Fabrication for Children:  
Toward the Frontier of Educational Construction

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Abstract: The notion of "educational computing" is rapidly expanding to accommodate not only computers themselves, but also the devices casually known as "peripherals". In particular, with the advent of a wide variety of fabrication tools and software, children are increasingly able to use computers to design and construct physical objects in a range of expressive materials. This paper looks at the current landscape of children's fabrication and identifies three central areas for research and development: (a) the design of new child-appropriate interfaces for construction, (b) the exploration and creation of new output devices for children's activities, and (c) the design of software infrastructures and community support for children's construction. Throughout the paper, we make use of examples drawn from the various educational construction projects undertaken in our own laboratory.

1. Introduction

The term "educational computing" traditionally conjures an image of a child seated before a desktop computer, interacting with software applications through the mediation of the computer's screen. Over the past decade, this image has been extended to include not only desktop computers, but a range of portable and handheld computational devices as well; still, the term itself tends to focus attention on the central processing unit (CPU) as the essence of the "computer". Recently, however, an increasing degree of attention has been paid to those devices historically (and somewhat misleadingly) known as "peripherals"—that is, the various devices (usually devoted to input/output functionality) attached to the "central" computational device.

Prominent among these peripheral devices are tools for fabrication and construction—laser cutters, milling devices, 3D printers, and so forth. While such devices are not new in principle—industries have used computer-controlled fabrication for decades—they are rapidly becoming smaller-scale, safer, more affordable, and more compatible with the landscape of home and school computation. In short, we are entering a fertile new landscape of educational (as well as hobbyist or amateur) construction. [Cf. [7], [6], [5], [3]] Indeed, in his popular book The Long Tail, Anderson refers to just one aspect of this development (3D printing) as “the sort of radical technology that sets the imagination soaring.” [1, p. 247]

The implications of this technological sea change for children's activities could well be profound: just as the traditional tools of children's construction (steel scissors, brightly-colored yarn, vivid paints, multi-purpose glues) themselves represent the "high technology" of earlier eras, the newer devices and materials could likewise become part of the day-to-day background of children's lives. What this means in turn is that the sorts of things that children can design and construct “by hand” are themselves likely to undergo rapid expansion: rather than purchasing ready-made tops or kaleidoscopes or engineering kits or mechanical toys or a myriad other objects, children now (or will soon) have the ability to create individualized and near-professional versions of these artefacts for themselves. They will be able to use laser cutters to cut out arbitrarily-shaped flat pieces of wood, acrylic, paper, or textile: they will use 3D printers to “print out” complex shapes in materials like plastic or plaster; they will employ computer-controlled milling machines to fashion forms in (e.g.) chalk or wax; they will embroider complex patterns in fabric with the use of computer-controlled sewing machines.
This paper looks to the near future of this burgeoning landscape of educational fabrication and construction. Rather than focusing on what exists at the moment, however, we feel that the time is right to turn our attention to what needs to be done. In particular, we discuss three central areas of research that are central to the near-term development of children's construction. First, although existing devices such as laser cutters and 3D printers are extremely powerful, the interfaces to these devices are rarely appropriate for children or students. Thus, a central area of research will be the design of novel interfaces appropriate for children, and enabling young people to make creative use of fabrication devices. Second, the landscape of construction devices themselves remains unnecessarily limited and conceptually linked to the image of "industrial fabrication" (as opposed to, say, "children's fabrication"). Thus, another area of research will involve the creation and design of novel output devices geared toward children's lives and activities. Third, there is a tremendous opportunity (and crying need) for software tools that serve to support a worldwide community of children's creativity and construction in the same way that many popular websites support (e.g.) the sharing of videos, photographs, music, and the like. The research here should focus on the principled design of software infrastructure for children's construction and craft activities. Without progress in these three areas, the evolution of children's construction will be slowed; and more important, the intellectual lives of a vast number of children will be needlessly impoverished.

The remainder of this paper is devoted to discussing, in turn, each of these three research areas, with attention to the state of current work and promising areas of near-term development. (Frequently, as a basis for our discussion, we make use of a variety of earlier or ongoing projects undertaken in our laboratory.) At occasional points, the discussion is arguably a bit futuristic; though even at these points, the intent is to remain within the bounds of technological plausibility. In the final section, we integrate the various themes and place our discussion in a somewhat broader historical context.

2. Child-Appropriate Construction Interfaces: or, Beyond the Industrial Mindset

Until recently, fabrication devices such as laser cutters and 3D printers have been conceived of as large-scale industrial tools. As such, their design has been guided by the values and concerns of their original community: high power (e.g., for the lasers in laser cutters), high precision, and software interfaces characterized by a concern for a very "high ceiling" (that is, it should be possible to do just about anything the user wishes to do). These are not necessarily mistaken values to hold, but they are hardly the first design features that come to mind when children are the users of these devices.

What sorts of innovations might emerge as we re-imagine fabrication devices as children's artefacts? Several distinct types of development seem to be promising.

2.1 Direct physical control

Typically, the current controllers for fabrication devices are characterized by complex software systems (even our own lab's desktop laser cutter, for example, must have files sent through the commercial drawing program Corel Draw). Imagine, by contrast, that we wish to create a child-appropriate interface to (say) a laser cutter. In this case, we might design tools so that a young user could draw a shape by hand–using, for instance a tablet device and digital pen (or even, plausibly, finger movements)--and by these means, specify the desired path of the laser. This represents a straightforward change in interface that directly responds to the nature of children's work: it does not pay much attention to high resolution (a child's hand movements are likely to be inexact), but it permits the laser cutter to be controlled in ways that respect the large-scale movements, immediacy, and informal nature of children's projects.

It is not hard to extend this vision of "direct control" in various ways. Hand-drawing on a tablet, for example, could similarly be used to control an embroidery pattern for a computer-controlled sewing machine. Or, moving beyond two dimensions, we might envision a more ambitious system in which a child uses gesture in space to (at least partially) control the figures output by a 3D printer. (It is plausible, for example, that at least some basic shapes such as cylinder, block, or cone could be specified this way.)
In our lab, we have developed a rough prototype of still another type of plausible interface device for three-dimensional modeling: a “3D Geoboard”. The basic idea behind this device is that it consists of a series of horizontal planes (or transparent shelves), spaced about six inches apart; in addition, there are a set of markers (each about the size of a golf ball) that can be placed in holes set within the shelves. Our mockup of the device is shown in Figure 1: as seen in the Figure, the placement of markers can thus designate a set of chosen points in a volume of space. Although this mockup is not connected to a desktop computer, by effecting such a connection the positions of markers could be "read in" to a software application and used to designate points in 3-space. Figure 1 (at right) shows our own prototype software system for working with such a device: here, the positions of markers in the 3D Geoboard are used to specify the vertices of a polyhedron. This shape could now be printed out on a 3D printer.

The purpose of this example is merely to show that there are numerous possibilities for designing child-friendly 3D input devices suitable for use with fabrication tools. The Geoboard device, even in principle, is limited in ways that would displease "industrial-strength" users—for instance, one can only place markers at the positions designated by spaces provided. Still, it would arguably be a highly usable (and potentially, educationally powerful) device for young children learning to make use of tools for physical modeling in three dimensions.

2.2 Combining "Informal" Scanning with Fabrication

The previous paragraphs outlined a variety of potential interface designs that would enable children to specify two- or three-dimensional forms for fabrication using their fingers, hands, and arms. Yet another way of specifying a form to print out is to begin with an existing form. Imagine, for instance, a relatively simple "silhouette-cutting device" that allows a child to place (say) a stuffed animal, on its side, on a table; the shape of the animal is read in by camera, and the laser cutter then produces as output a flat silhouette of the animal. (In effect, we are using the laser cutter here to produce a "shadow" of the animal as produced by a bright light.) Likewise, the child could simply place her hand on the table, and the laser cutter would produce an outline of her hand. Using more elaborate software, the same idea could be extended in a variety of ways: one might design a tool that permits a child to place (say) a doll or teddy bear on the table as a first step toward cutting out fabric pieces that could be used as elements of costume for the object.

In effect, we are describing here means for extending the design of "scanners" in ways that make sense for children's fabrication. There already exist 3D scanning devices for use in conjunction with 3D printers; such devices "read in" the external form of a given object and convert that form to a digital format that can then be output to a printing device. A plausible extension of these sorts of 3D devices for typical children's activities would be (for example) to create a "mold-maker": a device that scans a 3D object and then prints out a plastic mold that could be used to create a negative version of the object in plastic. The resulting negative would then allow the child to create copies of the (positive) object in a material such as candle wax or chocolate.
3. Fabrication Devices for Children's Crafts

The previous section outlined an agenda for development of novel, child-appropriate interfaces for fabrication tools; but in doing so, we implicitly assumed, as a given, the existing landscape of those tools themselves. A natural further step would be to reconsider the design of the fabrication devices—to imagine these devices as children's artefacts, rather than industrial artefacts upon which new interfaces should be grafted.

3.1 Fabrication at Children's Scale

A first, almost inevitable foray into designing children's fabrication devices would be to create smaller-scale versions of existing devices. At present, for example, most 3D printers are relatively large, stand-alone affairs (though at least one company is now advertising a soon-to-be-commercial desktop 3D printer [W1]). To some extent, the size of the standard current device is constrained by the maximal size of a printable object: in our own laboratory, our two modest 3D printers are each capable of printing objects of about one cubic foot in volume. For at least some genres of children's activities, however, this volume is very large. Children might (e.g.) print out customized charms for bracelets; or small plastic animals; or tiny props for model railroad scenes or dioramas; or special-purpose pieces for use with larger construction sets, such as Lego; or accessories for dolls. Moreover, in contrast to industrial settings, children are likely to print out only a small number of such objects, rather than thousands. Thus, a child-friendly 3D printer might actually be designed as a deliberately small device, geared toward the printing of a single miniature object at a time. Conceivably, the development of such a device would lead toward a genre of design that is at present nearly unthinkable: namely, portable fabrication devices that can be carried about into informal settings such as playgrounds or parks.

3.2 Fabrication-as-Decoration vs. Fabrication-as-Shaping

To this point in our discussion, we have not attempted a fine-grained definition of the term "fabrication device"; instead, we have used typical examples (such as 3D printers and laser cutters) to illustrate the term. While this is not the occasion for a thorough analysis of what, precisely, "fabrication" might mean, we should acknowledge that there is at least one broad genre of output device—namely, the standard desktop printer—that is often employed in fabrication projects. True, the desktop printer does not actually shape its material (as does a laser cutter): but by printing out patterns that can then be cut by hand, it is an invaluable tool for all sorts of craft activities. In our own lab, we have designed applications that children can use to print out decorated "folding nets" on paper; these nets then be cut out and assembled into polyhedral paper models. Likewise, another recent project allows children to design pop-up cards on a computer screen, and to view a 3D rendering of the card that they have made. Once the child is satisfied with his design, he can then (if he wishes) decorate the template for the card on the screen and print it out; and the printed-out template includes markings that show the child where to cut to produce the eventual physical pop-up. The purpose of this slight digression is to point out that the main purpose of some fabrication devices (if we include color inkjet printers in that genre) is simply to decorate, or place informative marks upon, materials that can then be cut or arranged by hand.

The aforementioned projects illustrate how rich the possibilities are for children's fabrication when employing the standard desktop printer; but again, even these now-common devices have not really been designed with the interests of students (and crafters) in mind. Just to take a simple example: it is in fact an extremely delicate operation to use a standard inkjet printer for accurate two-sided printing of the sort that would be useful for crafts: for instance, one would be hard pressed to print out (say) a decorated circle that appears in exactly the same spot on the front and back of the page. Two-sided textual printing is easy, and “duplex” printers for this purpose are numerous; but printing matched cut-out patterns on both sides of the page is still unnecessarily cumbersome. A child-friendly inkjet printer, then, might be designed to make precisely this type of operation simpler.

This is not the only design improvement that could be made in the homely inkjet printer. Many traditional paper crafts employ the use of long thin strips of paper that can be woven or shaped into interesting designs. (Indeed, the classic book of mathematical crafts by Cundy and Rollett [2] has a marvelous section devoted to the design of polygonal forms using folded paper tape.) A particularly useful creation, then, would be an inkjet printer that could be easily used with very thin, long strips of paper tape (as opposed to standard sheets of paper); such a device could be used to create computer-decorated strips that could be employed to make both accurate and spectacular craft designs. To date, we are aware of no easily accessible desktop printer designed for this sort of activity.
Going beyond the realm of the inkjet printer, one might imagine other types of "decorative" (as opposed to "shaping") output devices geared towards children's fabrication. It should, for instance, be plausible to create a "yarn-decorating" device that could output lengths of yarn or string with precise patterns of color decoration. Such precisely-decorated lengths of yarn could then be employed in mathematical string sculptures, weavings, and the like. (Just to give a sample of what this sort of machine might do: one could input a length of undecorated white yarn, and the output would be the original yarn decorated with a smooth color gradient in which the material changes from red to blue over a length of one meter.) A spectacular existing example of a craft-oriented decoration device is a machine for decorating eggs via computer control created by the engineer/artist Bruce Shapiro [W3]; sadly, to our knowledge, this is not a commercially available tool, but it perfectly illustrates the possibilities of employing computer peripherals for decoration in the types of activities that children (and adult crafters) find irresistible.

3.3 Expanding the Range of Fabrication Materials
A recurring theme in this paper is that, while fabrication devices have traditionally been conceived of as industrial machines, for use by professional adults, it is now time to reimagine these devices as staples of children's worlds. One dimension of this process of reimagination is to look to the materials that children use in construction, and to explore the possibilities of fabrication tools geared toward those materials. It should be possible, for instance, to design a printer that would decorate thick felt of the type employed by children in fabric crafts; at present, this is not a material that can be employed with inkjet printers (though fortunately there are some fabrics that can be used in this way).

Looking at the range of children's activities, one might brainstorm all sorts of playful fabrication devices tuned to the materials of childhood. One might create devices to play a role in the creation of colorful sand paintings; or devices that assist children in the fabrication of bead designs; or devices that can be used to shape or cut materials such as soft clay, cookie dough, or chocolate. It should be stressed that work in this direction does not by any means imply supplanting or replacing children's work with their hands—youngsters will always make sandpiles and mudpies—but at the same time, the tasteful design of novel children's technology has the potential to extend and enrich the day-to-day practice of children's crafts with all sorts of materials, ranging from high-tech "smart materials" [4] to the most traditional "stuff" of childhood play.

4. Software Infrastructure for Children's Construction Communities
The earlier sections of this paper focused on providing a fresh look at fabrication interfaces and devices in the context of children's activities. A third approach to the rethinking of children's fabrication and construction is to look at the social dimension of children's work. At present, children do not have the types of online resources to support their own growth in craft activities that characterize adult, professional work. A child who creates a new popup card design, or mathematical weaving, or string sculpture, should be able to exhibit her work to a community of interested, responsive viewers.

Certainly, children could, even now, post photographs and videos of their work to websites such as www.flickr.com or www.youtube.com. (And undoubtedly, many students do just that.) However, general sites of this sort lack some of the features that might be particularly appropriate or useful to children's design activities. For example, one might imagine a communal website for children's crafts that explores one or more of the following features:

- Links, where possible, to downloadable formats for constructions. For instance, a child's paper sculpture may include some portions created "by hand" and others created with the use of a tool such as HyperGami; patterns of at least the latter sort might be downloaded to facilitate the sharing of craft designs and ideas.
- Instructional material or video accompanying constructions to show how they were created.
- More general instructional material introducing children to software applications for crafts, the use of fabrication tools and devices, or the practice of techniques.
- Links to sites of professional or adult practitioners of "children's crafts". The purpose of these links is, in part, psychological. In our view, it is too often the case that children's activities are "ghettoized" and treated as lesser in dignity than adult activities. Yet there are brilliant adult practitioners of (among many other crafts) popup design, paper sculpture, polyhedral modelling, string sculpture, clay modelling and the like. A desirable feature, then, of our imagined website would be to encourage the view that there is a general community of crafters (or
artists) in all sorts of media, ranging from the very young to the very old. Links of this sort would also provide students with examples of the types of constructions that advanced practitioners are capable of making. A partial example of this sort of idea, from the work in our own lab, is represented by our website for polyhedral paper sculpture using HyperGami [W2]: this site includes a "polyhedral alphabet book" in which complex paper sculptures can be viewed to explore the range of the medium itself.

5. Conclusion

The pattern of usage of fabrication tools and devices bears some historical similarity with that of computers themselves. For the first several decades of their existence, computers were exclusively the province of adults (and exclusively highly-trained adults, at that); they were expensive, large-scale devices employed in military, business, or scientific applications. The evolution of computers into devices usable by children has been partly technological in origin—facilitated by the relentless miniaturization and cost reduction of memory and computation. At the same time, that evolution has partly been a matter of a sociological, or perhaps psychological, reappraisal of computers, sparked by visionary works like Seymour Papert's book Mindstorms. [8] One major benefit of Papert's work was that it encouraged a rethinking of the boundaries between adult technology and children's culture.

The argument of this paper, then, is that we have arrived at a similar moment in the evolution of computer "peripherals" for construction and fabrication. The themes discussed here—rethinking interfaces, devices, and software infrastructure—are arguably important, though probably incomplete: there are many more innovations to be imagined in this area. Nonetheless, it now seems possible to direct our attentions, as designers of educational technology, to a tremendous near-term enrichment of children's construction, activities, and intellectual growth.

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Websites:
[W2] HyperGami project site (Playground): 13d.cs.colorado.edu/~ctg/projects/hypergami/Playground.html