# Electronic/Computational Textiles and Children's Crafts

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## ABSTRACT
An astonishing array of new technologies is currently effecting a revolution in the professional design of textile artifacts. This integration of electronics and computation into textiles likewise suggests new directions in the practice of children's crafts. In this paper, we present a classification scheme that we believe will prove useful in structuring exploration and discussion of new directions in children's textile-based crafts. Within the context of this classification scheme, we describe several projects in our lab (along with early pilot-testing efforts) that offer examples of how children can work with computationally enriched textiles. We conclude by describing several extremely exciting–but nonetheless plausible–scenarios for continued work in this area.

### Keywords
E-textiles, electronic textiles, computational crafts, wearable computing.

### ACM Classificaton Keywords
K.3.0 [Computers and Education]: General*;* H.5.2 [Information Interfaces and Presentation]: User Interfaces – *haptic I/O, input devices and strategies*; C.3 [Special Purpose and Application-Based Systems]– *microprocessor/ microcomputer applications, real-time and embedded systems.*

## INTRODUCTION:
## FABRIC, COMPUTERS AND CHILDREN
A technological revolution is under way in the design of textile artifacts–a revolution whose impetus stems from the integration of electronic and computational devices with (both traditional and innovative) fabric materials. Novel designs for these "electronic textiles" or "e-textiles" might, for instance, include sensors to detect particular chemicals in the air; or they might include an acoustic array to detect the source or direction of a particular environmental sound [7]; or they might include fibers that detect strain, enabling a fabric structure to "know" whether it is performing correctly [9]; or they might include means for wireless communication [6]; or they might include light emitting diodes (LEDs) for whimsical aesthetic purposes [10].



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To date, there has been relatively little effort directed toward integrating this remarkable variety of new technologies into the world of educational and children's artifacts[1]. Traditionally, clothing and fabrics have been a fertile source of children's crafts: one can find youngsters making (e.g.) doll clothing, Halloween costumes, fabric hand puppets, quilts, or woven potholders. In all these activities, one could argue that children are making use of "advanced technologies"–synthetic materials, bright multicolored dyes, plastic fittings (such as buttons), and so forth. Thus, the world of children's craftwork in fabrics is, in a sense, already a world of (twentieth century) "high tech"; but that world has yet to explore, or exploit, the fascinating techniques that are currently having such an impact on the professional design community.

This paper, then, is intended to explore the ways in which e-textile and other new textile-related technologies can impact the practice of educational and children's crafts. We begin by presenting a taxonomy of ways in which children may work with the vastly-expanded landscape of fabric technologies; the purpose of this taxonomy is to provide a useful conceptual framework in which to place both our own projects and potential future efforts. In the second section, we describe several representative prototype systems, developed in our lab, that illustrate ways in which children can make creative use of "electronic/computational textiles". (These systems also allow us to reflect back upon the taxonomy of children's crafts presented initially.) The third section discusses our still-very-early attempts at pilot-testing our work with children; the purpose here is not to provide full-scale experimental case studies, but merely to reassure the reader that our various projects are quite plausible as instances of children's crafts. We conclude with a discussion of medium- to long-term future prospects for this work, and for the kinds of educational research that may be specifically encouraged by textile-based craft activities for children.

### Electronic/Computational Textiles and Children's Crafts: a Taxonomy of Strategies for Design
In part because the landscape of new textile technologies is so varied and rich, it is sometimes difficult to grasp the

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[1] See Berglin [1] for a marvelous counterexample employing temperature-sensitive fabrics in conjunction with computationally-enhanced stuffed toys.

sheer breadth of possibilities for children's crafts. We begin, then, by suggesting a taxonomic approach for classifying different ways in which children may interact with these new technologies. The purpose of this taxonomy is to help researchers think about, and compare, different approaches to children's textile-work. It should be stressed at the outset, however, that the categories presented here are not mutually exclusive: some projects may illustrate approaches derived from more than one of these categories simultaneously.

### *"Electronic" (or "Hardware") Craft Activities*

One style of textile-work for children focuses on the arrangement or placement of electronic/computational elements into a fabric substrate. For instance, children might be given a piece of fabric in which there are multiple available sites for the placement of (e.g.) LEDs, batteries, sensors, microcontrollers (small computer chips), and so forth. The fabric in this case acts as something like a flexible background onto which children can arrange various sorts of hardware "building blocks" to produce a wide variety of effects. More generally (and more powerfully), one could broaden this approach to allow children to place conductive pathways onto a fabric substrate–e.g., by stitching a trace with conductive thread or drawing a pathway with conductive ink. Essentially, then, this approach focuses on the electronic or computational "hardware" aspect of a textile artifact: the goal of the child is not so much to do fabric-work *per se*, but rather to use fabric as the material substrate for some electronic or computational effect.

### *"Fabric" Craft Activities*

As an alternative to the "hardware" focus of the previous category, one could imagine a wide variety of activities in which the electronic or computational behavior of the fabric is treated as a given, and the child's work focuses on customizing, shaping, or decorating the enhanced textile material. To take an example, one might provide children with a fabric already equipped with (say) an arrangement of touch sensors and lights, such that when a given sensor is pressed it activates a particular set of lights. The child's activity in this case might be to add decoration to the fabric (e.g., by hand with a fabric marker, or via embroidery), or to cut or shape the fabric in some interesting way. In essence, then, this sort of activity makes use of an enhanced material to enrich the more traditional arena of fabric-based crafts. It should be noted, though, that even this "traditional" arena may itself employ computers for different purposes: for example, one might use a computer-controlled sewing machine to embroider a complex pattern onto an electronically-enhanced fabric; or one might use a laser cutter to shape the fabric in some precisely-specified pattern.

### *"Software" Craft Activities*

The previous categories focused on the physical arrangement of electronic or computational elements on fabric, or on the decoration or shaping of fabric. Yet another possibility, however, is that the child's activity might focus on creating or customizing specific behaviors for enhanced fabrics via programming. Thus, one might begin with a fabric in which a geographic arrangement of lights and sensors has been pre-specified, but the particular relation between those elements can be programmed in by the child. (Essentially, one might think of fabric artifacts here as "display screens" that can be programmed to show particular patterns or animations; or, perhaps, a better analogy is to think of the fabric artifacts as rather like a genre of programmable "plush robots" that include sensors and actuators of various sorts.) Conceivably, this sort of activity might involve little if any physical manipulation of the fabric material itself: a child might use a desktop computer or handheld device to write a program which is then transmitted or downloaded to a garment or tapestry. Yet another style of "programming" is illustrated by one of the projects described in the following section ("Quilt Snaps"): here, a collection of electronically-enhanced fabric pieces can be combined via snaps to create larger programmed effects. Thus, in this case one can think of the "programming medium" as consisting not of a language editor on a computer screen, but rather as a set of fabric building blocks that can be directly combined into larger programs (analogous in spirit to some screen-based visual programming languages).

Once more, the purpose of this classification into "hardware/fabric/software-based craft activities" is heuristic: the categories help to structure our discussions of how some craft activities highlight certain themes (e.g., electronic design) while suppressing others (e.g., programming). In the following section, we present several projects underway in our lab, and discuss them in the light of our classification scheme.

## PROJECTS

This section will introduce three projects we are currently investigating: an electronic sewing kit, a fabric based computational construction kit (Quilt Snaps), and a range of programmable wearable displays. In the course of our discussion we will relate each project to an element of the taxonomy of the previous section. In our examination of electronic sewing kit we will focus on electronic activities; in our dialogue about Quilt Snaps, fabric activities; and in our exploration of wearable displays, programming activities. The final part of this section will discuss how children's craft projects might profitably include more than one type of activity and look at the three projects in this light.

### An Electronic Sewing Kit

In the Sewing Circuits project, we developed an electronic sewing kit intended to introduce children to electricity and circuits via e-textiles. We believe that the e-textile medium has several affordances that make it a rich material for this purpose. The remainder of this section will describe the components of an electronic sewing kit and then discuss what we believe are interesting implications of the kit and its associated crafting activities.

The electronic sewing kit includes the basic materials needed to begin embedding electrical components into fabric: conductive thread and a needle, a battery which can

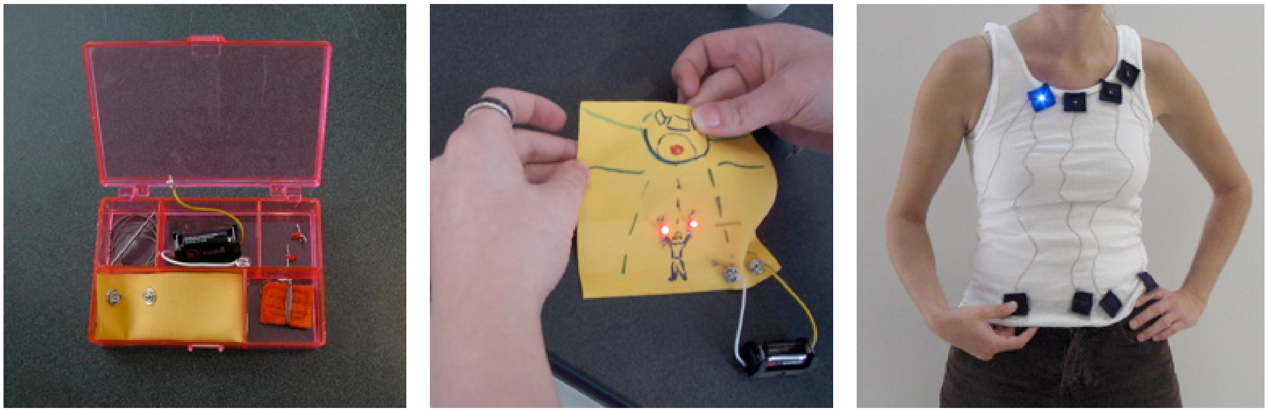

**Figure 1.** An electronic sewing kit, an e-textile patch designed and built by a high school student in one of our Sewing Circuits workshops, and a wearable electronic textile designed and built by one of the authors.

be either stitched or snapped onto a piece of fabric, LEDs which have been modified so that they can be sewn onto fabric like beads, and a soft fabric switch. Figure 1 shows an electronic sewing kit and a fabric patch and tank top that were built with such a kit.

We believe e-textiles have several important qualities that make them a wonderful medium for introducing electronics to children: the materials and tools are readily available and easy to use, the medium allows for creativity and ownership of the crafted object, and the medium looks and feels entirely different from traditional electronics media like robots, radios and remote control cars. The rest of this section will be devoted to a discussion of these properties, touching on what we see as some of the unique possibilities for traditional electronics as a medium for children's e-textile craft.

First of all, the raw materials for an electronic sewing kit are easy to obtain, and the components are simple to build. The kits are something teachers, parents or even kids can make themselves. The LEDs and batteries can be purchased from electronic hobby stores, and the conductive thread is easily obtained on-line. "Stitchable" LEDs and batteries can be made by twisting the leads of these components into hoops. The fabric switch can be made using a technique first introduced by Post and Orth, *et al.* [10] in which two conductors are separated by a piece of thick fabric with a hole cut out of it[2].

Because the kit makes use of readily available materials and straightforward techniques, we are optimistic that it could open up an opportunity for a child to become engaged in playing with electronics as a crafting hobby. Children using the kit are not working with a sophisticated designed artifact; they are working with simple raw materials. We believe this simplicity is an advantage—there is something empowering about working with the same stuff that professional engineers use. Nothing is mysterious or hidden from the child. Because of this simplicity, the electronic sewing kit is naturally very flexible and extendable. The kit can be easily augmented to include sensors, motors, microcontrollers and other devices. Given mentoring by a parent or teacher, a child could conceivably embrace or even request these extensions and eventually make additions on his own as the sophistication of his designs increased and his familiarity with the electronics hobbyist culture progressed.

In addition to being accessible, the materials that make up the electronic sewing kit are safe and easy to work with. Needles and thread are much less intimidating than the tools traditionally used to build electronics artifacts, and simple e-textile techniques are much less dangerous, involving no hazardous materials (like solder) or tools (like soldering irons). To be sure, scissors and needles are sharp, require fine motor control and are not suitable for use with children of all ages, but, as we will discuss later, we have had success in working with children as young as 8, and we are confident that most children over the age of 8 or 9 could successfully stitch circuits.

Furthermore, the electronic sewing kit enables children to design and build artifacts that they are personally invested in. Once a child decorates a shirt or patch or baseball cap with electronics, she can take it home with her; she can wear it around, embellish it with other crafting materials and feel proud of the work she did. This scenario stands in stark contrast to a common first experience with circuits, where students work with breadboards to experiment with electricity. Breadboards or "prototyping boards" are devices that allow users to experiment with circuit design by providing a surface that enables the quick rearrangement of electrical components. Breadboards present the same safety and accessibility advantages that electronic sewing kits do, but what is built on a breadboard is always temporary; and perhaps most importantly, the breadboard has none of the aesthetic possibilities that the e-textile medium does.

Finally, we believe that the qualities of fabric and the traditional application of textiles in areas like fashion may

[2] For a more detailed description of our electronic sewing kit, including information on where to purchase supplies and step-by-step instructions detailing how to make each component of the kit, visit our on-line instruction manual [3].

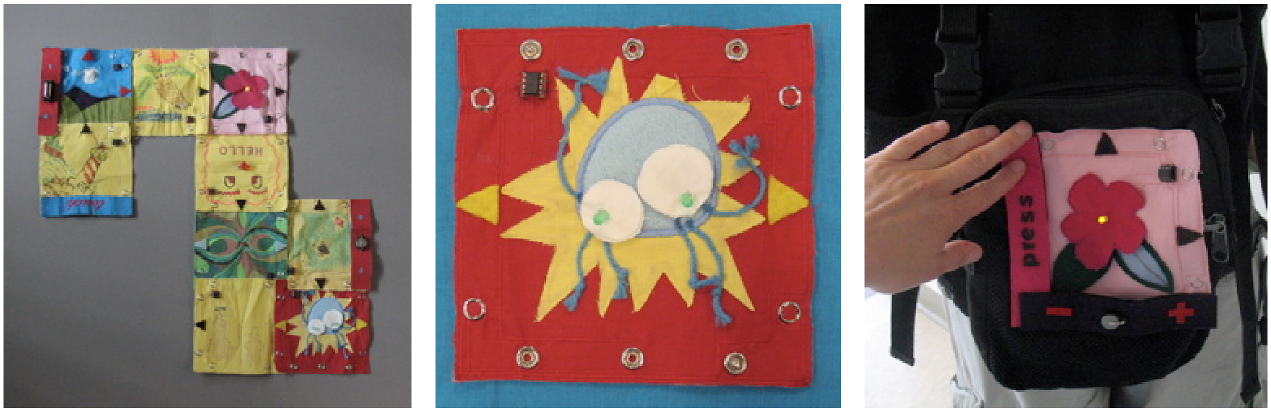


**Figure 2.** Quilt Snaps: (from left to right) a dynamic quilt, a close-up of a decorated patch, and a patch snapped onto a backpack.

entice new and diverse groups to experiment with electronics. As mentioned earlier, e-textile artifacts just don't look like traditional electronics artifacts. We are particularly interested in the possibility that e-textiles may present a unique opportunity to engage young women and girls in electronics and will explore this possibility in greater detail in our discussion of possible future research topics.

The electronic sewing kit is an example of a minimally designed artifact. As was discussed, we believe this is a source of strength for the Sewing Circuits project, but we are also interested in designing e-textile systems that communicate more specific intellectual content or encourage more specific activities, and the next subsection will detail our efforts to create an e-textile manipulative.

### Quilt Snaps

Quilt Snaps is a fabric based construction kit that consists of a set of computationally enhanced quilting pieces or "patches" which kids can decorate with crafting materials and then either utilize individually as personal displays, or snap together into quilts to create dynamic light and sound patterns [4]. Each patch is a piece of fabric containing a microcontroller, an LED or buzzer and snaps on each of its sides. Arrows on each side of a patch indicate whether it is an input or output side. Output sides can only be snapped onto input sides and vice versa. Once a quilt is snapped together, signals travel through the quilt, following the arrows. These signals are then displayed by the LEDs or buzzers on each patch. Sensor strips that can be snapped onto patches endow the pieces with interactive capabilities, triggering signals when activated. For example, touch strips generate signals in response to touch and light strips in response to the presence or absence of light. The overall result is a multi-piece quilt construction in which a path of light or sound travels from piece to piece, possibly prompted by a beam of light or a user's touch.

Our discussion here will focus on the crafting phase of this project, where children decorate blank quilt squares. Where the previous section described possibilities for creative use of electronic hardware, this section will explore the possibilities for creative use of fabric and other crafting materials, examining how these materials and traditional arts and craft activities may enhance the educational and cultural value of e-textiles. (The crafting phase for Quilt Snaps may also include work with electrical hardware, and we will return to this issue in a later section.) We will begin our discussion by examining the range of materials and techniques children might use to decorate Quilt Snaps pieces. We will follow this discussion with an exploration of how including possibilities for artistic expression in such an activity may encourage engagement in the activity and the artifacts being created or embellished. Finally, we will explore how kids might use their decorated patches as both personal display media and as media for collaborative investigation of various aesthetic and computational ideas.

In the crafting activity that we envision for Quilt Snaps, a user will design an image that incorporates the LED or other output device on his patch; then–employing, for example, felt, fabric paint, beads and ribbons–he will ornament his patch. The patches in Figure 2, decorated by a group of novice adults and researchers at our lab, show how various fabric materials and techniques might be utilized and also illustrate how different users are likely to decorate patches in very different styles.

We believe that by providing this opportunity for artistic expression and allowing kids to keep the patches they make, we will strengthen their interest in and attachment to Quilt Snaps, and any lessons a mentor is attempting to convey with the manipulative and its accompanying activities. We hope that these lessons will encompass everything from circuit theory to artistic composition, and are optimistic that in combining content from multiple realms we may spark long-term interests in electronics, computer science and art. We also believe that by providing multiple ways for kids to express their creativity, through the engineering activities discussed in the previous section and the artistic activities discussed here, we will have a greater chance of sparking an e-textile crafting culture for kids.

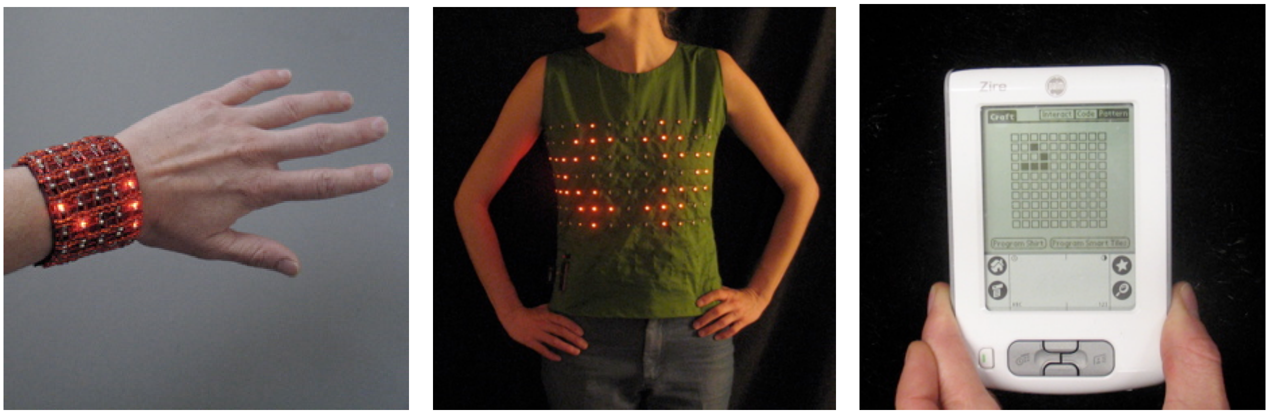

**Figure 3.** Bracelet and tank top displays and the PDA programming interface.

Once the patches are decorated they can be used as both portable displays and as collaborative crafting media. The rest of this section will examine these two uses in turn.

As was discussed in the introduction, children are simply surrounded by fabric, and frequently use items like clothing and handbags as elements of personal expression. Quilt Snaps were designed to exploit the unique role that textiles play in children's lives. The soft patches can be attached to almost anything—for example, they might be snapped onto notebooks, lunch boxes or hats in addition to clothing. Figure 2 illustrates the possibilities with a patch attached to a backpack. We hope that kids who are given the opportunity to decorate Quilt Snap patches and shown how they can be embedded into personal items will integrate the patches into their personal artifacts and lives, proudly displaying the result of their creative efforts.

Quilt snaps are not only a personal artistic medium; they are a social one as well. Hoping to retain the spirit of traditional collaborative quilting, the Quilt Snaps activities encourage kids to decorate and individually use their own patches, yet also provide a means through which users can combine their patches with others to build quilts that create complex computational and artistic patterns. Though users can interact with single patches via the input strips, they will obtain much more interesting patterns by linking their patches with others.

The directed graph configurations created by the quilts might be used to model the movement of electricity or water, or to explain concepts such as control flow. The act of snapping together patches to build quilts, combining discrete computational elements to create larger and more complex behavior, can be thought of as a type of programming. The next section will examine the programming aspect of e-textile crafts in detail, relating it to more sophisticated e-textile artifacts than the ones we have looked at so far: wearable displays.

### Programmable Wearable Displays

In the course of our investigations into electronic textiles, we have built several displays in which lights, arranged in a grid pattern, are attached to wearable artifacts like jewelry and clothing. These grids of lights are controlled by microcontrollers and can be programmed to display a range of low-resolution animations (scrolling text, for example). Figure 3 shows two of the displays we have built: a beaded bracelet woven out of glass beads, metal beads, and LEDs, and a tank top with stitched-on LEDs.

The remainder of this section will introduce cellular automata as an example of the type of programs children might explore using wearable displays, explain why we think cellular automata are an interesting educational and conceptual application of wearable displays, and then describe our preliminary efforts at building programming interfaces for wearable displays in general and cellular automata on wearable displays in particular.

Cellular automata are mathematical models that explore how local rules executed in discrete time steps can result in complex global patterns [5]. Cellular automata are usually implemented on a computer screen on a grid of colored "cells" (the squares in the grid). Cells can display their "state" through their color, and can communicate with their immediate neighbors (the squares surrounding them). As the cellular automaton evolves in time steps, each cell computes what its state will be at time t+1 based on its state and the state of its neighbors at time t. Cellular automata are used to model a variety of physical phenomena from biological behaviors like the flocking of birds to chemical reactions and particle collisions. (Probably the best-known cellular automaton is the "Game of Life", a system in which two states—"live" and "dead"—interact to form beautifully complex and intriguing patterns [5]).

We believe that cellular automata provide an interesting domain of exploration for wearable displays in an educational or intellectual context because of their ability to model or provide good metaphors for understanding sophisticated scientific concepts. The ideas that cellular automata are best at illustrating are some of the most important and misunderstood of the day: how seemingly irrelevant small behaviors can lead to large scale consequences and how complexity or apparently designed phenomena can arise naturally as the result of simple local interactions. These ideas can help make sense of our modern world; the understanding of topics from evolution to global warming could be informed by study of cellular automata.

Having stated our case for the intellectual relevance of cellular automata, let us examine how children might use wearable displays to explore them. A particular cellular automaton like the Game of Life is "programmed" by the setting of an initial state. Different initial configurations of live and dead cells on a grid will result in different dynamic behaviors when the rules of the Game of Life are applied.

Arrays of LEDs, like those shown in the wearable displays in figure 3, provide a perfect medium for displaying cellular automata. We have implemented a variety of cellular automata on the displays, including an ideal gas simulation and the Game of Life, and we are in the process of developing and refining programming interfaces for the displays that will allow users to set initial configurations for the automata.

In our first attempt along these lines, we have embedded wireless communication capabilities (specifically an infrared (IR) receiver) into the tank top shown in Figure 3, allowing it to be programmed by a PDA or other IR transmitting device. The tank top in the figure is running the Game of Life. The figure also shows a close-up of the PDA interface that is used to set the initial state of the shirt.

While the tank top is currently the only device that can be programmed by the PDA, since all displays are essentially grids of lights (or, potentially, other actuators), the same basic PDA interface should work with a variety of devices. Our immediate goal with this work is to develop a general-purpose e-textile display programming tool that, perhaps after setting a few parameters defining the size and shape of the display, would be able to send relevant information to any such device. It should be noted that the programmer would be able to initialize configurations for applications other than cellular automata. For example, in a text display application of the wearables, the same interface might be used to set the initial text that will be scrolled.

We are excited by the possibilities that wirelessly programmable wearable displays present for a different type of creative engagement in e-textiles than the ones we have already discussed. The wearable and thus mobile and ambient nature of the displays again provide unique opportunities for student participation, but in this case with programming. We are excited by the possibility that the ability to essentially wear one's programs around, making them visible in a way that no screen based artifact ever is, may spark in budding developers a new kind of pride and interest in programming.

The portability and wireless communication capabilities also make wearable displays fruitful artifacts for collaborative activities. Wearable displays might not only communicate with PDAs, but other e-textile devices as well. Imagine a classroom full of children wearing communicating displays, similar to the environment envisioned by Borovoy *et al.* [2]. A child might be able to program his shirt with a Game of Life configuration and then stand next to a friend to watch the configuration march onto the friend's shirt. Alternately, such an environment might stimulate a playful hacker community in which students strive to infect or crash each other's clothes and jewelry.

### Blurring the edges between electronic, fabric and programming crafts

The three preceding sections looked at each component of our taxonomy in isolation, providing examples of each type of craft, but there is no reason why working with electronics, traditional craft materials and programming should be mutually exclusive activities. Indeed, while the previous sections did not stress this aspect of our work, many of our projects already blur these boundaries. For example, in our Sewing Circuits workshops, children work with crafting materials like fabric paints to decorate their electrical designs, and Quilt Snaps users have used electronic sewing kits to place LEDs and other components into their patches during the decorating phase of that activity. Finally, we see the wearable displays presented in the last section as examples of the more sophisticated artifacts users of the electronic sewing kits may eventually learn how to build.

## PRELIMINARY USER TESTING

This section will discuss our still-very-early attempts at pilot-testing our work with children and adults. These exercises have not been full-scale experimental case studies, but have served to guide our designs and assure us that our ideas are reasonable. The first subsection will describe our experiences holding Sewing Circuits workshops and the second subsection will describe our even more preliminary pilot tests of Quilt Snaps.

### Sewing Circuits

We have recently held four Sewing Circuits workshops in different countries and in different settings, with children of varied interests, age groups and backgrounds. In every workshop, each participant was given a kit like the one described in the projects section and shown in figure 1. The participants were also equipped with scissors and fabric markers. The sessions began with a brief description of the kit and its contents, and a short introduction to circuits. A workshop leader (one of the authors) would then demonstrate what the kids should do by designing and beginning to sew a circuit into a fabric patch. The participants would then embark on their projects; the kids designed artistic patterns and electrical circuits, drawing out pictures with the markers and sewing out circuits with their needle, thread, switch and LEDs. Throughout the session, the workshop leaders were available to assist the participants with their work. At the end of a session, participants were allowed to take home whatever artifacts they had built.

The first two sessions were a half hour long and occurred with groups of high school girls, from grades 10-12, who visited our lab. The second workshop was two hours long, and was held at a family home in London with 3 girls ranging in age from 9 to 14. At this latter workshop, the

**Figure 4.** Sewing Circuits workshops: high school girls decorate fabric patches (left), and two boys work on sewing electronics into an umbrella and a knapsack.

girls were introduced to artifacts from previous workshops through pictures, and were encouraged to mix art and electronics in order to create "interactive art" that reacted to touch.

In the third workshop, also two hours long, we worked with 3 boys, aged 8, 10 and 12, at a research institute in France. In this workshop, rather than have the children sew onto fabric patches, we had them augment personal items including bags, purses and an umbrella. Figure 4 shows children from two of our workshops working on their projects.

The results of these pilot tests have been encouraging. Our participants have been enthusiastic and inquisitive. Though they sometimes struggled with issues like determining what caused a short circuit, and the fact that LEDs are diodes that can only conduct electricity in a single direction, almost every participant was able to construct a working circuit by the end of the session. In our work with almost twenty children, only two failed to complete working circuits in the time allotted.

It was exciting to observe participants helping each other "untangle" their circuits, and, in one instance, spontaneously design a parallel circuit after having been shown examples of series circuits. It was also gratifying to hear expressions from children that indicated that they wanted to integrate their fabric-based circuits into their lives. Here is a sampling of some of their comments:

> "I'm going to bring mine to school!"
> "I'm going to hang this on my wall."
> "I'm going to sew this on my quilt."

### Quilt Snaps

We have so far held one Quilt Snaps pilot study. In a workshop that was in many ways similar to the Sewing Circuits workshops described above, a group of eight novice adults, most of them either teachers or museum employees, sewed LEDs into Quilt Snap pieces. Along with an electronic sewing kit and fabric markers, each participant was given a blank Quilt Snap piece to decorate. The workshop differed from the Sewing Circuits activities in that users were asked to leave their patches with the organizers at the end of the session. (It should be noted that several participants expressed some dismay at this request, seeming rather attached to the pieces they had ornamented.)

Again, the result of this pilot test was encouraging but inconclusive. All but one out of the eight participants were able to stitch out working circuits, and everyone seemed enthusiastic about the workshop and the technology.

## OPPORTUNITIES FOR THE FUTURE: RESEARCH AND APPLICATIONS IN E-TEXTILES AND CHILDREN'S CRAFTS

To this point, our discussion has focused on the classification and description of illustrative projects that use electronic/computational textiles as a medium for children's crafts. In this final section, we attempt to take a longer view, imagining plausible future projects and research opportunities in this area.

### A Sampler of Future Project Ideas

One of the most compelling reasons for pursuing an interest in children's e-textile craftwork is that fabrics and textiles have such intense, pervasive, and personal importance in children's lives. Children might use electronic fabric to create (say) personalized textbook covers, or hair ribbons, or jacket patches, A child might incorporate personalized textile crafts into curtains or wall-hangings in her room; or sew a patch onto a backpack; or embed a customized set of LEDs into her sneakers. Unlike many other craft materials, textiles seem to lend themselves to a remarkable array of objects that have profound importance in children's lives–clothing, accessories, room furnishings, and so forth.

We can imagine the development of a variety of software tools combined with physical "kits" of pieces to assist children in the creation and programming of all sorts of fabric-based artifacts. For example, a design system for backpack patches might include a computer-based graphics tool for decorating a patch and printing it out onto a sheet of inkjet-printer-compatible fabric; once printed out, the child could then cut the outline of the patch with a laser cutter; he could then sew a power source, touch sensor, and lights onto the patch (in a manner similar to the Sewing Circuits project).

There are many technological innovations that could–and should–be explored beyond those mentioned in our particular examples. A wide variety of sensors may be incorporated into fabrics (beyond the touch and light sensors that we have explored to date): some possibilities include sensors for sound, strain, or humidity. (Just to take an example: one might imagine a child's pendant that responds in some interesting way to the act of waving.) Commercially available light-sensitive pigments allow fabrics to change colors in response to sunlight; these might be combined with elements of a computer-controlled display.

There are other possibilities for fabric-based actuators as well (beyond the use of LED lights). A fabric artifact might, for example, send an IR signal in response to a change in light or temperature; or it might emit a sound. Again, just to take an example: one might design a child's "programmable umbrella" that emits sounds of various sorts when it is rained upon.

Indeed, one of the most exciting developments in professional textile technology involves rethinking the purposes to which textiles may be put. Architects now employ robust textiles (e.g., with carbon fibers) to create stand-alone structures [8, pp. 103-136]. In the longer-term future, then, children's use of e-textiles may not be limited to the "softer" materials of clothing and quilts, but may also be closer in spirit to construction in wood or plastic.

### A Sampler of Future Research Topics

We believe that the study of children's craftwork with novel textiles offers several unique, and extremely provocative, possibilities for research in developmental cognitive science. As noted earlier, textiles have a striking degree of importance and "presence" in children's lives; and as a result, many of the most prominent and natural topics for research in this area have a sociological (or perhaps anthropological) emphasis. For instance, it would be interesting to see what sorts of programming children do when the programs in question are intended to direct the behavior of their own garments–i.e., what sorts of programming tasks do children attempt when the purpose of the program is a matter of personal display? Clearly related questions would include whether these programming decisions vary with age or gender.

Gender issues, in general, would seem a plausible and interesting choice for study in the area of children's textile crafts. Historically, there has been a strong cultural identification between textile crafts–sewing, weaving, garment design–and "girls' interests". It would be interesting, then, to see how and whether girls in particular appropriate and explore the wide variety of new technologies and systems discussed in this paper. Since many activities involving computer technology (e.g., video games) are disproportionately associated with "boys' interests", textile crafts might prove to be an effective means of promoting girls' enthusiasm toward programming and engineering.

Still other areas of research might focus on issues such as growth of complexity or sophistication in children's engineering or programming work. Do children who work with electronically or computationally-enhanced textiles develop their own "styles" of programming (cf. Turkle [11] and her discussion of stylistic differences in early Logo programming)? Are there types of programs or effects suggested by "shared" programming media like Quilt Snaps, in which multiple children may contribute a small personalized piece to an overall group construction or more sophisticated communicating artifacts like the conversing wearables imagined earlier? In sum, then, the territory for research and exploration of children's textile work seems no less exciting than the technological developments in the world of textile design.

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