# Transhumanism and Education: Embodied Learning in an Era of Altered Bodies

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**Abstract:** In the past decade, both cognitive science and the learning sciences have been significantly altered by an increased attention to the theme of *embodiment*. Broadly speaking, this theme complements (or pushes back against) the notion of purely abstract, "disembodied" cognition and emphasizes the role of physical interaction with the environment in the course of learning and development. A common, if usually implicit, assumption in this work is that learners' bodies are more or less constant from one era to another: after all, human senses, limbs, physiology, and the basic parameters of cognition are part of an ongoing evolutionary human endowment. This assumption, while historically reasonable, is likely to need reconsideration in the near future, as a variety of "transhumanist" technologies (enhanced senses, bodies, and internalized interfaces with the outside physical environment) become more prevalent in children's lives. This paper discusses several foundational issues and questions that are poised to emerge, and to challenge our enduring ideas about children and education, in the foreseeable future.

## Introduction: Embodied learning and human enhancement

As a field, the learning sciences by now has a sufficiently long history (over 25 years since the founding of the flagship journal) so that it is possible to identify "phases" of disciplinary interest. Whereas the earlier years of research focused primarily on applying computational cognitive models to educational scenarios (e.g., by studying cognitive misconceptions in students, or creating intelligent tutoring systems based on symbolic models of the learners' cognition), the past decade has witnessed an increased attention to the notion of *embodiment* in learning. Broadly speaking, this notion emphasizes a number of core ideas: (a) that cognition and learning cannot be thoroughly understood without attention to the physical and environmental context in which they are manifested, (b) that brains and their associated bodies (whether human, animal, or robot) must be studied as an interrelated system, and (c) as a consequence, purely abstract symbolic formalisms (of the sort associated with traditional cognitive science) are an insufficient basis for studying and improving learning and education. (For eloquent extended statements of this argument, see for instance Clark (1997), Pfeifer & Bongard (2007), and Gallagher (2005).)

The application of these rather general ideas to specific educational projects takes a variety of forms. Some research has focused on creating physical objects or experiences that promote understanding of abstract mathematical ideas (Abrahamson, 2017; Hall & Nemirovsky, 2011); in a sense, this work could be seen as a continuation of an earlier tradition of "mathematical manipulatives" (such as number rods, clock faces, or geoboards) to provide a real-world scaffolding to notions such as numbers or modular arithmetic. Other efforts have focused on "full-body" interfaces and activities in which children move within larger settings that illustrate mathematical or computational ideas (Ma, 2017; Malinverni & Pares, 2014). Yet another style of work has pursued the tradition of "hands-on" science and engineering education, often in conjunction with new technologies and computational media, creating novel scientific instruments or construction materials (Blikstein *et al*., 2016; Resnick *et al*., 2000; Eisenberg *et al.,* 2002). Computationally-enriched wearables have been employed as an entrée to computer science, engineering and the natural sciences (Buechley *et al*., 2013), integrating bodily movement with a variety of educational content. In short—and this is only a brief sketch of the territory—it is now fair to say that the perspective of embodiment has become increasingly central and productive within the learning sciences and the design of novel educational technologies.

While the "embodied learning sciences" arguably take a non-traditional stance toward cognition and educational design, at the same time they have implicitly, almost reflexively, taken a highly traditional–even conservative–stance toward the "bodies" in which embodied education takes place. There appears to be, in all this research, a steadfast (and admittedly historically plausible) assumption that the basic physical parameters of "the student" are constant, from one era to another. According to this view, students--like all human beings--have more or less the same sensory endowment; likewise, they share the same basic, evolutionarily determined human morphology and physiology. (1) As a result of this assumption of "bodily constancy", the focus of design in the embodied learning sciences is on *the external environment*–creating new scientific instruments, classroom apparatus, physical experiences, and enriched settings. The essential idea behind this sort of design is that, by altering the external world and creating a richer or more instructive physical environment, we can accommodate the tangible or kinesthetic dimensions of student learning.

The purpose of this paper is to challenge this (usually unstated) notion of bodily constancy, and to argue that emerging movements in technology create the opportunity to rethink the "embodied learning sciences" from the perspective of changing the nature of the body itself. Before expanding on this idea, however, it should be noted–as an important prefatory note–that in the enduring practice of mathematics and the natural sciences, "embodiment" is often considered as something of a hindrance to understanding. This theme would not have been unfamiliar to Plato, whose veneration of classical geometry was combined with a distrust of physical bodies that had never actually experienced, in the course of real living, ethereal objects such as a "circle" or "straight line". More generally, much of scientific and mathematical content is difficult to learn (and to teach) precisely because it challenges the assumptions of day-to-day physical experience. Understanding Newtonian mechanics is made more arduous by the ubiquitous role of friction in our everyday world; quantum mechanics, with its notions of photons that somehow pass (with a given probability) between two separated slots at once, is even more puzzling. Scientific ideas that play out over long periods of time–continental drift, the evolution of species–are hard to envision; vast differences of scale (the distance between the earth and moon compared to the distance between the earth and sun) are problematic; events that take place at time-scales too short for human perception (e.g., the physical deformation of a batted ball when it is first hit) render ideas from basic physics more mysterious. For this reason, much of the attention to "embodied learning" centers–as it must–on translating abstract or physically unfamiliar content into the comfortable zone of basic, biological human understanding.

## Transhumanist technologies: altering "embodiment" in education

It now appears that "basic, biological" human understanding can itself be a target of experimental redesign. The reason for this development is that a variety of new technologies are beginning to enable extension or alteration of human sensing, action, and cognition. (Cf. Barfield, 2015; Jebari, 2015; Lilley, 2013; Seedhouse, 2014.) Not all of these technologies are at equivalent stages of development or deployment; some may achieve the status of availability (by hobbyists, researchers, commercialization) before others; and many pose a variety of thorny, even disturbing, ethical or intellectual questions. Nonetheless, there is clearly a kind of collective momentum visible in the move toward these *transhumanist* technologies for human enhancement. Even if some of the more futuristic ideas never materialize, the most plausible of these technologies–those which are likely to become available in *some* form over the next decade or two–bid fair to profoundly alter our ideas about learners' bodies and minds, and thus in turn alter the opportunities and boundaries of embodied learning.

The main lines of technological development, for the purposes of this discussion, fall into three general categories:

*Sensory extension.* One body of work in transhumanist development involves the extension, elaboration, or customization of human senses. In one simple (and early) instance of the idea, Platoni (2015) describes a small community of hobbyist "body-modders" who implant small magnets in their fingers; as a result, they are able to "feel" nearby magnetic fields (including, as it happens, the fields generated by alternating current sources). The current state of the art for most of these devices is still rather primitive, but there are clear avenues for further experimentation (assuming that there is the will for both researchers and potential subjects to make the attempt). For instance, while devices such as cochlear implants are generally conceived as restorative devices, it is not hard to imagine variations of such implants that would enable the wearer to "hear" sounds at frequencies or amplitudes outside the normal human range of sensation. The most extreme versions of sensory extension involve this sort of internal bodily modification (e.g., via implants); but many less extreme technologies–for instance, wearables for long-term usage–might have analogous effects. People with eyeglasses or contact lenses already know something of the power of "external" sensory enhancements when these become near-constant presences at the surface of the body. One might imagine similar sorts of attachments for (among other possibilities) "hearing" ultrasound, "seeing" the polarization of light, or "smelling" traces of organic solvents. As the design techniques for such extensions become more nuanced, one might expect a move toward tunable or selectively deployable senses: a person might, for example, choose to see varying light frequencies under different circumstances. For the purposes of embodied learning, then, the upshot of these technologies could be a steady alteration both in the *range* of sensation (what we can see, hear, smell, or touch) and in the *conscious control* of sensation (when we choose to deploy various sensory extensions).

*Bodily/actuator extension and brain-machine interfaces.* While the previous examples focused on the extension of what we can *sense*, it is likewise possible to extend the range and nature of actions that can be taken with the body. Current work in robotic exoskeletons and customized or high-performance prosthetics (see Piore (2017), Ch. 1) augurs an expanding landscape of bodily actions. In many instances, such extensions to bodily actuation are complemented by novel types of brain-machine interfaces; in the most straightforward examples, signals from an externally placed electroencephalogram (EEG) "cap" might be used to control limbs or actuators even at some distance from the physical body. One might imagine, then, new limb-like devices that allow people to grip objects of very small size, or of extremely high fragility (like certain types of bubbles in air); other types of extensions might permit people to extend the frequency range of their voices (e.g., for communication with certain animals, or with appropriately enhanced human sensory apparatus). As with sensory extensions, the distinction between an "external" augmentation (a handheld tool, for example) and an "inbuilt" augmentation (a prosthetic limb, for example) admits of many intermediate variants. Likewise, and again as with sensory extensions, the design issues include not only the nature or range of the bodily extension in question but the types of interfaces that we could use to control or tune these extensions: under some circumstances we might, say, elect for different types of hand-grips.

*Cognitive and genetic enhancement.* Probably the most controversial of plausible enhancements to human performance is through the direct alteration of an individual's genome via techniques of genetic manipulation. The advent of CRISPR technology (Doudna & Sternberg, 2017) has greatly altered the accuracy, ease, and affordability of such alteration (though it is almost certain that CRISPR is itself not the last word in genetic therapy). Some types of genetic alterations (e.g., to remedy the mutation that causes sickle cell anemia (Ledford, 2016)) have relatively straightforward and predictable effects, while many others (e.g., attempting to change genes to "improve intelligence") are far more complex and poorly understood. It is nonetheless likely that we will eventually-perhaps in the near-term future–begin to see efforts to link genetic alterations to "enhancements" of various types. These efforts may take the form of animal experiments, life-saving experiments in humans, or "hobbyist" attempts (whether illicit or ill-informed) much like those of the body-modders in Platoni's account. Over time, it is likely that the connection between such efforts and issues of learning or cognition will become too prominent and urgent to avoid notice. A less dramatic–and more immediate–issue has to do with the use of pharmacological methods of (particularly cognitive) enhancement. (Cf. Wenner Moyer, 2016.) The efficacy, safety, and specificity of many "cognitive-enhancement" substances are still much in debate (caffeine, nicotine, and Modafinil are among the substances investigated); it may not be too much of a stretch, however, to imagine the development of substances whose direct advertised purpose is to (e.g.) improve mathematical cognition, manual dexterity, or other functions of brain and body. For both genetic and pharmacological enhancement techniques, the target of improvement is biochemical–the intent is not to add some sort of novel material to the body (as in cochlear implants) but rather to alter the fundamental chemistry of the learner's body itself.

These emerging technologies leave us with a number of larger questions–perils as well as opportunities–for education and learning. Broadly speaking, there are many reasons to believe that the effects of these technologies on educational issues–on the lives of young people in general–will be profound. The consensus within the "embodied cognition" literature is that the functions of the human mind are intimately linked with those of the body. By implication, alterations to the body should in turn produce alterations to the mind. A person able to perceive fluid flow (via sight or touch) with high accuracy might in turn have an unexpected way of understanding fluid dynamics. A person able to feel the textures of solid objects with high precision might have a unique style of working with ceramics or stone. A person able to distinguish colors or tones in a novel manner might create unexpected graphical or musical compositions. A person who is able–genetically or pharmacologically–to concentrate on abstractions for extended periods of time might have advantages in certain types of mathematical reasoning.

As the range and specificity of enhancements evolves in time, so too will the issues posed for learning and education. Several of these issues will be discussed in the final section of this paper, but it is clear that issues of safety (what are the downsides of "enhancement"?), equity (will enhancement only be available to the very wealthy?), and choice (who gets to decide whether and when these technologies should be employed?) are paramount. Other questions–perhaps less central, but still fascinating–are likely to arise as well. Will it be possible (or desirable) to design new curricula for students with altered bodies? Might one create a physics curriculum for those able to sense a wider range of electromagnetic radiation; or a chemistry curriculum for students with enhanced 3D visualization skills? Might it be possible to design new types of interfaces for students with (say) enhanced manual apparatus or extreme levels of hand-eye coordination? Pursuing these scenarios, the advent of enhancement technologies poses deep questions for the disciplines themselves. Perhaps, as a society, we prefer *not* to encourage or allow certain types of human augmentation, even if that augmentation might be done in the service of creating new mathematical, scientific, or artistic ideas. That is, we might collectively decide that a goal like "the advancement of mathematics" is secondary to some essential notion of human constancy or limitation.

The remainder of this paper will discuss several general issues at the intersection of human enhancement and the learning sciences. We will explore in turn the themes of designing extended senses for science education; creating new types of physical apparatus or experiences for altered bodies; and treating the learner him- or herself as a target of “educational technology design”. In the final section of the paper we explore several of the (very pronounced) ethical issues that are likely to emerge as techniques of “enhancements for learning” evolve over time.

## Human enhancement and its impact on education: Several scenarios

The previous section outlined the general argument that technologies for human enhancement are likely to have a powerful impact on the practice of education, and on cognitive science more generally. In this section, we discuss several possible avenues by which this impact might be manifested.

### Extended senses for science education

As noted earlier, the evolutionary limitations of human perception pose an enduring challenge for science education. It is hardly surprising that we intuitively believe that the earth is flat, that land masses (like continents) don’t move over time, that stars are eternal, or that air is continuous rather than particulate in nature: these are the beliefs consistent with our everyday experience and sensory apparatus. One line of pursuing science education, then, would be to begin by designing devices and techniques for extending human perception in ways that mesh with scientific notions beyond those for which we are originally adapted.

A natural inspiration for sensory enhancement exists already in the animal world. Bees are capable of detecting the polarization of sunlight; eagles have far more acute distance vision than human beings; star-nosed moles “feel” the earth in front of them with their remarkable noses; dogs can respond to tones beyond the range of human hearing; fish use their lateral line sensory organ to detect nearby disturbances of water currents. In each of these cases–and many more–one need not postulate an “unnatural” sensory talent (like “seeing” at an atomic scale); we already have existing biological models of potentially expanded cognition. A transhumanist “style” of educational design would be to create sensory augmentations to which students could adapt over long periods of time (e.g., through wearables or implantation) rather than external laboratory apparatus: for instance, rather than designing a handheld microphone for detecting sounds available to dogs, the transhumanist approach would be to design earphones (or, in more extreme form, novel forms of implants) to extend the student’s everyday perception of sound. Realistically, augmentations of this type would be designed to be reversible, either by removing a wearable or by “turning off” specific effects of a particular implanted device. The (admittedly early) experience of Platoni’s body-modders suggests, however, that sensory extensions are perceived as benefits by their recipients, and it might well be that young scientists will, over time, strongly prefer to extend their sensory abilities in various ways.

Not all animal-themed sensory extensions need be “simple” extensions for extending the physical range of sight or hearing. One might design computationally enriched extensions that are more complex in nature, aligned with the social demands of particular species. For example, songbirds are particularly alert to the calls of members of their own species; one might therefore design sensory extensions for “picking out” the calls of particular species of birds. A student equipped with this type of augmentation might have a “tunable” sense of hearing, alert to distinct calls at different times. In the same vein, sensors for specific pheromones could give students a particular ability to detect the nearby presence of particular insect species; or sensors for particular types of pollen could be used to note the presence of certain plants. Even in human affairs, sensors of this complex type might have their uses: a computational sensor for (e.g.) levels of vocal stress, or particularities of facial expression, might be employed as an informal (and imprecise) “lie detection” organ, or a sensor for particular accents, patterns of speech, and word usage might be used as a “geographic origin” detector.

The notion of making such sensory extensions “tunable” is likely be a recurrent one. For instance, one might design highly sensitive tactile wearables that would allow students to touch surfaces and (if the touch sensation were modeled on that of a fly, or spider) “feel” the irregularities in even a smooth surface such as wood paneling. Conceivably this sort of wearable would allow for varying range of sensitivities so that the user could feel surfaces at progressively higher levels of resolutions: “feeling” objects in the manner of a human, a mouse, a housefly, or a dust mite in succession.

### Designing physical apparatus or scientific experiences for extended bodies

Most educational design in science education concerns the creation of sample experiments, experiences, or types of apparatus. In line with the examples of the previous subsection, it should be possible to create new types of educational materials for extended sensory and bodily functioning. One might imagine creating circuit design kits for students equipped with sensory augmentations to “feel” the nearby presence or absence of direct current (there are a variety of ways of imagining the engineering of such augmentations); or a chemical indicator for students with an augmented or extended perception of color.

Many possible examples along these lines could be constructed by creative redesign of "classical" school experiments and apparatus. For example, a venerable scientific toy is the "tornado in a bottle" in which water is swirled within a plastic bottle (draining into another) to create a pattern much like a whirlpool. One limitation of this toy is that the fluid phenomenon can only be seen from the outside: the student can see the "tornado" as from an external camera, but not from the perspective of a person caught within the tornado itself. It might be possible to give students experiences with a panoramic cylindrical "eye" designed for such apparatus; by placing the eye toward the center of the upper bottle, and by conveying the visual input from that eye to the student, it might be feasible to experience this (and other) fluid phenomena "from within". The utility of this sort of apparatus would depend on the student's ability to interpret visual input from novel geometries of "eye-like" devices (e.g., cylindrical or spherical "eyes" (cf. Krishnan & Nayar, 2009)); this in turn might be the subject of studies in human sensory augmentation.

Still other traditional science experiments could be the subject of experimentation with devices for augmented sensing or actuation. One might create extensions to fingertips so that they could feel the surface tension of liquids (a subject of the classical "floating needle" demonstration), or so that they could have an enhanced perception of static electricity (the focus of the "balloon adhering to a sweater" demonstration). The purpose of these types of scenarios would not be to redesign simple experiments into horribly complex or expensive variants, but rather to provide opportunities to investigate the potential for enhanced sensing of scientific phenomena.

## Transhumanist technologies as part of "learner design"

Over an extended period of time, it is plausible that the language of educational design will begin to incorporate the affordances of transhumanist technology. Traditionally, educational designers think of themselves as creating *external* materials for a (more or less constant) human physiology. We create scientific visualizations and notations for standard human eyes and visual systems; we create instrumentation and physical materials to be operated and shaped by standard human hands; we devote more time to explaining those concepts that are least consonant with human experience.

This type of education implicitly assumes that we can only teach what human minds and bodies can learn. And the physical body is an important element in this equation: indeed, one of the recurring themes of embodied cognition is the interdependence of "abstract" cognition and the affordances and constraints of our biological inheritance. The roboticist Rodney Brooks expresses the idea succinctly:

> "[T]he physical manifestation of the body is primary. The stuff of intelligence has evolved in conjunction with that body, and is a modulator of its behavior, rather than a primary and central control system." [In (Pfeifer & Bongard, 2007), p. xv.]

By altering, even in relatively mild ways, the constraints and affordances of the learning body, we can begin to explore alternative dimensions of human thinking and learning. Human bodies and senses are in fact not fixed quantities. Again, this is hardly an original observation: the results of early research in embodied cognition imply that human perception is in fact surprisingly malleable, mediated by historically evolving material and cultural artefacts. As Clark (2014) observes,

> "[H]uman cognition is structured by culturally distributed processes that spawn a succession of designer environments whose impact on the development and unfolding of human thought and reason can hardly be overestimated…. [T]he human-built environment becomes a potent source of a new intergenerationally transmissible structure that surrounds, scaffolds, and perhaps even fundamentally transforms the activity of our biological brains." [p. 245]

The overall implications of this line of thinking are that human cognition–the ideas and concepts available to us–are strongly influenced by the materials we use and the environments in which we develop. By the same reasoning, humans with extended or altered experience of their environments–through augmented sensation, a greater range of human actuation and functioning, or genetically mediated alteration of sensation, cognition, and control–are likely to develop different types of cognitive strengths and limitations from those with which we have become familiar over evolutionary time.

For the learning sciences, education will thus increasingly be viewed as a potentially integrated system of both experience design and what might be called "learner design". A physics curriculum may be conceived as a combination of material to be learned, media and environments through which to highlight and present that material, and human faculties through which to interact with those media and environments. A music curriculum may be conceived as a combination of instruments for performance and composition, and human bodies and senses tailored to those instruments. A foreign language curriculum may be conceived as materials and experiences to present the language and sensory extensions to hear and distinguish novel phonemes with greater ease.

The upshot of this sort of development might be that new *types* of material could eventually be learned. It might be possible to create mathematical "manipulatives" or experiences to communicate ideas of non-Euclidean geometry or four-dimensional spaces. It might be possible to design or teach specific forms of mathematical or physical analogs to synesthesia, linking distinct modes of perception: just as people with the condition sometimes report that numerals are linked to colors in their minds, one might imagine (say) links between colors and imaginary numbers, or between musical tones and specific types of matrices.

At this stage in our argument, it is likely that the reader is experiencing a salutary sense of caution (or perhaps alarm): what is happening, or is about to happen, to education and (more broadly) the human condition itself? These questions are indeed urgent, and they are the subject of the final section of this paper.

## Human enhancement and education: Social and ethical issues

As with any long-term (and speculative) discussion of major technological change, the social and ethical issues raised are complex; this is particularly true when the plausible long-term changes are likely to impact basic notions of "human nature" itself, and when the eventual subjects of change are likely to include children and adolescents. Broadly, there are several recurring strains in this sort of discussion–strains that have in their way become clichés, but are no less important for being commonplace. One such strain is that technological change tends to be accompanied by unexpected (and often malign) side-effects. In urbanized society, problems such as environmental degradation, diseases linked to diet (such as diabetes), loss of privacy, and many others are intimately connected to technological developments that were originally envisioned with human betterment in mind. Another recurring strain is the notion of "technological inevitability": the notion here is that as technology becomes available, there is little we can do to control its use. If (say) technologies such as genetic alteration or cognitive-enhancing pharmaceuticals are invented, people are going to experiment with them regardless of the potential dangers to themselves or their communities.

In the case of transhumanist technologies, a number of social and ethical issues deserve particularly close examination:

*Safety.* We have very little experience–very little to go on–in assessing the long-term impact of transhumanist extensions on human health and safety. What would it mean for someone to actually experience an enhanced sense of hearing or touch over a period of years or decades? What would it mean for a child to grow up, from an early age, with the ability to see wavelengths outside the normal human range? What would it mean for a person to control, over extended periods, novel sorts of limbs with functionality beyond those of human limbs?

In our view, the short (and honest) answer is that no one can possibly know the answers to these questions in the absence of experimentation; and (to borrow from the "technological inevitability" theme) it is overwhelmingly likely that there will indeed be certain people, like Platoni's body-modders, all too willing to experiment on themselves. If history is any guide, these people will primarily be teenagers or young adults; and thus, the longitudinal nature of the experimentation will follow from the self-selection of the subjects. While it is certainly possible that dangers will be unearthed in this process, it must nevertheless be pointed out that a myriad of technological developments over the past century–motion pictures, television, accessible recorded music, home computers, mobile phones, and many more–have themselves been "social experiments" performed on child subjects. There has been, and continues to be, intense argument over the effects of television viewing on children; more recent books (Twenge, 2017; Freitas, 2017) have pointed out the downsides of social media for their young users. The point here is not to disparage the potential dangers of transhumanist technologies, but merely to note that there is nothing unique in the deployment of technology with unknown and well-intentioned, but potentially adverse, effects. It would be desirable if these new technologies could be held to a higher standard of safety than previous technologies; but there is little reason at present to predict that this will be the case.

*Availability and Equity.* Another prominent issue raised by transhumanist technologies is that of equity: if such technologies do indeed prove desirable, will they be accessible only to certain select (most likely, wealthy) people? In the worst case, one might imagine a broad sort of growing "divide" between those who have access to technologies for extension and those who do not; and the sense of this divide will be felt most keenly among younger populations. Again, this is not the first time that such issues have been raised: unequal access to the Internet, or to advanced medical technologies, is a painful manifestation of economic inequality. In our own view, one design principle to uphold as these technologies become more prevalent is to facilitate and allow inexpensive or "hobbyist-based" versions of the technologies, even at the concomitant risk of reduced regulation; but this will undoubtedly be a source of fierce debate in the near-term future.

*Choice and Control.* An especially disturbing issue in this context is that of choice: will individuals be able to determine whether or not they wish to experiment with various forms of human augmentation? This issue is highlighted by the applications to education and childhood development: should a parent be permitted to deploy some particular technological extension on his or her child? Conversely, should a parent always be *prevented* from deploying any technological extension on a child, regardless of the circumstances? At what age (if any) would we allow individuals to self-experiment: should eighteen-year-olds have the right to explore changes to their bodies or genomes without parental consent? A particular concern here is the potential commercialization of certain types of augmentation technologies: should companies be able to offer, and advertise, enhancement technologies as pharmaceutical firms currently do (with problematic results) with medications?

None of these issues, in our own view, is dispositive for rejecting the idea of transhumanist technologies out of hand, even if such rejection had a hope of being effective in the long term. The terrain here is highly complex, and the coming years are bound to be stormy ones for education and the learning sciences, and for society more generally. The argument here is that there is good reason to be excited and even optimistic about the possibility for human betterment, and for expanded possibilities for human achievement in the sciences, arts, and engineering, as a result of these emerging technologies. As human beings alter themselves, and their environments, they will experience new varieties of childhood–and new interpretations of the material and cultural worlds in which they grow.

## Endnotes

(1) For the purposes of this necessarily brief discussion we will ignore important lines of work focusing on education for students with sensory or physical impairment.

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