Chapter 2

Sensory Extension as a Tool for Cognitive Learning

Michael Eisenberg  
University of Colorado, USA

Ann Eisenberg  
University of Colorado, USA

ABSTRACT

The practice of educational technology has long been driven by a relatively restricted set of operational metaphors: typically, computers are identified as potential “teachers” or “tutors” of material or (arguably more productively) as “learning tools” for students. Recent developments in technology suggest the advent of another, perhaps still more fruitful metaphor – namely viewing educational technology (not limited to computers) as a means of sensory extension. In this view, technology is seen not as a repository of content, but rather as an extension of scientific instrumentation (telescopes, microscopes, bubble chambers) and prosthetics (eyeglasses, cochlear implants). This chapter is intended as an initial, partly speculative exploration of what it would mean for science and arts education to rethink the role of technology in terms of sensory extension rather than classroom instruction.

INTRODUCTION

Man has, as it were, become a kind of prosthetic God. When he puts on all his auxiliary organs he is truly magnificent, but these organs have not grown onto him and they still give him much trouble at times.... Future ages will bring with them new and probably unimaginably great advances in this field of civilization. (Sigmund Freud, Civilization and Its Discontents [1930])

Educational technology, over the years, has been driven by metaphors. In the early era of computing, when computers were popularly referred to as “giant brains” (as in Berkeley’s (1949) popular title), the recurring image was that of computers as agents of mechanized thought; and when applied to education, that image became one of “computer-assisted instruction” (cf. Suppes, 1966), with the computer patiently presenting individually-customized material to students. By
the early 1980’s, the range of metaphors applied to educational technology had expanded somewhat, as reflected in the title of an excellent summary by Taylor (1980): “The Computer in the School: Tutor, Tool, Tutee”. For Taylor, the “tutor” role was exemplified by Suppes’ work, with the computer as classroom instructor; the “tool” role was exemplified by the (still relatively new) idea of having children use computers as calculators and word processors, among other possible uses; and the “tutee” role (exemplified in the work of researchers such as Seymour Papert) involved having children “teach” the computer via programming.

The power of these originating metaphors continues to be felt, and productively pursued, in educational technology today. There are still active research projects, not to mention commercial development, in computer-based training and tutoring (see, for example, the proceedings of the Intelligent Tutoring Systems conferences, such as Trausan-Matu et al. (2014)); in the use of computers as tools for such tasks as simulation (Wilensky & Rand, in press) and educational gaming (Shaffer, 2006); and for child-friendly programming (Kafai & Burke, 2014). Indeed, none of these venerable metaphors is at all objectionable. At the same time, however, metaphors not only tend to structure and inform the educational technology community; they also channel and constrain that community as well. The associations of the early images of computing – an “artificial mind” sitting in a box on a desk – tend to make us think of the computer as an object and source of activity, profoundly separate from the student. The computer, in this vision, is something to communicate with. Even in more current images – students enrolling in MOOCs, or viewing lectures on the Web, or collaborating with other learners via websites or email, or playing multi-person educational games—the computer is fundamentally something set apart from the learner, and it affects the learner only via relatively abstract channels such as typing (for input to the machine) and viewing a screen or listening to speakers (for output from the machine). The computer – and the community accessible through it – are thus seen as repositories of expertise, and the educational dimension of technology is realized by tapping that expertise.

This essay is a frankly speculative exploration in what it might mean to pursue a rather different metaphor – a metaphor for education suggested by the advent of various new technologies, and likewise suggested by the guiding theme of this collection. Broadly speaking, the idea here is to think of technology as a matter of sensory extension, as being a means of extending or augmenting the sensory apparatus of the student or child. Taking this metaphor seriously means devising uses of novel technologies that suggest analogies with certain types of scientific instrumentation: telescopes and microscopes (for extending the range of vision), Geiger counters (for extending sensitivity to phenomena such as radioactive decay), and so forth. In a less rarefied sense, there might be technologies analogous to that of eyeglasses, hearing aids, or walking sticks– prosthetic devices that improve or repair our everyday senses.

The idea of educational technology as sensory extension is one that gives rise to complexity on many fronts. First, it should be emphasized that sensory extension need not be viewed in opposition or contrast to existing traditions in educational design, but as complementary to those traditions; there are obviously many potential areas of overlap and collaboration with these existing traditions, and this chapter will touch on several possibilities. Perhaps more pointedly, the topic of sensory extension involves wading into potentially uncomfortable territory, of “brain-computer interfacing” or body modification. Such subjects raise delicate questions of what it means to alter, extend, customize, or experiment with ourselves as humans; and if these issues are thorny for adults, they are even more anxiety-provoking in the context of education and children’s technology. Nonetheless, it will not do to completely ignore the topic of sensory extension merely because, in certain instantiations, it raises uncom-
able questions; rather it seems preferable to face those questions with an eye toward formulating principles of educational design consistent with the fundamental goals of human dignity and development. As a society, we may decide that certain types of sensory augmentation are to be avoided, forbidden, encouraged, or regulated; but ultimately these questions of technological design are likely to force themselves upon us by circumstances.

The remainder of this chapter is structured as follows: the following (second) section delineates many of the research themes and traditions that are now leading us toward an educational technology of sensory augmentation. The third section begins by exploring the potential of sensory augmentation for science and arts education: in a sense, this is the “positive” or optimistic side of the subject. Later in that same section the more problematic side of the subject, involving questions of what education in fact means for human extension, are introduced (though it would be vastly overstating the case to say that they can be resolved here). The third section closes with a discussion of several early, and relatively uncontroversial, projects that could well be undertaken in this area. The fourth section discusses a variety of additional related themes that could enhance the educational potential of sensory augmentation for education, including combining novel sensory apparatus with (also mildly futuristic) extended means of actuation or movement. Finally, the chapter concludes by revisiting the discussion of metaphors, and how they structure educational design, in the light of the previous sections.

THE TECHNOLOGICAL ORIGINS OF EDUCATIONAL SENSORY AUGMENTATION

The previous section introduced an idea that may seem (at first blush, anyway) radical: namely, that education can be approached as a matter of technologically enhanced sensory extension, rather than merely as communication of content. This section makes the case that in fact, the idea is hardly as unorthodox as all that—and indeed, might be seen as a natural, even inevitable, continuation of technological and research themes already under way. A thorough treatment of all these themes would be well beyond the scope of this chapter, but a brief summary of these contributing historical trends serves as a useful reminder of how, as educational technologists, we arrived at the current moment.

Wearable Technology

Perhaps the most natural place to start, in thinking about sensory augmentation, is in the burgeoning area of wearable technology. Broadly speaking, the general idea behind this work is that computational artifacts are now sufficiently small, light, and accessible so that they may now be worn on the body for a wide variety of purposes. A prominent commercial example in this vein is Google Glass (www.google.com/glass/start/), a wearable technology that could easily be characterized as a type of “sensory augmentation” (though not particularly profound or educational). The Google Glass wearer can, among other things, use the device to identify a place where she happens to be (via GPS), or to learn historical details of a particular site where she is walking, or communicate with others via email read directly from the wearable accessory itself. A related sort of commercial technology involves personal health monitoring (e.g., through wearable devices that monitor one’s heart rate, sleep, or the distance that one has walked or run—for representative though by no means exhaustive examples, see www.fitbit.com or www.withings.com/us/).

Typically the sorts of commercial wearables already mentioned are designed as “accessories”: glasses, wristbands, and so forth. Another style of wearable technology design incorporates sensing capabilities into textile material itself, e.g. for sensing ambient chemicals. This area of wear-
Sensory Extension as a Tool for Cognitive Learning

able e-textiles (that last term an abbreviation for “electronic textiles”) may be seen as a variation of wearable technology in which electronics are integrated with specialized materials such as conductive threads. There is something of a cultural distinction between wearables such as Google Glass (on the one hand) and e-textiles (on the other), in that the emphasis of the e-textile community is often on creating innovative fashions and pursuing artistic or aesthetic goals.

Craft Technology

Researchers such as Leah Buechley (Buechley & Perner-Wilson, 2012) and Nwanua Elumeze (Elumeze & Eisenberg, 2008) in our own lab have combined wearable technology with overlapping interest in personal crafting and construction. The idea behind much of these researchers’ work is that e-textiles and computational wearables are part of a growing “maker movement” (Anderson, 2012) that emphasizes an integration of technology with venerable traditions of homespun building, design, and artistry. (See the examples in Figure 1). Buechley’s popular LilyPad Arduino device (Buechley et al., 2008) is an exemplar of this sort of work, in that it allows hobbyists and students to create their own personalized computationally-enhanced clothing by sewing components into clothing and connecting the components via conductive thread or fabric; the LilyPad is likewise accompanied by a variety of standard sensors for (among other things) light, touch, and sound. For the purposes of this chapter, the important themes of craft technology include not only the ability for personalized creation and construction, but also an abiding interest in educational design, encouraging students and novices to learn about art and technology through expressive, playful extensions of traditional crafts.

Pervasive/Ubiquitous Computing

Both wearable technology and craft technology may themselves be seen as related to a long-standing research tradition in integrating computational (or “smart”) artifacts into the larger designed environment. (For a good compilation in the realm of education, see (van ’t Hooft & Swan, 2006).) The areas of pervasive and ubiquitous computing are vast in scope and literature; but for our purposes, it is simply worth noting that there is

Figure 1. The LilyPad Arduino toolkit, with a microcontroller at center. Left: accelerometer, light sensor, tri-color LED, and power supply. Center: Leah Buechley wears a LilyPad-equipped biking jacket. Right: Nwanua Elumeze’s “Schemer” device embedded in light-up fairy wings created by Angela Sheehan (from the website www.aniomagic.com). (© 2014, M. Eisenberg. Used with permission).
Sensory Extension as a Tool for Cognitive Learning

a recurring interest in “ambient sensing” within these traditions that dovetails with the suggestions of this chapter. For example, it is not unusual to encounter projects whose goal is simply to detect whether a room in a house is occupied or unoccupied (e.g., for the purposes of automatically turning on electronic appliances). More ambitious projects involve the use of embedded computational systems to (e.g.) identify particular faces or voices, or to monitor environmental variables. A related theme in this area is that of augmented reality (Feiner, 2002), in which artifacts within the real-world environment are endowed with the ability to communicate with or send information to mobile computers. Just to take a typical scenario: a complex mechanical device might be equipped with materials (such as RFID tags) that permit a repair person, equipped with a head-mounted display (or suitably programmed Google Glass), to visually identify the elements within the device.

Embodied Cognition

On the theoretical side, one of the most provocative recent developments in cognitive science has been the advent of an “embodied” view of cognition (Clark, 1997) is a good summary of this view; Gallagher (2005) and Shapiro (2011) are also useful introductory references). Briefly, the theme of this work is that instead of viewing thought and intelligence as purely abstract exercises of information manipulation (the image purveyed by the earliest work in cognitive science), it is more productive and realistic to view thinking as taking place in the context of an active, ecologically engaged body. Again, just to take a single example from the realm of education: Goldin-Meadow (2003) and her colleagues have studied the role of gesture in both indicating and influencing cognitive change in children’s reasoning about physical situations. That is, by watching how children move their hands in responding to questions of how materials behave, one can gain insight into the state of their thinking about fundamental ideas such as conservation and reversibility.

For our purposes, the theoretical stance of embodied cognition is central to the idea of designing sensory enhancements for education. To the extent that scientific and artistic ideas and interests are acquired or developed through the senses, it stands to reason that by equipping children with an expanded range of sensory apparatus, one might likewise expand the range of ideas and thinking available to the child. We will return to this issue a bit later in this chapter.

Prosthetics

Finally, it should be mentioned that one could view the notion of sensory augmentation as a continuation, or re-application, of ideas taken from the medical realm of prosthetics. Consider, for example, the role of eyeglasses (or contact lenses, or direct surgical reshaping of the cornea) in the improvement of vision. Here, the intent of the technological intervention is to repair or improve sensory performance; although the goal is general visual improvement, there is no denying that the interventions have an intellectual or cognitive component as well (e.g., by helping people read more fluently). Similar observations could be made about cochlear implants or hearing aids for hearing, or (in the realm of touch) about the role of walking sticks in extending the range of accessible surfaces for sight-impaired people.

One recent example in this vein is particularly provocative for this discussion: the development of an eyeglass-like device for viewers with at least modest degrees of color blindness (Pogue, 2013). Such glasses in fact filter out specific wavelengths of light that are hard to interpret for color blind people, and in doing so they effectively extend the sensory capacities of those people by making certain colors (reds and greens) easier to distin-
guish. In effect, then, these glasses can be used to enrich the sensory experience of those wearing them (though as is typical for prosthetics, the goal is not specifically educational).

Collectively, these various themes of research and design are now reinforcing each other to the point where it seems to us unavoidable to consider their implications for educational artifacts. The study of embodied cognition provides the theoretical motivation for sensory enhancement; work in wearable technology, pervasive computing, and prosthetics provide technological background and infrastructure to this work; and the notions of craft technology and a “maker culture” supply the tone of the work (toward playfulness, personal expression, and creative participation) that we would wish to adopt.

EDUCATION THROUGH SENSORY EXTENSION: OPTIMISM AND PESSIMISM

The previous sections argued for the viability of a move toward sensory extension in educational design. In this section, we present a variety of possible project ideas along these lines, drawing from examples in both education for the natural sciences and the arts. We conclude this section with an introductory (though by no means complete) discussion of potential worries or problems that might well arise in pursuing this agenda of work.

Science Education

It is arguably easiest to begin this discussion by imagining relatively straightforward (and likely less controversial) sensory augmentation devices for science education. One might devise a variety of artifacts that enable students or researchers to “see” wavelengths of light that are usually invisible to the human eye. For example, a head-mounted device equipped with an ultraviolet sensor might enable students not only to view sources of ultraviolet radiation, but to note the presence of UV light in outdoor settings; that is, the device could be constructed to contribute to physics education at the same time as supplying sensory enhancement. Similar efforts could be tried for infrared light, or (at still longer wavelengths) one could devise artifacts for viewing the presence of certain radio frequencies.

Specialized eyeglasses for “viewing the invisible”, or devices for responding via sound or touch to sensory stimulation, could be created for other input besides light. One might imagine glasses or gloves that respond to the presence of atmospheric chemicals or chemical gradients; or the presence of “loud” ultrasonic or subsonic noise. Again, the purpose of such artifacts could be explicitly educational in nature, allowing the wearer to become cognizant of the surrounding world beyond the realm of the ordinary senses; the purpose, then, of such a device is not dissimilar in principle to that of (say) a microscope, but the experience of extending the senses in day-to-day circumstances could be profound. Pursuing this idea, it may well be feasible to design gloves that allow the user to “feel” variables such as the pH of liquids, the conductance of a metallic surface, or the frictional coefficient of a tabletop.

The earlier mention of wearable devices for health monitoring likewise suggests an avenue of design for learning about physiology through portable devices. Here, the idea is that one might sense one’s own heartbeat, respiratory rate, brain activity (via EEG sensing devices placed on the head), and so forth. The purpose of this design would not be primarily for monitoring health or exercise (though this might be a desirable side-effect) but instead to contribute to education in medicine or biology.

Higher-Level Sensors

The suggestions made thus far are relatively simple ones, and involve repurposing existing sensors (ultraviolet light, ultrasound, conduc-
Sensory Extension as a Tool for Cognitive Learning

Beyond this, however, it should be possible to create “higher-level” sensors that combine direct sensing with a certain degree of computation to create devices that can respond to environmental stimuli beyond raw data. As an example from the commercial world, consider those recent cameras whose viewfinders identify the presence of human faces in the viewing field: these cameras are in fact “sensing” not merely the presence or absence of certain wavelengths of light, but rather higher-level patterns or configurations of stimuli in the environment.

Here’s an example of how this might play out in an educational setting. Imagine that a child could put on a wearable device that would allow him to “see” a range of light (including polarization of light) in a manner similar to that of a bumblebee; the goal of the device would be to convey the sense of the animal’s “Umwelt” [cf. Clark, 1997], and to understand better the means by which other animals sense and navigate their environments. Similar ideas could be pursued to allow children to “hear” the tones accessible to dogs, or to be alert to motion in the way that a frog might be. An echolocation device might enable the wearer to experience (at least in a mild way) the idea of navigating by sound in the manner of flying bats. Indeed, one might characterize such devices as contributing not only to biology education, but to a broader sense of empathy with other creatures: it would be possible to (if only partially) inhabit the sensory world of another creature.

There are still other possible directions for high-level educational sensing. For those readers who have ever taken a stroll in the park and experienced frustration at all the things that they don’t observe, one might imagine creating wearable devices that help alert the user to (e.g.) the direction of birdsong, and that are tuned to seek patterns of movement typical of birds: the result could be a set of “birdwatching glasses” that enhance the alertness of the wearer. Similar devices might be employed to listen for insect calls, look for the movement of beetles on the ground, or respond to the presence of particular scents or pheromones.

In the physical realm, one might devise sensory enhancements to seek out meteorological patterns (e.g., to note wind direction, subtle changes in humidity, or patterns of storm movement), or to assist in the viewing of moving fluids (noting regions of laminar flow or turbulence). It might be possible to create glasses for viewing certain types of natural or laboratory phenomena in physics: for example, one might create a visual device to estimate (at least for certain phenomena) the potential and kinetic energy of a moving body.

Arts Education

Just as science education could be viewed as a matter of “learning to sense things beyond the ordinary”, so might arts education be likewise viewed as a matter of sensory training, development, or refinement. In this view, mastering a fine art is a matter of changing one’s awareness or alertness to elements of one’s world. There is something of a cultural contrast here between the style of “enhanced alertness” desired for arts education, and the sorts of (day-to-day information retrieval) functions typically imagined for a device such as Google Glass. In most typical scenarios (at least as presented by advertising), Google Glass is intended to make one’s life more convenient: one can acquire information or communicate with others with relatively little effort. By contrast, the idea of artistic sensory enhancement might well make one’s experience more complex, or draw attention to elements that would have otherwise gone unnoticed.

It is probably easiest to imagine applications of this idea for use in the visual arts. One might begin by extending or altering the functionality of the earlier-mentioned glasses for color blind wearers: here, the goal might be to create visual...
Sensory Extension as a Tool for Cognitive Learning

aids that can be interactively tuned to highlight or suppress certain colors, or that enhance particular color contrasts. It is not implausible that such a device might assist graphic artists in noting or choosing colors for their own creative work. Along similar lines, one might devise vision enhancements that compare colors between two surfaces; an artist might, for instance, use this to compare the shades on her canvas to those of her subject matter.

Color is of course not the only subject matter that could be of interest for sensory enhancement. An animator might use visual devices to slow down the experience of visual motion in order to learn how to render that motion smoothly in a sequence of animated frames; or motion might be “frozen” in mid-view to get a better view of a particular moment in time. (As an aside, one might note the historical example of Leonardo da Vinci, whose uncanny ability to “stop” visual motion is beautifully demonstrated by a well-known page from his notebooks depicting numerous sketches of cats in various positions of movement.) Visual devices might be used to enhance or blur edge contrasts, or to blend multiple views of physical objects, or to assist in understanding perspective, or to perform selective distortions of a visual scene.

There are still other types of sensory enhancements one might attempt for artistic purposes. An aural device might help musicians decompose sounds into component frequencies, or compare those sounds to particular musical instruments or settings for digital sound devices. Likewise, one might imagine devices whose role is to assist in listening to component timbres within a larger soundscape: for instance, one might wish to hear the oboe part of an orchestral composition with particular clarity at a given moment. The earlier “scientific” example of a sensor that listens for birdsong could be plausibly perturbed for artistic goals, allowing the listener to alter or distort ambient calls interactively. In the area of touch, one might devise gloves whose role is to respond preferentially to certain types of textures or to “feel” natural phenomena such as running water in novel or unexpectedly complex ways.

Many of these imagined examples for artistic education productively blur the distinction between “low level” and “high level” sensors that played a role in the previous discussion of science education. In many cases, the goal of sensors for the arts would not be merely to note environmental stimuli (such as infrared light) but to assist in their interpretation—a task that might well involve higher-level computational function. For example, one might try to devise a visual sensor that could preferentially respond to (e.g.) certain types of symmetry, geometric form, or recursive (fractal) patterns; or one might attempt to create sensors for higher-level environmental features such as tones of voice, foreign accents, or prosody in speech. Creating such sensors would represent significant (but undoubtedly productive) challenges in computational research.

Things to Worry About

Lurking behind the optimistic discussion of the previous paragraphs, the reader may well have anticipated a note of caution as well. It is one thing to use a computer (or for that matter a book or DVD) to convey information to a student; but do we really want to experiment with human sensory apparatus? Do we want to make it our task, as educational designers, to redesign human boundaries?

In our view there is no simple answer to this question. We might begin by noting that in a very real sense, the population-scale experiment of day-to-day sensory extension has already been going on for centuries in the form of eyeglasses (and their more recent high-tech descendants). After all, numerous people spend their days experiencing a voluntary extension of the sensory apparatus with which they were born. Conceivably, however, an additional source of nervousness in
the present discussion is that whereas eyeglasses are intended to repair a perceived deficit in sight, the suggestions presented here are more in the line of enhancements. Intuitively, the discussion has a note of hubris and potential downfall, like the tale of Icarus’ wings.

One legitimate concern for this type of design is the factor of perceptual adaptation. That is, we might be concerned that a person wearing “color-contrast enhancing glasses” (just to take an example from the discussion above) might experience alterations of some sort in their day-to-day unenhanced vision. The classic account of this sort of perceptual adaptation comes from the 19th-century work of Stratton (cf. Wade, 2000), who famously experimented on himself by wearing image-inverting (“upside-down”) glasses. In Stratton’s report, a degree of visual adaptation to the glasses occurred within a matter of days, and once the glasses were taken off his vision, though affected after prolonged usage of the glasses, re-adapted to its normal state. Stratton’s experiment brings into high relief several elements to be aware of in sensory extension: the plasticity of brain function (the ability of the brain to adapt to altered patterns of sensory input), the temporal patterns of adaptation with or without the sensory enhancement, and the issue of sensory integration between multiple senses (in the case of the “upside-down” glasses, adaptation was perhaps motivated by the need to integrate visual and tactile experience).

To put the matter most bluntly, then: we may wish to be extremely cautious about designing artifacts that could potentially alter, even if temporarily, the user’s sensory apparatus. Conceivably the alteration would cause difficulties in the absence of the artifact; or the alteration would cause an adaptation that (unlike Stratton’s) would not disappear relatively quickly. Moreover, the effect of such adaptations on children’s brains, still in a state of ongoing development and with a higher overall degree of plasticity, might be more risky than the effects on adult subjects.

These are indeed reasons for caution, but at the same time it is difficult to know what level of caution is appropriate. Again, people “experiment upon themselves” in myriad ways every day—and not only with eyeglasses, but with other sorts of prosthetics. One might even classify some of these uses as “recreational”: after all, audiences pay to wear vision-altering “3D glasses” so that they can watch blockbuster movies, or spend their workdays with miniature headphones piping music into their ears. It is more touchy, arguably, to bring up people’s recurring experiments with various substances to alter sensory experience; but even a morning cup of coffee or tea represents something of a self-performed sensory experiment. In other words, while we would argue that educational sensory enhancement should be approached with experimental caution, it is easy to overstate the element of risk-avoidance. Human beings repeatedly, and in large numbers, do things to alter their own experience; and while there are dangers, many if not most such self-experiments are voluntary and apparently relatively harmless if not actively beneficial.

What would caution, then, mean in this context? In our view, it would mean that educational enhancements (again, imagine something like “color-enhancing glasses”) could be tried for brief periods by adults over an extensive schedule of trials before any further use was attempted. For this reason we would advocate a design principle of removability: educational enhancements should be designed (like eyeglasses) to be worn temporarily rather than (like corneal repair) to become integrated within the boundaries of the body itself. For the present, the issue of plasticity for particular choices of enhancement is an empirical question: we won’t know what the effects of certain enhancements might be until we try them, a little at a time. We might also, as a society, decide on giving individuals a measure of freedom in what enhancements they wish to design and use for themselves (again, this is perhaps uncomfortably consistent with the philosophy of the maker move-
ment), permitting a degree of latitude in personal educational experimentation. Our own belief is that it would be wise to confront such policy decisions proactively, since it is likely that these issues will arise in numerous variations as people begin to create novel technological artifacts that augment their own sensory experience.

**FUTURE DIRECTIONS: OR, GOING STILL FURTHER**

The discussion in this chapter has focused on educational uses of what might be called “primitive” modes of sensory enhancement: that is, we have presented possible scenarios for the design of extensions to the senses of vision, hearing, and touch. At the same time, as noted earlier, the larger point of this exploration is to suggest ways of complementing, not replacing, the existing landscape of educational design. One could imagine, then, combining sensory enhancements with more traditional bodies of literature and research. A tutoring program or online lecture series might make use of specialized sensory enhancements, perhaps as elements of single curricular units or assignments; an application for teaching people how to draw 3D objects, or how to paint in oils, might employ specialized sensory apparatus to help in visualizing perspective or color; a home scientific experiment might be accompanied by sensory extensions to experience phenomena that would otherwise be invisible or unnoticed.

Additionally, the topic of sensory enhancement leads naturally to a related (and also perhaps anxiety-provoking) topic of enhancements in actuation. That is, we might wish to devise artifacts to train or enhance the performance of certain actions or muscular movements, in tandem with artifacts that enhance sensory input. Just to imagine a couple of possibilities, one might devise artifacts that (e.g.) enhance dexterity or extend one’s hand-span for playing certain types of musical instruments; or one might want to create novel types of musical instruments that require particular types of bodily extensions to play them. We might create artifacts that help train artists in (e.g.) holding a paintbrush, or novel types of expressive paintbrushes that are manipulated by technological “enhancements” to the unaided hand. Devices could be imagined that train, alter, or enhance vocal performance in systematic ways, e.g. by facilitating unusual vocal effects or imitations. Still more broadly, one could think of wearable “trainers” designed for less specialized purposes—to enhance both sensory alertness and physical movement in one’s environment, or to alter sensory input in response to particular types of movement.

**CONCLUSION**

The discussion in this chapter has been deliberately both speculative and tentative; while there are many existing hints of this sort of work (in the use of Google Glass, wearable health monitors, or prosthetics) there has to date been an absence of discussion on the educational role of sensory enhancement. The purpose of this chapter has been to initiate a more wide-ranging discussion of what “education” means in the context of the current technological landscape. To return to the theme from which we began: metaphors are powerful structuring devices to creativity and design. If we see technology as a source “computer tutoring”, we tend to build tutors; if we see it as “storage” we tend to build libraries and archives. These, and many other metaphors, are productive and provocative; but they do not exhaust our creative possibilities. We might, for example, decide to view educational technology as a new form of eyeglasses.
ACKNOWLEDGMENT

The research discussed in this paper was supported in part through a grant from the National Science Foundation (IIS1231645). Many thanks especially to Katie Siek, Swamy Ananthanarayan, Clayton Lewis, Andy diSessa, and Gerhard Fischer for helpful conversations.

REFERENCES


**ADDITIONAL READING**


**KEY TERMS AND DEFINITIONS**

**Augmented Reality:** A design philosophy of computer-human interaction in which elements of the physical world may be viewed or sensed in enriched ways, often by the user wearing or employing specialized technology for that purpose. In many cases, the physical objects may be “tagged” in ways that allow the user (when suitably equipped) to view additional information about the object.

**Craft Technology:** Blending craft activities (often with a particular emphasis on children’s or educational crafts) with novel technologies and materials.

**Embodied Cognition:** A philosophy of cognitive science that emphasizes the physical, active, “embodied” qualities of cognition (typically in contrast to a style that emphasizes purely symbolic or “intellectual” dimensions of cognition).

**E-Textiles:** Textile materials that have been enriched or augmented with electronic components (e.g., for sensing, specialized actuation, or display).

**Pervasive/Ubiquitous Computing:** A style of technology design that, broadly speaking, emphasizes the ways in which numerous settings and physical objects may be endowed with computational capabilities. (Often contrasted with a style of design in which computers are “set apart” as visible or stand-alone entities, such as desktop devices).

**Sensory Augmentation/Extension:** A style of design (particularly, in this context, for education) emphasizing the ways in which technology can be used to alter or augment the human sensory apparatus.

**Wearable Technology:** A broad term denoting not only e-textiles (as defined above) but also (among other possibilities) technological accessories to be used for such purposes as communication or health monitoring.