Machines and minds: The new cognitive science, and the potential evolution of children's intuitions about thinking

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An odd thing has happened in the nearly four decades since Seymour Papert wrote his classic book *Mindstorms* [1]. The themes addressed in that book, and the arguments for introducing children to programming, seemed radical and startling to contemporary readers in 1980. *Mindstorms* was published in an era in which home computers were still in an embryonic state, seen largely as hobbyist instruments (the Apple Macintosh was introduced in 1984); and the idea of children using computers for creative purposes seemed outlandish, much the way that many readers today view Freeman Dyson’s [2] argument that children should be given access to the tools and instruments of biotechnology.

As time has passed, several of Papert’s arguments in *Mindstorms* have become so familiar and comfortable to current-day readers (especially young readers coming upon the book for the first time) that they seem almost anodyne. Of course children should use computers! In fact, our culture seems to regard computers as primarily the artifacts of children: the recurring media images (even if trite and not quite accurate) of pre-teen hackers and youthful gamers living out of basements and bedrooms testify to that. Computers, and computer technology, have been juvenilized nearly to the point of caricature. And of course computers aren't inaccessible—quite the opposite! It may be forgotten that a significant passage in the introduction to *Mindstorms* actually does the arithmetic to show that personal desktop computers are affordable for schools. That argument has long since been vindicated; at most American universities, it is simply assumed that every incoming student will have a personal computer (probably a more powerful and recent model than their professors own). And of course children should learn programming—the President and Secretary of Education and everyone else of importance (including parents) now says so! How will a child otherwise be able to get a job in the coming century?

In all these respects, for modern readers, *Mindstorms* is preaching to the converted. And yet, in other respects, the book is still a shock, making unfamiliar claims. Not all of Papert’s themes have been amplified in the intervening decades—one, in particular, has been nearly forgotten. Consider again that last argument for learning programming: it is phrased in economic terms, almost as an imperative for survival. Children now have to learn programming, or by assumption something terrible will happen: they’ll starve in adulthood, the nation will fail economically (the threat du jour seems to have shifted from Japan to China), someone somewhere will fail to make a fortune, and all sorts of other disasters. Papert, and the home computer enthusiasts of his era, did in fact sometimes make such economic arguments; but in *Mindstorms*, the pragmatic reasons for learning programming took second place to more provocative, intellectual goals. The benefits of learning to program, as argued there, involved allowing the child to obtain a deeper sense of his or her own mind: the computer could be a child’s entrée into reflections on what it means to think at all. The computer could be a means of developing a vocabulary of learning, of solving problems, of how human languages (not only computer languages) express ideas.

The discussions along these lines in *Mindstorms* were not uniformly triumphalist about computational models of mind. There was at least a suggestion in the book that programming could give children a means of reflecting on the distinct limitations both of humans and machines. Children were not (it appears) intended reflexively to identify their thinking with computational processes, but rather to use the computer as an imperfect mirror, a loose and intriguing model against which to compare their own minds and selves. The computer was thus seen as an educational instrument even beyond the particular content of study (say, turtle geometry): it opened the door to questions about philosophy of mind, and about oneself as thinker. These were themes prevalent in the early artificial intelligence and cognitive science communities, and in *Mindstorms* the computer was an instrument to welcome children...
into the most inspiring elements of the zeitgeist. The child of 1980
could now embark on a more poignant intellectual journey than
had been available to previous generations. In [3] Sherry Turkle’s
book *The Second Self*, published 4 years after *Mindstorms*, the theme
was reiterated more explicitly:

Some objects, and in our time the computer is preeminent
among them, provoke reflection on fundamentals. Children play-
ing with toys that they imagine to be alive and adults playing with
the idea of mind as program are both drawn by the computer’s
ability to provoke and to color self-reflection. The computer is a
“metaphysical machine”, a “psychological machine”, not just
because it might be said to have a psychology, but because it
influences how we think about our own [p. 16].

It is this theme, above all others, that has been swept under the
twenty-first century rug of economic necessity. No more do we
hear that programming is an aid to a child’s self-knowledge, or
a step toward exploration of the nature of mind; no more is the child
supposed to adapt the ideas of programming toward reflection on
his or her own learning (cf. the example in *Mindstorms* of learning
to juggle by thinking algorithmically [ch. 4]). The current rhetoric
of children’s programming lacks the element of joyful relaxation
that Papert exemplifies in his discussion of the samba schools of
Brazil [ch. 8]. Relaxation, indeed, is the last thing any child would
be urged toward today. The current-day message, to risk a bit of car-
icature, is something like: you *must* study computing, *or the coming
century will make you wish you did*. The expansive, optimistic tone
of *Mindstorms* has been rendered increasingly pinched and grim.

Re-integrating Cognitive Science and Children’s Technology

It is not too much to hope that children’s computing—and chil-
dren’s expressive technologies more generally—can once more be
infused with the intellectual excitement that motivated so much
of Papert’s language in *Mindstorms*. To achieve that, however, we
must begin by acknowledging that the foundational conceptions
of cognitive science, philosophy of mind, and (to some degree) tech-
nology itself have evolved since 1980. That is, we cannot simply
place ourselves back in the cultural climate of forty years ago, and
treat children’s technology as an entrée into ideas that are now two
generations old; to do so would be an odd exercise in academic
nostalgia.

The field of cognitive science has indeed undergone substantial
changes since the days of Logo’s development. At that earlier time,
it is fair to summarize by saying that cognitive science focused
on a portrait of mind that was largely a matter of symbolic in-
fomation manipulation. In particular, the strongest version of the
“computational metaphor of mind” held that it should be possible
to view the mind (perhaps in both humans and machines) as
an abstract device for integrating sensory input with some form
of memory (including experiential memory) to solve problems,
plan, and make decisions. The language of *Mindstorms* reflected
that historical moment, with passages devoted to planning the
solutions to problems through the use of procedural thinking,
modeling thinking as the collective result of complex “societies” of
agents, making use of computational heuristics as an extension of
the problem-solving ideas of George Polya, and so forth.

All these passages retain their interest and vibrancy today;
notions such as problem decomposition, agents, and heuristics are
still valuable elements of a rich intellectual repertoire for thinking
about thinking. At the same time, there were many subsequent,
productive developments in cognitive science that had yet to occur
in 1980. There was, for example, relatively little direct connection
at that time between the biological brain sciences and the field
of artificial intelligence (with the arguable exception of computer
vision, as reflected in [4]). Indeed, for many AI researchers, the
division between neuroscience and artificial intelligence was de-
liberate; the idea was that one did not have to delve into the
nuts-and-bolts of physical/neurological implementations in order
to understand information processing in the abstract (in much
the same way that computer programmers typically work with
abstract languages removed from the specific hardware of any one
particular machine).

This is not the occasion to resolve the cognitive science debates
of the 1980’s; suffice it to say that over the years a substantial
proportion of cognitive scientists and AI researchers would now,
at the very least, see neuroscience and brain science as sources of
important ideas for the study of mind. Nor is this by any means
the only (or even necessarily the most important) shift in the
climate of cognitive science. The forty years since *Mindstorms*
have seen, among other developments: an increased attention to the
evolutionary origins and purposes of human and animal thinking
(“evolutionary psychology”); a burgeoning interest (“embodied
cognition”) in the link between the mental/symbolic description of
thinking, on the one hand, and the nature of physical and situated
behavior, on the other; a vigorous debate (“extended cognition”) on
analyzing cognitive systems as heterogeneous collections of
materials and mechanisms; and a new interest in social cognition
and decision making (motivated in large part by work in game
theory). In other words, the study of mind—animal, human, or
computational—is now a much richer landscape than it was in
1980. Brains, bodies, external tools, evolutionary histories, and
societies have now augmented what was once an exclusive focus
on symbolic manipulation. The zeitgeist is no longer what it was;
and we, in educational technology, can now aspire to introduce
children to still more powerful and wondrous ideas and debates
than were apparent forty years ago.

In working toward this goal, it is well for us to remember
that the computational and technological landscape is likewise far
different, far richer, than that of the *Mindstorms* era. Those who
design educational artifacts have a much broader and more nu-
anced palette of devices, materials, and techniques at their disposal
than heretofore. In *Mindstorms* (and indeed for at least a decade
thereafter) there was a foundational pragmatic assumption that
“children’s technology” meant, by default, “children’s computing”;
and that the “computer” in question was, most likely, a stand-alone
desktop device. Even at the time, there were obvious limitations to
this situation: indeed, as early as 1972, Alan Kay had articulated
a remarkable vision of the “Dynabook”—a portable, networked
computer for children’s use [5].

The issue for us now is not simply that computers themselves
are far more varied than before—insize, in purpose, in portability, in
cost; nor is the issue simply the advent of the Web; nor is the issue
simply that there are (at least a few) more computer languages ac-
cessible for children’s use than before. All these developments are
important and ongoing; but the real point is that the time is now
right to return our attention to children’s intellectual narratives
about minds, thought, learning, and the nature of the self. Web-
enabled phones, youth-oriented vlogs, child-friendly wearable fit-
ness devices, and their myriad cousins are all interesting develop-
ments in children’s technology; to deny that, or at least to deny
it outright, would seem unnecessarily grumpy. Yet at the same
time, the purposes of these technologies, and the human purposes
that they implicitly present to children, have drifted away from
the introspective, potentially profound questions raised in Papert’s
and Turkle’s books. Children’s technologies—again to paint with
a bit of caricature—seem to be regarded as part of a consumerist
culture of technological acquisition: it is important to have the
newer phone, the higher-resolution video and camera, the more
feature-rich tablet. At the extreme, this culture of technology-as-
status-symbol exudes something frantic, something grimly hostile
to long attention spans and lengthy reflection. The idea of a child
using technology, the questions raised by technology, to actually
ponder their interior thoughts and selves now sounds every bit as
shocking as it would have to a *Mindstorms* reader of 1980.
The available technologies appropriate to this renewed mission of intellectual growth in fact extend well beyond computers. They include the burgeoning space of lightweight, “maker-oriented”, hobbyist devices for personal construction and creation; the rapidly evolving panoply of devices for personal fabrication in the physical world; the shelves of novel materials available for children’s construction and expressive creation; the exciting development of interfaces for (e.g.) reading gestures, facial expressions, and physiological data; the advent of powerful presentational devices for experiencing virtual reality environments, or for portable lightweight projection of computer images; and so forth. Perhaps most interesting, they most likely include devices and technologies that have not yet been designed or conceived—technologies that do not exist nor because they are too implausible or futuristic, but rather because they lend themselves to an intellectual narrative that is not meant to be viewed through the lens of product marketing. As designers of educational technologies, we can feel empowered to create artifacts whose purposes are refreshingly idiosyncratic, slow-paced, experimental, context-specific, and skeptical of the value of endless acquisition. We can work toward the design of artifacts that are genuinely mind- and life-changing, in the sense hinted at by Mindstorms—artifacts that are strangely, personally provocative and challenging, and therefore, in the current climate, optimistically subversive.

What to Build?

What would it mean to design activities and artifacts to this end? In this final section we sketch several directions in which children’s technology could be designed to reconnect with the continuing human quest to understand how it is that we or any creature (including perhaps computational “creatures”) can think, learn, or identify oneself. These sketches reflect in some measure our particular research interests; but they also extend well beyond our own parochial concerns and projects. The intent here is to suggest some still-earlier directions for educational technology—directions that others may pursue in novel ways beyond those that we ourselves are able to predict. The suggestions are also slanted to emphasize, and provoke intuitions about, more recent themes in cognitive and brain sciences.

• The notion of “embodied cognition” is often associated with the field of robotics (see, for example, [6] or [7] for foundational works making this philosophical linkage explicit). Children’s robotics is a thriving educational subculture, but it’s fair to say that many projects stress performance (getting a robot to perform some particular task) as opposed to reflection on the nature of embodiment itself. An emphasis on embodied cognition might well lead to constructions with an alternative style: free-standing simple creatures whose job is to be placed in a terrarium or aquarium alongside living creatures and to interact with their (biological) environment; creatures made of novel materials (including craft materials, pliable or flexible “soft robotics” materials, biomimetic materials, and so forth); robotic elements whose role is to act as extensions or wearable augmentations to children’s bodies (e.g., an “artificial extension” to one’s arms or fingers, or an “artificial gesture enhancer” to add expressiveness to one’s hands), to provoke reflection on the embodied nature of the child’s own thinking.

• Pursuing the previous theme a bit further, we could imagine the design of wearable “sensory extensions” of various sorts that would (e.g.) allow children to “see” infrared wavelengths, “hear” ultrasonic tones, or “feel” magnetic fields in their vicinity. (See, for example, the embryonic and provocative hobbyist projects described in [8].) Again, the intent of such projects would be to provoke reflection on the power and limitations of human sensory affordances, and how they contribute to our thinking.

• In the history of educational technology, a recurring goal has been to create “artificial tutors” or “artificial teachers” with the intent of providing children with personalized instruction. (The Logo tradition was generally uninterested in such efforts on philosophical grounds.) An alternative direction would be to build “artificial co-learners”: models of students (rather than teachers) that would accompany children in learning new material and articulate (perhaps simplistic, but concrete) strategies for thinking about the material. Such models might be customizable or programmable for students—that is, students might be able to create (in high-level form) particular rules for learning to see how those rules play out in the behavior of their artificial colleague. A system of this form might offer children the opportunity to think of their own learning strategies as objects of (at least partly) conscious reflection. Other projects related to this idea might be to design co-learners whose emphasis is on articulating strategies for Web search—seeking out high-quality educational materials appropriate to a child’s tastes or interests. (One might think of this as a child-friendly, partly-programmable instantiation of the currently popular “Stumble-Upon” search engine.)

• Yet another style of project might be to allow children to design artifacts for guiding, or experimenting with, the learning processes of themselves or other creatures. For example, children might create birdhouses (to be placed in natural settings) that offer food and shelter preferentially to certain species of birds, or only under specific conditions of temperature or illumination; studying how birds respond to the artifact over time might be an introduction both to ontogenetic learning in animals and (over still longer periods) to the notion of evolutionary constraints. Alternatively, children might create artifacts whose purpose is to influence their own intellectual environments—conceivably, a child might be able to design replicas of objects to remind them of the biographies of their own intellectual heroes (e.g., a child might make her room subtly or stylistically resemble the laboratory of Marie Curie, or the creative recording studio of The Beatles’ recording studio). The notion behind this more general idea of environmental modification is related to the evolutionary “Baldwin effect” (cf. [9, ch. 3]): by altering one’s own environment, it might be possible to promote certain types of learning or attitudes that fit with, or are encouraged by, the newly-altered environment.

These sketches are hardly intended to be anything more than hints at the sorts of projects that could be undertaken. More broadly, their purpose is to suggest (by analogy with Papert’s image of “mathland”) a portrait of children’s environments for reflection on the nature of self and thought. Can we alter our own learning (and if so, how, and by how much)? How dependent is our thinking on our biological “hard-wiring” of sensory mechanisms? Can we design new tools or artifacts that alter our own cognitive abilities? Do we think differently in groups, or in collaborative pairs, or in competition with other learners, than we do by ourselves?

Providing children with activities, materials, devices, and systems to reflect on these issues would offer us the possibility of returning to the spirit of intellectual self-discovery that pervaded Mindstorms. More broadly, this sort of technology could be designed for a type of socialized, informal learning—reflecting on questions of mind is less the subject of standardized curricula, and more the stuff of impassioned late-night (or lunchroom) discussions with friends. Building extensions to one’s environment (or one’s body!) is likewise a sort of exercise in playing—less in the sense of structured games, but rather playing with one’s own identity and self-image. There is something about these themes that doesn’t quite fit in most school settings; the subject is too personal and urgent, and the work too experimental and lifelong. Children’s technology designed in this spirit can thus serve as a refreshing alternative to the frantic educational emphasis on skill-building, employability, and material survival; rather, it might permit children to turn instead to a more patient fashioning of their own sense of personal identity and biographical narrative.
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References