# The Material Side of Educational Technology

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## INTRODUCTION

When people talk about "educational technology", they usually mean "educational computing"–or perhaps, a little more broadly, educational uses of media such as television and film. The interface between technology and the child is assumed (almost as a reflex) to take the form of a color screen. Nonetheless, there is a different side of technology, a more ancient side–and it's making a comeback. In fact, one could make a very good case that many of the most exciting developments in "educational technology" are to be found in the area of materials science. The advent of a remarkable array of novel materials over the past quarter century, ranging from high-temperature superconductors to liquid crystals to optical fibers, suggests that the material environment in which children grow and learn will be substantially richer, more complex, more expressive, and perhaps more problematic in the coming century than it has ever been in the past.

This article is an attempt to broaden the discussion of “educational technology” to reflect some of these (still embryonic) developments in materials science. Much of the discussion here will, of necessity, be tentative; it is hard to know precisely which materials (or which classes of materials) will be prevalent in children’s environments within even a time span as short as five years. Still, while we can’t be sure of the details, we can confidently predict that there will be a massive and profound change in the “stuff” with which children work and play over the next generation. Moreover, in many instances, this new stuff of children’s work and play will interact in powerful ways with computer technology.

The remainder of this article, then, will explore a variety of possible uses of new materials in educational settings. Although occasionally futuristic, the discussion here will try to keep to a standard of plausibility; in several cases, the uses of novel materials will be illustrated through working prototypes developed in recent years within our “craft technologies” laboratory at the University of Colorado. Our hope is that this still-early discussion can be useful in promoting a more systematic appraisal of “educational materials science” in general.

## KIDS’ STUFF: THE EMERGING LANDSCAPE

There are several excellent non-technical introductions to modern materials science ([1], [2], and [4]). Here, we will simply provide brief descriptions of several classes of particularly interesting or important new materials.

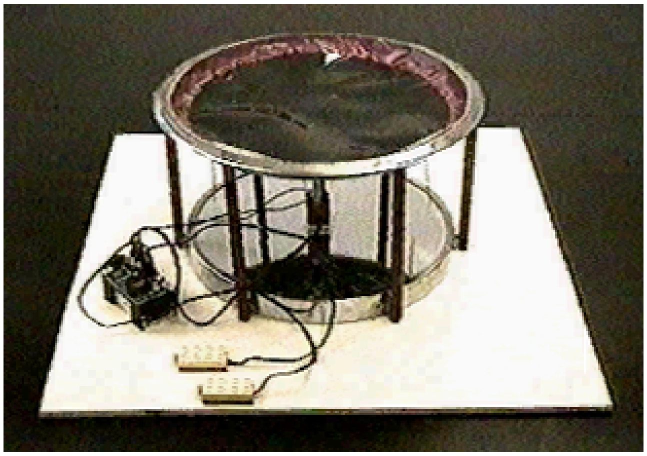

*Figure 1.* A surface of temperature-sensitive film has been placed above a computer-controlled motor that can be used to complete various circuits in an array of wires beneath the film.

### “Output”, or “Responsive”, Materials

One important class of materials might be regarded as “output” materials, in that they seem suited to uses of displaying information, or transforming electrical signals (e.g., signals sent by a computer). While this is undoubtedly a very loose classification of a large group of disparate materials, it will help somewhat to structure the ensuing discussion.

*Temperature-sensitive films* are liquid crystal-based materials that change color in response to a change in temperature over a specified range. A natural use for such films is to change color in response to a temperature change caused by an electrical current in a nearby wire. An example of this idea can be seen in a project developed in our lab by A. Warmack, shown in Figure 1 (see also [7]). Here, a surface of temperature-sensitive film has been placed directly above an array of wires; when a particular pathway within the array is used to complete a circuit, current runs through the pathway and the temperature-sensitive film changes color to show the areas of running current. (Sitting below the temperature-sensitive film, and the array of wires, is a computer-controlled motor which, when it turns, causes different points within the wire array to complete a circuit across a battery.) Here, then, temperature-sensitive film is a “display device” that shows the presence (or absence) of current in nearby wires. More generally, one could employ these films in settings (say, outdoor science projects) where a color-change can signal a fairly large-scale change in temperature; by using a set of these films tuned to distinct temperature ranges, one can create a coarse-grained color-based "thermometer".

*Shape-memory alloys* are metallic alloys that have the remarkable property of "remembering" a particular shape in which they have been set. The basic description of these materials' behavior is as follows: first, the alloy is brought to a high temperature and "set" within a particular desired shape. The material may then be cooled, at which point it can be bent into some alternative shape; when the material is reheated, it returns to the shape or configuration in which it was originally set at the high temperature. (Cf. [9])

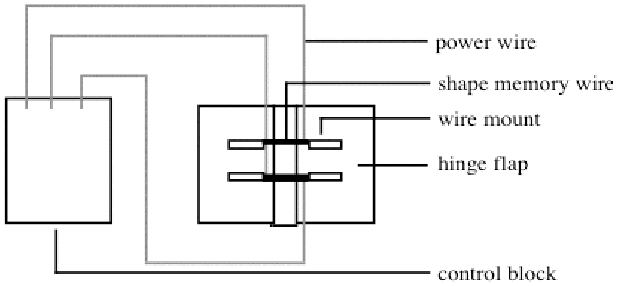

*Figure 2.* A schematic view of T. Wrensch's "programmable hinge" showing the control block (including a small computer) at left and the hinge with two strips of shape memory alloy at right.

Once more, an example can help to make this description clearer. The "programmable hinge" developed in our laboratory by T. Wrensch [10] makes use of a shape-memory alloy to design a hinge that can open or close in response to a computer-generated signal. A schematic of the hinge is shown in Figure 2. Here, the hinge has two wire-shaped strips of shape-memory alloy across its length; one strip of alloy "remembers" a bent position (like a letter "V") and the other "remembers" a straight position (like a letter "I"). When a current is passed across the first alloy strip, that strip heats up and bends the hinge into a letter V-shape; when the current across this strip ceases and a current is now sent across the other alloy strip, that second strip returns to its straightened position, opening the hinge.

There are still other materials that can behave along similar lines. *Electroluminescent materials* "light up" in response to an electrical current; *electrorheological fluids* can change their viscosity in response to an electric field; some varieties of glass can change their degree of transparency in response to an applied field; novel types of "programmable paper" [cf. 6] act, in effect, as flexible computer display screens that can be used to present patterns of pixels on a variety of surfaces. For all these materials, a typical pattern of usage would be to have some artifact respond to its user (by changing color, shape, etc.) in accordance with a program from a desktop or embedded computer.

## "Input", "Sensing", or "Communicative" Materials

The materials described in the previous paragraphs can be naturally imagined in the role of "output"; in contrast, several other major classes of materials may be plausibly imagined as "input" or "communicative" substances.

*Piezoelectric materials* [9] denote a collection of (mostly inorganic) materials that deform (by expanding or contracting along specific axes) in response to an applied electric field, and that conversely can produce an electric field in response to a mechanical deformation. Many types of sensors employ piezoelectric materials of some sort [5]; a simple, commercially available product is a small disc of piezoelectric material that can respond to the press of a finger. (That is, by pressing the disc, one causes a mechanical deformation in the material, which can in turn produce an electric signal; the overall result is that the disc acts as a "button" which can be positioned onto arbitrary surfaces and connected via wires to computers or other electrical devices.) In more sophisticated scenarios, it is possible to coat a surface with an array of piezoelectric sensors that respond to the mechanical stress caused by (e.g.) the human hand; thus, one could make an artifact that responds to the position and orientation of the user's touch.

*Optical fibers* are cables in which a glass "cladding" surrounds a glass core of a different refractive index; the net effect is that the fiber can be used to conduct light signals along its path. Optical fibers are used extensively in telecommunications because of their high bandwidth and low cost; for the purposes of this discussion, though, the interesting thing about optical fibers is their wide utility as a means of conducting light signals within and between physical objects. That is, one can think of optical fibers as a means of "wiring up" an object so that by shining a light (or perhaps blocking a light) at a particular point, the object can send a signal over an optical fiber to a sensor (or computer) at some other location.

An example along these lines is shown in Figure 3, which depicts a prototype of a "talking alphabet block"–one of a set developed in our lab by K. Kaowthumrong, N. Lee, and W. Lovett [3]. Each block includes an embedded computer (one of the MIT Media Lab "crickets" developed by Mitchel Resnick and his colleagues [7, 8]); these computers are able to send and input an infrared light signal, which in most cases requires that the communicating computers be positioned so that they are in a direct "line of sight". The talking alphabet blocks, however, employ fiber optics cables to communicate a light signal between neighboring blocks. In the Figure 3 schematic, an orientation sensor on the surface of the block determines which side is up or down, while the internal computer sends a signal (indicating which letter is visible in this particular block) to the next block in the sequence via the fiber optic cable. (In the complete block, the fiber optic cable emerges from a hole in the side of the block; figure 3 shows an "open" view of the block, exposing the internal computer and its optical fiber.) When blocks are in series, each block communicates both its own letter and those of preceding blocks to the following block; the final block sends the entire word to a speech synthesizer in a desktop machine.

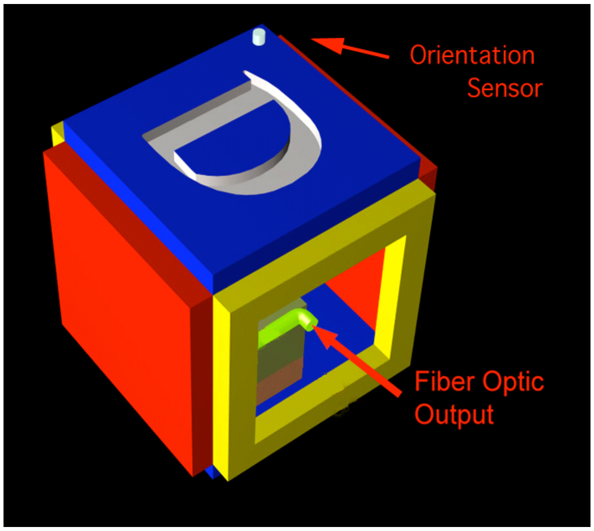

*Figure 3.* An open schematic view of a single "talking alphabet block", showing the block's orientation sensor at its surface and the fiber optic cable that is used to communicate signals between the computers embedded within each block.

There are still other types of materials that can be used for sensing or communication. *Thermistors* are temperature sensors that work by altering their electrical resistance in response to changes in temperature; they are typically composed of metal oxide semiconductors [5]. Numerous *chemical sensors* have likewise been developed in recent years for a variety of specific purposes (such as detecting pollutants); some of these sensors employ biomaterials such as enzymes to detect specific substrates. (See [5], Chapter 17.)

### "Miscellaneous" Materials

There are, of course, still many other interesting, affordable materials that are likely to play an increasingly prominent role in children's lives; the catalogs and websites of science hobbyist enterprises offer fascinating examples. These materials include novel types of plastics and other polymers; semiconductor-based solar power cells; demonstration kits for "high-temperature" superconductors; and so forth.

## NEW MATERIALS AND CHILDREN'S ACTIVITIES

Emerging materials could transform classroom apparatus. One could incorporate coatings of piezoelectric sensors into (say) an anatomical model, so that a child could (e.g.) ask for the name of a particular muscle or bone by touching its representation in a physical model. A wave tank could be designed to employ electrorheological fluids to produce highly complex or beautiful patterns of controllable fluid flow; a mathematical model of a surface might be created of material that changes shape over time to display a sequence of parameterized surface constructions; dioramas or displays might change appearance with ambient temperature or humidity.

But perhaps it would be even more compelling to integrate new materials within the sorts of homespun activities that have always captivated children. One might imagine incorporating electroluminescence into the string games that children play, so that a handheld string figure lights up in gorgeous colors; trading cards might be made of "programmable paper" so that each card can include a child-designed graphical effect; constructions currently made in paper (such as polyhedral models and pop-ups) might eventually incorporate "programmable" paper elements to produce spectacular dynamic displays in children's creations. Children might create mosaic constructions on sensor-equipped substrates, so that by pressing a "personally coded" sequence of stones in the mosaic, the construction responds in some interesting way; more generally, sensor-equipped surfaces could be customized by their child users so that individual patterns of touch are used to play music, open (or close) locks, record diary entries, and so forth. Puzzles and games are especially fertile ground for this sort of brainstorming. One might imagine topological puzzles whose pieces change shape over time, or jigsaw puzzles whose pieces change color in response to light or sound, or board game pieces that alter depending on how they are moved. Construction kits could be composed of pieces that communicate via optical fibers, or that conduct or manipulate patterns of light, or that change color or shape.

The landscape of new materials is thus likely to create a pervasive change in children's artifacts and activities that is comparable in scope and creativity to that effected by computers over the previous generation. In a sense, children have always played and worked with interesting new materials, wherever those materials become available: paper dolls, glass beads, synthetic rubber balls, plastic construction pieces, have all represented technological advances at some point in the past. What is unique about the present historical moment is the way in which the range, variety, and expressive power of new materials is poised to explode within the next generation or two.

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