tool in any electronics workshops and maybe even more so in a Kit-of-No-Parts workshop. Left: Participant testing a silver paint and wood circuit for continuity. Right: Another participant looking at the resistance of her cast latex coil.*

Participants spent the majority of the workshop working on their projects. Most participants began with a sketch of their initial idea but soon moved on to building. Because participants chose to work with techniques that they were familiar with they were able to work more independently. Also, most of the participants in this workshop had prior experience with electronics and were comfortable using the components and circuitry involved, working from the schematic drawing I provided. The fact that participants in this first workshop had prior electronics experience might have lead me to take this for granted in preparing for the second workshop and not giving a better introduction to electronics, when it would have been necessary.

In the following I briefly summarize the kinds of projects that participants built as well as the techniques and approaches they took.

Four out of the eight participants focused primarily on using paint and paper. Painting their speaker coils and thermochromic heating elements as well as the connections to the other parts of their circuitry using the conductive silver paint. One participant who worked on integrating the speaker and thermochromic elements into the image of a frog found that his silver painted coil was not conductive enough to play loud enough sound, so he went on to successfully plate his painted paper coil. Although the first attempt at this failed because the paper was too absorbent and affected by the plating bath which took a while because the conductive surface area was rather large. The images in Figure 67 show the paper circuit submerged in the plating bath and then the finished circuit with yellow thermochromic paint added as eyes that disappear when the heating connection is made.

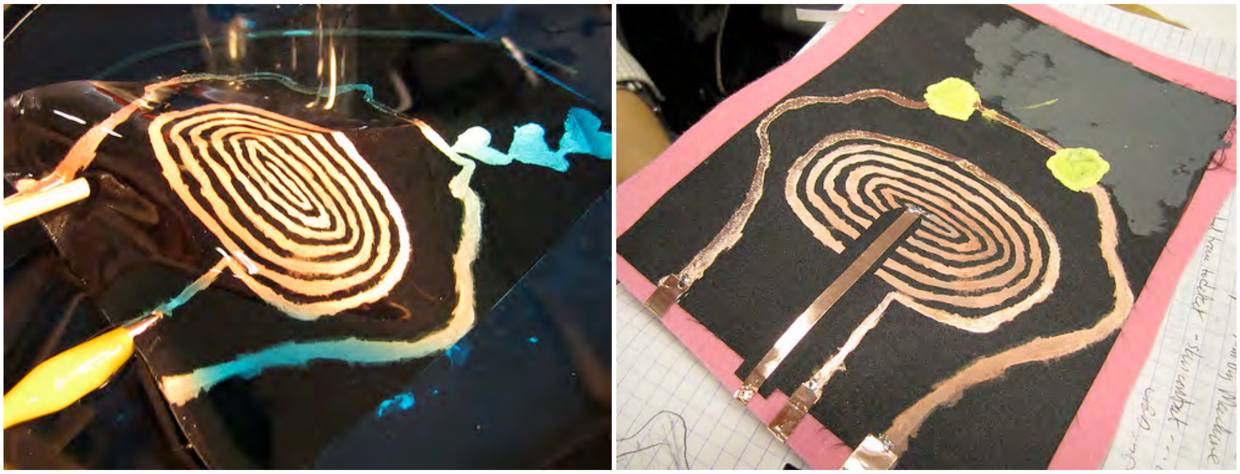


Figure 67. *Left: Painted paper speaker coil submerged in plating bath. Right: Finished circuit with yellow thermochromic eyes.*

One participant was inspired by a wooden cheese box she picked out of one of the materials bins that were part of the workshop and build a maze from it. She used cardboard to construct the walls of the maze inside the box and conductive paint to create the circuitry on the back. Two metal balls inside the maze could recede into two holes, closing the circuit and turning on one of two LED lights [Fig. 68]. This participant had previous experience with electronics and although LEDs were not introduced as part of the workshop she asked to use them. As the workshop organizer and facilitator I was not always sure how much I should direct people's ideas towards incorporating the Kit-of-No-Parts techniques instead of reaching for standard components. In the case of the LEDs I feel the participants could have possibly produced a more unique and materially integrated piece if she had instead used thermochromic paint or even the speakers as her choice of actuated feedback. But on the other hand her idea included the LED lights and at that time I was in the mindset of helping participants realize their ideas, rather than thinking to persuade them to go in specific directions. In retrospect I could have been more upfront about stating this as a goal of the workshop. Telling participants that they were encouraged to take the less explored approaches and apply the underused techniques. I could have more actively suggested specific solutions that lead to the use of certain techniques, rather than leave it entirely up to participants to decide how they wanted to work.

This same participant went on to gild a speaker coil on the inside of the lid of the wooden cheese box [Fig. 68]. The idea was that when the box was closed, the power connection of the circuit would complete, turning the circuit on and playing sound through the speaker. While the participant got her maze to work, she struggled with the gilding technique, as metal leaf is extremely finicky to work with. Although we got the speaker coil to be consistently conductive we ran out of time before getting it connected to the rest of the circuitry in order for it to play sound.

Figure 68. *Left: Maze constructed inside a wooden cheese box. Right: Gilded speaker coil.*

Two participants took a similar approach in two different areas. Both of them explored the materials and techniques through making samples rather than working on a concrete project. One participant took to casting a variety of latex samples with thermochromic paint [Fig. 65], as well as with steel yarn and conductive powders to achieve heating elements. The other participant experimented making a variety of speaker coils on different papers and substrates such as tape. One of his more successful speakers was made on a post-it note, which then lead to some possible project ideas.

And finally, one participant incorporated sculpting and electroplating to make metal chimes. The chimes were intended to be suspended in a space where they could be affected by passers-by. Causing the chimes to move and make contact with one another, which would trigger sounds and ambient lighting effects. This participant sculpted a whole series of chimes, fired them in the toaster oven and then plated them in batches. The plating did not go so well with so many at one time and we reduced the number of chimes to get them to plate completely. The images in Figure 69 show the sculpted chimes in the toaster oven as well as a batch of them in the plating bath.

Figure 69. *One of the few participants who tried sculpting Fimo and electroplating it to create metal chimes.*

Half an hour before the end of the workshop participants gathered to briefly present their work to each other and to share not only what they had made but also how they had experienced the process. Participants seemed pleased with what they had made and excited about the variety of techniques, even if they had not been able to try them all. To give a better impression, here are some representative quotes taken from the responses to the post-workshop surveys.

When asked what their favorite thing about the workshop was:

"Seeing the demonstrations and then using the processes."

When asked if they had suggestions for how the workshop or the tools and techniques used could be improved:

"I just wish the gold leafing was a bit more reliable. It looks so neat and yet I am afraid it is too fragile to be able to have a durable circuit."

"Drawing smooth concentric spirals is difficult. Maybe have a stencil?"

When asked to share any other reflections or comments:

"It really allowed me to see how circuits could potentially be made from so many substrates. It was almost an invitation to start experimenting with different materials and reinventing the form of the circuit and how it can be integrated in a new way in an object."

Second Workshop

Of the ten participants that attended the second workshop six were female and four were male. All participants filled out the pre-workshop questionnaire and eight the post-workshop questionnaire. Of the people that filled out the questionnaires all were between the age of 21 and 40.

The charts in Figure 70 illustrate some of the following observations. The majority of participants considered themselves artists, crafters and designers. Few people had prior electronics or programming experience. Participant's art experience included painting, sculpture, ceramics, video and electronic art. Participant's craft experience included repurposing materials, metal smithing, woodworking, ceramics, glass, paper crafts, jewelry, carpentry and a whole range of textile crafts such as sewing, knitting and embroidery. It is interesting to me that this workshop, that was directed at individuals with prior craft experience, attracted less participants with electronics experience than the first workshop did.

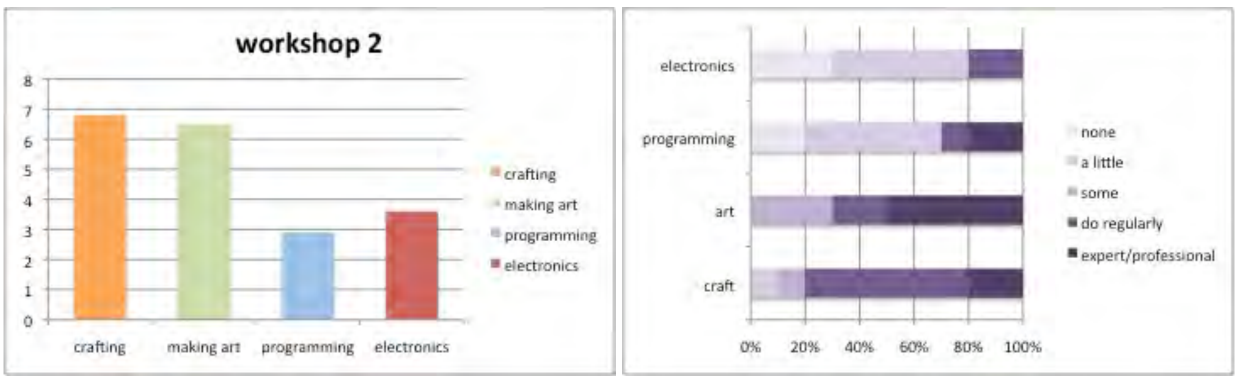


Figure 70. *Workshop 2. Graphs showing participants' responses to the pre-workshop survey. Left: On a scale from 1 to 7, how comfortable do you feel crafting, making art, programming and building electronics? Right: How much experience do you have with craft, art, programming and electronics? None, a little, some, do regularly, expert/professional.*

In response to the question about what motivated them to signup for the workshop, one participant replied:

"I've always been interested in getting involved somehow, and was waiting for a workshop to open up that seemed appropriate."

I narrowed the number of techniques I introduced in the second workshop down to four: gilding, electroplating, carving, and molding and casting. I also asked participants to bring something with them that they had made and could possibly incorporate in the workshop, but did not have to. In the previous workshop a number of participants had shown a keen interest in using thermochromic paints that can be made to change color when heated up. So besides focusing on the speakers I also included these color changing paints. Instead of using the greeting card circuits as a source for sound I decided to use a pre-programmed microcontroller, a small computer with eight legs and a program loaded on it that played a different note, depending on the value of input connected to one of its pins. This variable input could be achieved by painting a strip of carbon paint to create a resistive track along which to move a conductive wiper that connected to the electrical ground of the circuit. As with the greeting card circuit this option also included the transistor and 9 Volt battery for amplifying the sound signal.

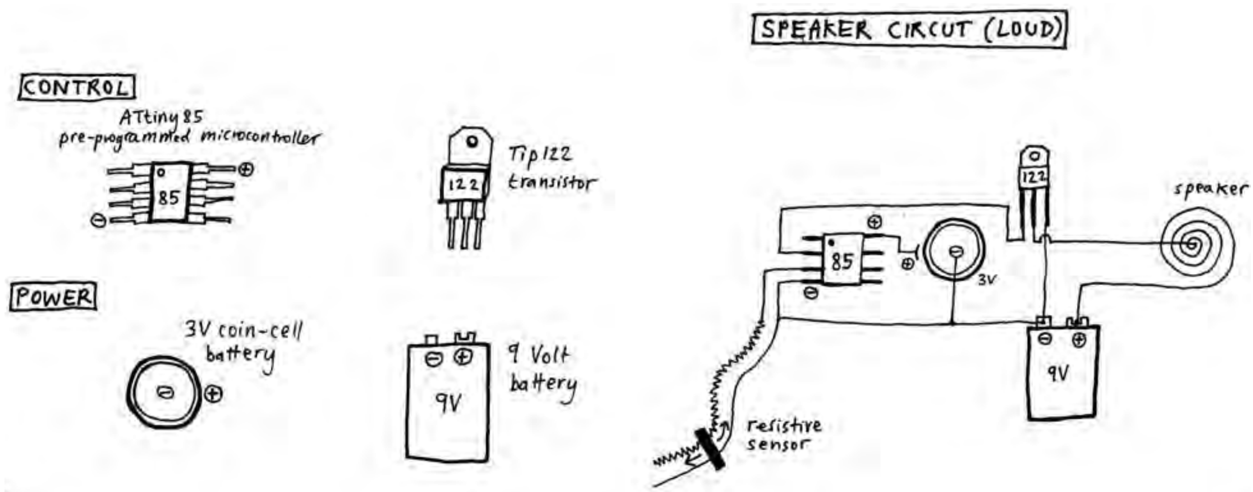


Figure 71. *Images from the booklet handed out at the second workshop.*

In addition to triggering the notes, the same microcontroller ran another set of commands. Every time the input pin was triggered, no matter what the value, the program toggled between on and off (high and low) on three output pins, allowing somebody to connect three different outputs to these pins. This setup sounds complicated, and it was. In order to make all of this more accessible to the participants I prepared a small booklet containing four circuit diagrams. One for making a very silent speaker circuit using just a 3 Volt coin-cell battery. Another for making the amplified version of the speaker circuit. A very simple circuit for triggering and heating the thermochromic paint that worked without the microcontroller. And the last, the most complicated, and which nobody attempted, for toggling between three thermochromic pixels. Figure 71 shows two pages from this booklet that introduce the different components and illustrate the amplified sound circuit. It turned out to be too much for such a short workshop.

As participants begin to sketch out their ideas they used pens and paper to draw sketches and schematics, but they also took the components and configured them around their object in order to get a better idea of how things might come together. This happened more so in this workshop than in the first. For one because some participants had brought artifacts with them that they wanted to use in their design and so they had an object in front of them. And also because at the beginning of the workshop I handed out bags containing the booklet and the components they would need to build any of the four circuits it described. Going back and looking at some of the images I took during the workshop the following two images struck me as reprehensive of this processes. Seeing these images also made me think about some of the finer details of this initial sketching process.

The left picture in Figure 72, left shows a participant who brought a plain metal bracelet she had made with her to the workshop and decided to “apply” the silent speaker circuit to it. In the processes of figuring out where the components should go she experimented with different placements, both by sketching a layout on paper as well as physically arranging the parts where she imagined they could go on the bracelet. Having both the artifact and the components in hand allowed her to think a in a certain way about the combination of crafts and electronics.

The right picture in Figure 72, right shows another participant as he sketched out his circuit on paper. He did not bring an artifact with him and so through sketching designed both the circuit and the artifact. Though I can't say exactly how this particular design process developed and what kind of back and forth happened between electronics and artifact, I feel it worth thinking about how in the process of crafting electronics one moves back and forth between the different worlds, both of craft and electronics, as well as of two-dimensional representation and the reality of final piece. And to think about how the media used in facilitating this process such as flat paper and real materials influence this prototyping/building process. I discuss these ideas more in the final chapter where I try to summarize and reflect on different styles of approach.

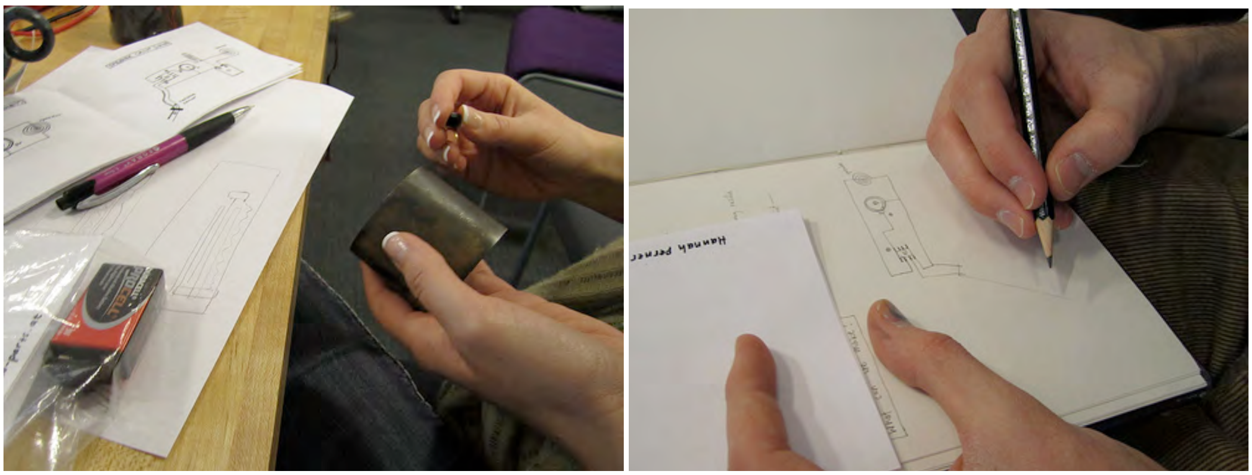


Figure 72. *Left: This participant brought a plain metal bracelet she had made with her to the workshop and decided to integrate the electronics on her bracelet. Right: Another participant sketches out his circuit on paper.*

One participant shared a really interesting comment with me about her intent to focus solely on the layout and visual aesthetics of the circuitry. In her design, which was painted on plywood, she first used blue acrylic paint to prepare the surface upon which to paint the conductive silver paint. The blue paint backdrop also created a prominent visual effect [Fig. 73, left]. I thought it was interesting to consider her focus on two-dimensional, two color, two material aesthetics as a nice concentration that could be the focus of a future workshop.

Trial and error! One participant working with the thermochromic paints did not mix in enough medium and when the paint dried it was very flaky [Fig. 73, right]. But an interesting thing that he also did in this example was to paint the conductive paint on top of the thermochromic layer. While I had taken to painting the conductor in the background to keep it invisible, I very much like the idea of painting the conductor on top. Though I am not sure if in this case it was a conscious decision or not.

As in the first workshop participants spent the majority of time working on their own projects. Compared to the first workshop a majority of participants had little or no prior experience with electronics. I found myself challenged to better explain the electronics I was introducing for which I realized I had not prepared a simple enough introduction to. While the booklet I handed out described the components and the circuits I had prepared, it was directed at an audience that was already familiar with electronic components and schematics.

Figure 73. *Left: Participant focused on design of circuitry. Right: Trial and error.*

Being used to working with circuit schematics one comes to more naturally view them as abstractions of the actual implementation of a circuit and its components. Observing how participants who were new to electronics worked with the circuit diagrams, this was not the case. The way the circuit was layed out and represented in my hand-out, which can seen in Figure 71 on the left, was very literally taken up by some participants. Rather than consider other formats for representing circuit connections, such as listing what connects to what and not drawing the connections, it would have been better to start with a simpler circuit that only included a power supply, a switch and some actuation. Of course, needing a sound source and amplified power, I had had a hard time solving this for the speaker. But the thermochromic paint on the other hand can work very nicely in such a simple configuration, where you paint your heating element and short your battery across it in order to actuate the paint.

Of the ten participants in this workshop roughly half worked on projects that included speakers. The other half used thermochromic paint. Unfortunately many of those incorporated the speakers were less successful in getting them to work. I believe that to some degree this was because participants really made an effort to integrate their speakers with their artifact and in doing so encountered some challenges that took time to resolve. While with the visual qualities of craft you can often begin to appreciate them even before they reach their ultimate form, with electronics it can depend on everything being finished before there is even a chance that it might work. And then the process of debugging begins. While debugging is part of the process it is a shame when it takes up the majority of the workshop.

In the following I describe two projects that included speakers. They are also the projects that I first introduced when talking about styles of approach in sketching and prototyping ideas, shown in Figure 72.

The participant who brought the bracelet she had made with her to the workshop came up with the idea of using the metal bracelet itself as the common ground connection that every component connected to. She also used a small magnet on the battery so that this could be moved around the bracelet. Because the metal of the bracelet was now part of the circuit, other parts needed to be isolated from it in order to form separate connections. For this she used a clear nail varnish. Using a dremel tool she drilled holes and cut slits in the bracelet to accommodate the components that included the battery, the resistive sensor, the microcontroller and the speaker. She made the speaker coil by weaving magnet wire in a circle, through the holes she had drilled in the bracelet. But the insulation of the wire kept shearing on the edges of the metal holes, causing it to short with the common ground and requiring it to be undone and redone multiple times. Ultimately we tried testing the circuit by just wrapping the wire into a coil and taping it to the bracelet. The speaker did not produce audible sound and, although I can't be sure, I suspect this could be because the wire coil was not fixed to it well enough causing it to vibrate the metal as its membrane, or else the metal of the bracelet was too stiff to vibrate at such low power. In this case she could have tried implementing the amplified version of the circuit, which would have required the extra components, including the rather bulky 9V battery. Figure 74, left shows the bracelet as it looked at the end of the workshop.

A project that incorporated the paper speaker was made on a piece of plywood cut out in the shape of a washboard [Fig. 74, right]. The idea was that you could play the washboard with a conductive wiper, which in this case was a chopstick coated in conductive paint, by moving it up and down the resistive track painted with carbon paint. The rest of the circuit was painted with silver paint on wood, in a similar style to the previously mentioned example of another participant that used blue paint as a backdrop. The speaker was not painted on the wood but on a piece of paper that was then connected to the wood circuit through two small metal screws. The speaker was extremely quiet because it used only the 3 Volt coin cell and did not amplify the sound. Again, adding the transistor and 9 Volt battery to amplify the sound would have made it louder but also bulkier.

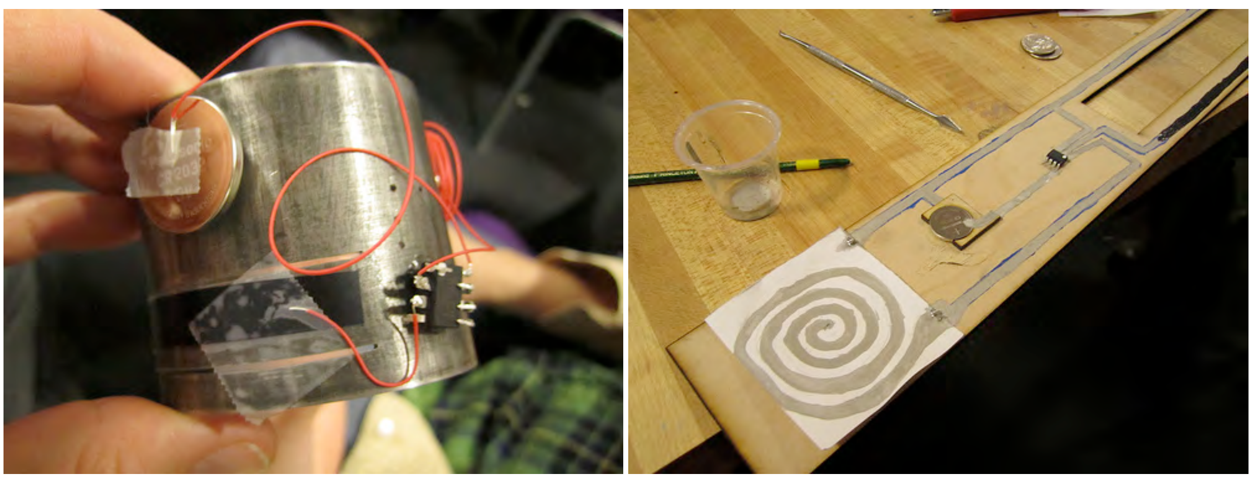


Figure 74. *Left: Bracelet with simple speaker circuit. Right: Wooden washboard instrument with paper speaker.*

The following three projects all used thermochromic paint as well as some carving, molding and casting.

The work of one participant plays with our perception of the rather obnoxious sentence shown in Figure 75. When the circuit is powered the image changes and an outline of the country of Spain appears around the text. The result is a reference to how the participant feels about living in New York during its cold winters, while in Spain, which is at roughly the same latitude, the winters there are sunny and warm.

Figure 75. *Artwork by one of the participants, before (left) and after (right) completing the circuit that causes the painted circuit to heat up and appear through the thermochromic paint.*

The participant who made the artwork referencing Spain's sunny winters was also one of the few who began her process by creating a series of samples before attempting the final piece. She was used to working with paint and also the idea for this artwork is something she already had in mind. Coming at this process with skills to leverage as well as a strong idea makes a difference in how you can work given a new set of tools and techniques.

One participant brought a selection of gemstones with him to the workshop and proceeded to make Fimo molds of them that he could then use to cast latex mixed with thermochromic paint in [Fig. 76, left]. He also included a layer of conductive paint in the mold as his heating element that would cause them to change color. Unfortunately, even though the molds were small, the latex took forever to cure when cast in these shapes. Another participant constructed a wooden box and painted thermochromic paint on the different sides. Contacts underneath the paint revealed different shapes when the cube was oriented in different positions to make electrical connections with the battery [Fig. 76, right].

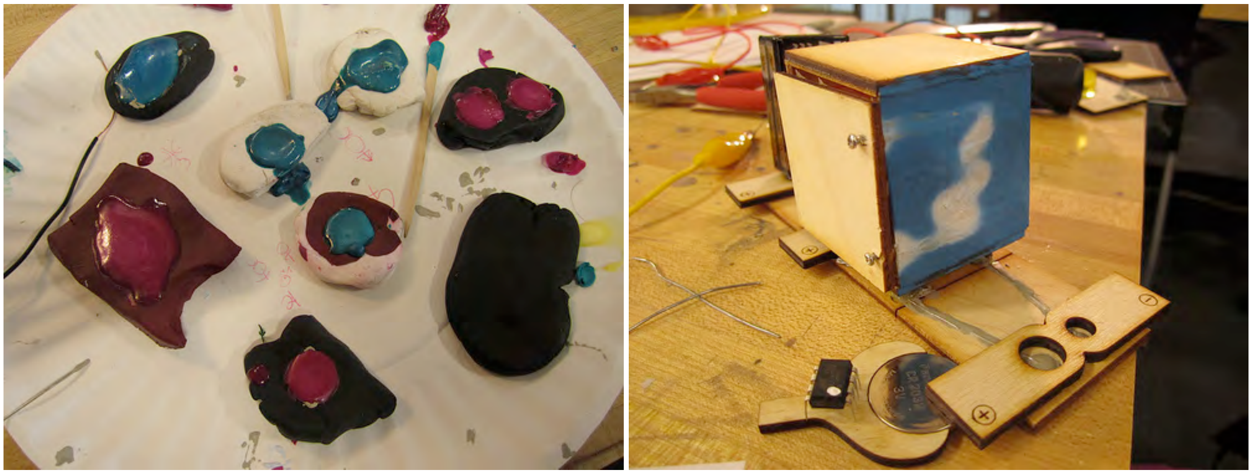


Figure 76. Left: Thermochromic gemstones cast with latex in Fimo molds. Right: wooden box with thermochromic display that reveals different elements depending on the orientation of the box.

The following final two examples of thermochromic paint were done on wood with heating patterns painted underneath in the shape of the tree's leaves [Fig. 77]. In the first example nothing but the carved recession of the tree trunk and branches are visible until the circuit is powered to reveal the leaf structures. A second and smaller iteration of this project changes color more dramatically because the painted heating element heats much faster. This second version is coated it in a clear lack, giving it a very finished quality. It also includes holes in the wood that bring the power connections for the circuit to the back. The holes were drilled and then saturated with paint and small screws were screwed in to make connections that could be clipped to with the alligator clips.

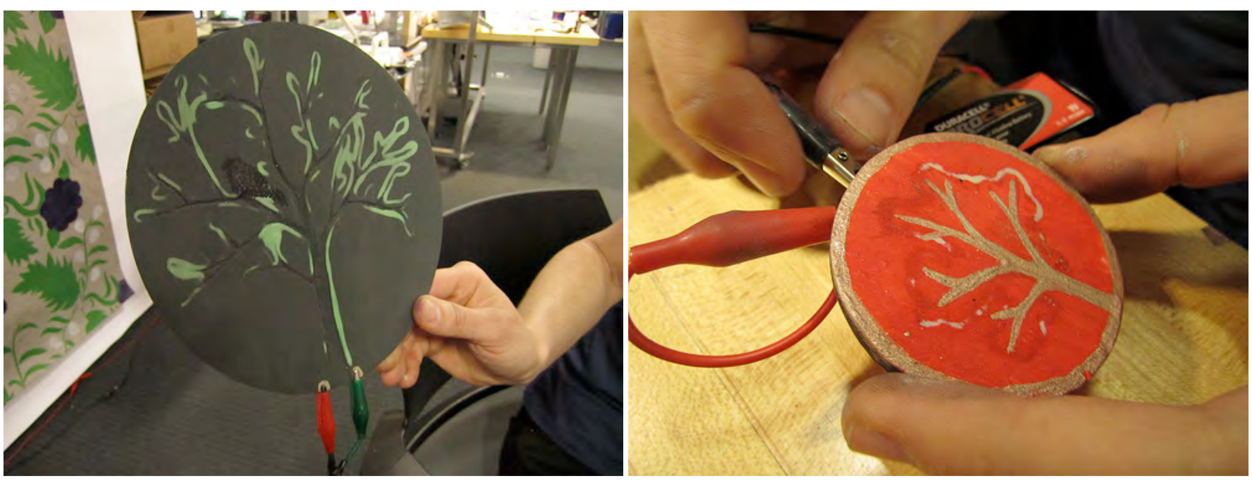


Figure 77. *Left: Finished version of the work in progress featured at the very beginning of this chapter in Figure X. Right: A smaller example of the tree featured on the left. Because of the much shorter painted heat conductor, this one changes color much faster and spreads more dramatically.*

At the end of the workshop participants gathered together to briefly present their projects. I asked them also to reflect on how the workshop went as well as how it could be improved. The following quotes taken from responses to the online post-workshop survey nicely represent participant's conclusions.

When asked what their favorite thing about the workshop was:

"Learning about different conductive materials."

"Seeing all the possibilities!"

When asked what their least favorite thing about the workshop was:

"It was hard to learn the skills quickly enough to make a project that worked."

"Not being taught how to make electronic connections."

When asked if they had suggestions for how the workshop or the tools and techniques used could be improved:

"I think the workshop should either be longer, or focused on a smaller number of crafts/materials."

"Having to figure out the circuit and the new materials at the same time was maybe too hard."

"It needs to be longer, and demonstrating applications can be nice."

REFLECTIONS ON PROCESS

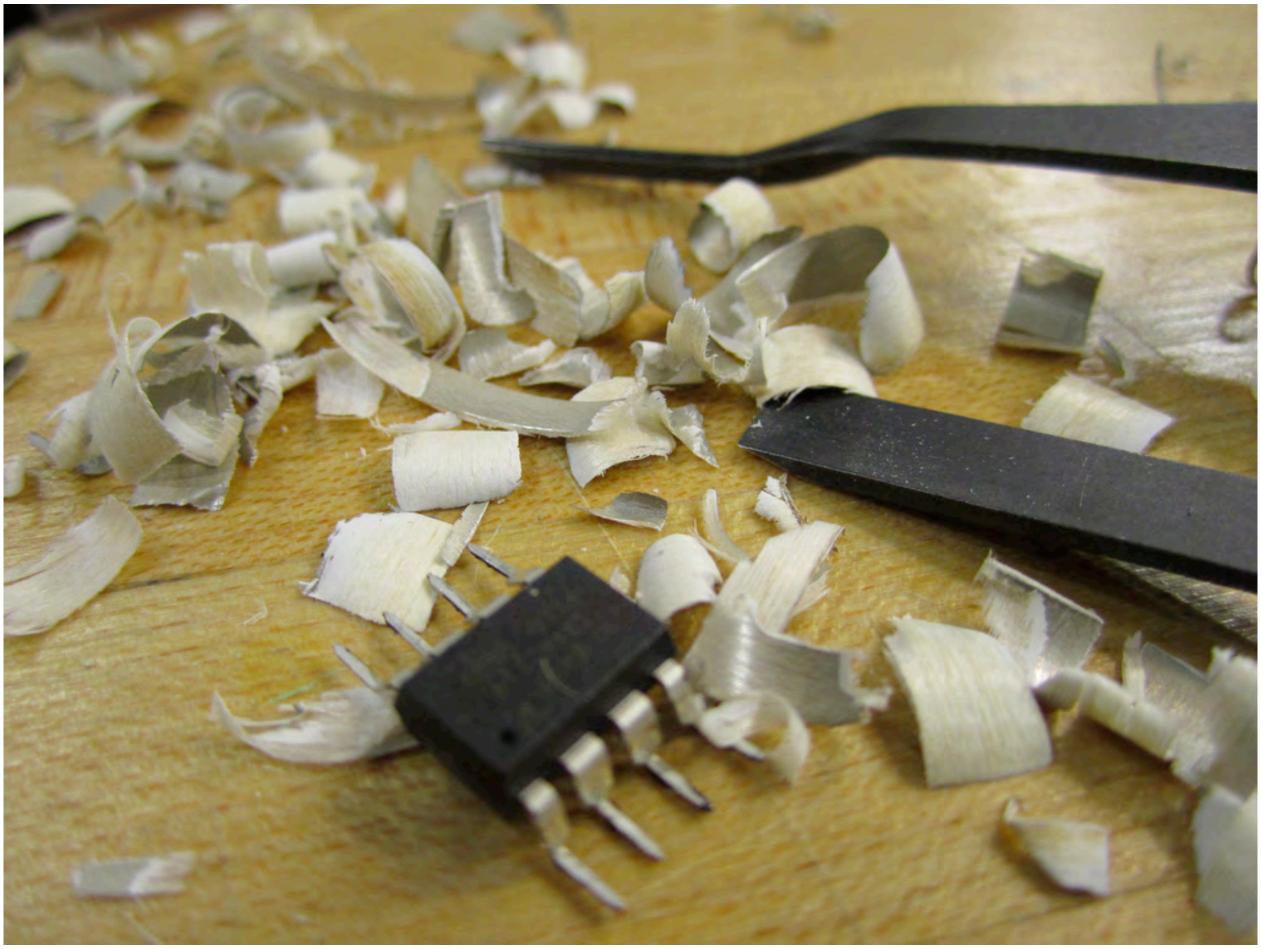


Figure 78. *The remains of carving a wooden circuit; a microcontroller, flakes of carved wood with conductive silver paint on them, and the tips of two carving tools.*

In the previous chapters I have detailed the process of developing and documenting my thesis, and presented the outcome, which includes the website, a collection of examples and two workshops. I would like to conclude my thesis with a series of reflections on process.

In terms of my own process I reflect on balancing method and intuition throughout my sample making process. I discuss what it meant to document my results, in real-time, as I was producing them. I describe how launching the website, as a platform for organizing and sharing my work, helped me to be more explicit about my processes and techniques.

Based on observations I made during the workshops I reflect on their different styles of building. I describe the roles that sketching, prototyping, rehearsing and debugging play throughout different kinds of building processes.

Balancing Method and Intuition

Throughout my sample making process I had no set strategy for balancing method and intuition. Intuition played a part throughout the whole process, from sourcing the materials and tools, to deciding what samples to make and how to test them for valuable results.

The more familiar I was with a certain material or tool, the more my intuition played a role in my decisions. As I came to know a material, I would work more intuitively with it, producing samples biased by what I thought would work and often refrain from trying things that I did not believe could work. The less familiar I was with a material, the easier it was to stick to planning and executing a particular series of experiments. This was due to the fact that I had not developed a feeling for or an opinion on how a material would behave, and so my intuition did not bias me and disrupt my plans. Interestingly enough, although this sounds like a whimsical way to approach solving a problem, it worked very well for me in many cases. And, though I have no proof for this, I do believe that finding a good balance between these two forces can lead to successful results, faster and more efficiently than a process based on pure intuition or methodology.

Part of finding this balance between fact and feeling, method and intuition was also in knowing how and when to transition between the search for prior work and hands-on experimentation. Being able to draw upon other people's results is an extremely valuable part of this process, but so is experimentation. My own experiments often took me weeks and lead me to the same conclusions that I could have read up somewhere. But the knowledge I build from experience was more complete and embodied that anything I could read up. Not only did I gain a sense for what could go wrong, but also I developed an intuition for how to make things work.

Being Explicit About Tacit Knowledge

Being new to the variety of crafts I was introducing myself to, I tried to leverage my position of simultaneous learner, experimenter and documenter. Nicola Wood [Wood and Horne, 2008] does research into how tacit knowledge can be elicited through the help of an intermediate expert learner and the structure provided by the documentation process. She describes how the expert learner is able to construct "bridges" that can be used by the novice to acquire skill. Harper talks of a similar process and calls it "disassembling intuition" [Harper, 1987]. The term codification describes the process by which tacit knowledge is transformed into explicit knowledge.

As I was learning and documenting, I was in the position of an intermediate expert learner, and became very aware of the tacit knowledge I was acquiring. Such knowledge included hunches about how a particular material would behave, being able to predict what tool would work best for a certain job, as well as becoming tactful in my practice. This heightened consciousness, regarding my developing skills, did not necessarily make it easier for me to convey them. But, prompting myself to produce documentation based on this awareness, did help me elicit information that in turn enabled me to better reflect on how, and why, I was doing things a certain way.

In my role as learner, I drew upon and came to appreciate other people's documentation. As I became more familiar and experienced with certain tools I realized that I was able to uncover or recognize additional information embedded within their documentation. The more I had in common with the person who had written the documentation, the more I was able to relate to their accounts and recognize important bits of information, where I had previously just seen text.

I able to detect embodied forms of information that were often embedded in their documented accounts. As a novice learner it is often impossible to discern what kinds of information refer to more embodied practices. This observation prompted me to try and include remarks that would make this distinction even more explicit in my own documentation.

Documenting in Real-Time

My best strategy for insuring that I document well, and that my documentation captures relevant parts of my process, is to document in real-time and throughout the whole process. I take notes along with every sample; I take pictures of everything in process, finished, material, tool, broken, fixed and working. I use video sparingly because it is time-consuming to edit as well as watch, but it is great for capturing procedures that are hard to convey otherwise. I always keep in mind the fact that I will be using my documentation to convey my process to others. This helps me be diligent about capturing moments that have become trivial to myself. I consistently take pictures of what I am doing, especially while I am learning and making mistakes.

While it occurred to me that I could mount a camera above my workspace and simply film my entire process, I don't believe this would result in better documentation, or that such an overwhelming amount of documentation would be capable of conveying my process more precisely or in greater detail. There is a huge amount of knowledge and detail embedded in the pictures I choose to take, simply by the fact that I chose to take them. Every time I think of documenting, I document, and have over time trained myself by be consistent in my documentation. While I don't spend much time thinking about documentation during the process, I do reflect on it when I am not in the middle of producing work. I go over the documentation I have gathered and am able to detect gaps that I can then go back and fill. I rarely repeat a process solely for the sake of documentation, but it does happen. I also spend time thinking of good ways of capturing certain details or procedures. Pictures are one of the mediums I use most in combination with written descriptions. I also try to sketch and draw diagrams when I think they are helpful.

I launched the Kit-of-No-Parts website roughly halfway through my process of sourcing supplies, which was very early on in my process of getting hands-on with the materials and tools. Setting up the website at this early stage meant I could post my documentation there and develop the structure and layout of the site alongside the techniques and recipes I was developing. Setting up the website and figuring out the structure and design as I worked, turned out to be an excellent way of capturing my process as well as the transformations of my thoughts as I was making, learning and documenting. Publishing my process in this live manner meant that anyone who cared to check the site regularly could follow my flow of organization in which I structured my thoughts through categorization and layout.

Styles of Approach

During the workshops I observed participants' processes and began to pay attention to the different ways in which initial sketches translated into electronic artifacts.

Most participants began with a two-dimensional sketch of their circuit and sometimes also their artifact. Almost always the two were drawn in separate stages, one after the other. In the cases where a participant was working with a particular artifact already in mind, the artifact might be sketched first and then the circuit "applied" to it. To further visualize the final artifact with this approach, participants would sometimes also physically layout the circuit elements on the actual artifact to get a better feeling for how things came together. "Applying" the electronics to an existing artifact, not traditionally associated with electronics, helped introduce new shapes and aesthetics to the circuit layout and design of certain components, such as resistive switches, which could be painted in many shapes. On the other hand this approach very much implies that electronics are being applied to craft, that both are not part of the same process. That craft and electronics don't happen at the same time, that they are distinct and separate materials, tools and processes.

The most fluid approach to blending electronics and materials that I experienced and observed in my own process, was that of having the materials in my hands, and being able to continuously work them into their final form. This process involved being able to go back, make changes and undo some of the things I had done. When working with conductive textiles and craft techniques such as knitting and crochet I reached a point where I was not thinking about integrating electronics into textiles, nor applying textiles to electronics, but was simply building and thinking equally and inseparably of both domains.

Rehearsing and Debugging

The Kit-of-No-Parts approach blends crafts and electronics approaches to building, and in doing so also blends the various steps associated with either process. In the following I would like to briefly describe the roles that rehearsing and debugging played in my process of building and working from a Kit-of-No-Parts.

Reflecting on the craft process, Tim Ingold describes the following relationship between rehearsal and performance.

"There is a critical moment, in implementing any task, when getting ready gives way to setting out. This is the moment at which rehearsal ends and performance begins. From that point on there is no turning back. Pencil marks can be rubbed out, but an incision made with the blade of a saw cannot be contrived to disappear." [Tim Ingold "Walking the Plank" in "Defining Technological Literacy – Towards and Epistemological Framework" p.68]

What Ingold describes as rehearsing, for me was my sample making process. By making samples I explored materials and mastered knowledge to develop my various techniques. I was then able to apply this knowledge and skill to building the collection of examples that I presented.

While very much an electronics term, debugging is a process similar to the process of sample making. Debugging is a process of spending time figuring out why something does not work. I would argue that debugging is more prevalent in building processes that build upon pre-designed and manufactured components, whose exact functions are not all known to the person using them, giving cause for the builder to spend additional time to understand how things work, when they don't work as intended. Debugging is a process you learn through experience, not only what to look for, but how to keep looking until you figure it out. Debugging requires a mindset of not giving up, because you know that the mistake lies somewhere and that you will find it eventually.

Through producing my samples I learned not only how to achieve desired results, but was also able to characterize undesirable results. Being able to recognize why something did not work was almost more useful than only knowing how to make things work and never experiencing failure. This experience, that came from making samples, was of great help later on in the process of debugging my final artifacts. These ties between an experimental sample making approach and a problem-finding debugging approach are part of what makes the Kit-of-No-Parts different from established electronics building. These ties also contribute to making the Kit-of-No-Parts a more transparent and understandable approach.

Concluding Remarks

I hope that the accounts of my process, which I have reflected on in this final chapter, convey that the Kit-of-No-Parts approach to building electronics is truly different from the style of building we currently associate with electronics. And that the techniques I have developed and presented in this thesis demonstrate the potential of this different approach as well as show that it is capable of very different results. Results that are not just different because of the materials they are made from but different because of *how* they were made.

APPENDIX

A Kit-of-No-Parts

Recipes for Materially Diverse, Functionally Transparent and Expressive Electronics

WORKSHOP 1

The Kit-of-No-Parts workshop introduces participants to a craft approach to building electronics. Imagine you could sculpt a switch, carve a circuit or plate your own speakers. This workshop will cover a range of traditional and contemporary craft techniques including gilding, carving, casting, sculpting and plating, and demonstrate how a variety of craft materials can be formed into functioning electronic artifacts.

Saturday 26th March 2011, 11-6pm
High-Low Tech research group, MIT Media Lab, Cambridge/MA
- no prior experience with craft or electronics necessary
- no fee, materials and tools provided
- max. 10 participants, email to reserve a spot: plusea@mit.edu

www.kit-of-no-parts.at

A Kit-of-No-Parts

Recipes for Materially Diverse, Functionally Transparent and Expressive Electronics

WORKSHOP 2

The Kit-of-No-Parts workshop introduces participants to a craft approach to building electronics. Imagine you could sculpt a switch, carve a circuit or plate your own speakers. This workshop will cover a range of traditional and contemporary craft techniques including gilding, carving, casting, sculpting and plating, and demonstrate how a variety of craft materials can be formed into functioning electronic artifacts.

Saturday 2nd April 2011, 11-6pm
High-Low Tech research group, MIT Media Lab, Cambridge/MA
- craft experience required (any craft), no experience with electronics necessary
- no fee, materials and tools provided
- max. 10 participants, email to reserve a spot: **plusea@mit.edu**

www.kit-of-no-parts.at

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