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The Immeasurables

An eight-year-old sits braiding the hair on the tail of her My Little Pony doll, completely absorbed in the job. The shining plasticized hair is long and resilient; she plays with it for hours.

She starts by taking the tail and dividing it into three pieces that she braids together. Then, she undoes that braid and begins to nest layers of braids. She divides the tail into nine pieces and braids each group of three until she has three braids, and then takes these three braids and braids them together. After a while, the girl is starting with twenty-seven pieces, braiding them first into nine, then into three, then into one. The girl is playing with My Little Pony but she is thinking about recursion.

The eight-year-old is one of my MIT students, telling a story of her childhood. For the past thirty years, I have begun each class at MIT by asking my students to write about an object that was important to them on their path toward science. What they have had to say testifies to the importance of objects in the development of a love for science—a truth that is simple, intuitive, and easily overlooked. And it is cause for optimism because it offers a hopeful note as we face our national crisis in science education.

As we argue about testing and standards, about the virtues of digital tools, about whether or not to move to online courseware, we have a tendency—as in any emergency—to look for salvation in the next new thing or things. In this case, these next new things are testing, measurement, and the computer itself as a way to provide educational solutions. But we can also look to the last things that worked. And one of the things that has always worked in getting young people interested in science has been object passions. From my very first days at MIT in 1976, I met students and colleagues who spoke about how as children they were drawn to science by the mesmerizing power of a crystal radio, by the physics of sand castles, by playing with marbles, by childhood explorations of air-conditioning units.

Certain trends are apparent as I look at the objects that have drawn children to science over the past thirty years. One is an interest in "transparency." Through the mid-1980s, MIT students wrote about being drawn to science by radios, vacuum cleaners, wooden blocks, and broken telephones. These are things to take apart and put back together again. By the end of the 1980s, the emphasis shifts to objects that are investigated through the manipulation of program and code. Yet even with the passage from mechanical to electronic, and from analog to digital, students express a desire to get close to the

In *What Are You Optimistic About?: Today's Leading Thinkers on Why Things Are Good and Getting Better*, John Brockman (ed.). New York: Harper Perennial, 2007.

inner workings of their machines. Even with machines that are increasingly opaque—with a printed circuit board one can no longer "open the hood and look inside"—young people with a scientific bent continue to search for at least a metaphorical understanding of the mechanism behind the magic. And they find it.

Beyond seeking a way to make any object transparent, students extol the pleasure of materials, of texture, what one might call the resistance of the "real." For one, geology became real through her childhood experience of baking a chocolate meringue: "Basic ingredients, heated, separated, and cooled equals planet." A thirteen-year-old looks up at the motion of his fly line while fishing with his father and is reminded of drawings of long, continuous, flowing lines he had made in algebra class. "I realized that the motion of my hand had a very direct effect on the movement of the line, much in the same way that the input to a function produced a given output. Without any formal understanding of the physics involved, I was able to see the fly rod as representing a given function for which I was the input... From this point on, the fly rod was my metaphor for understanding function in mathematics."

Young scientists are encouraged by a personal experience with an object they can understand and with which they can tinker. Playing with objects in their own way leads children to build a personal scientific style. There has been no simple migration to a new digital world. Children grow up in many worlds—they are seduced by the virtual, but always brought back to the physical, to the analog, and of course, to nature.

Science is fueled by passion, a passion that often attaches to the world of objects much as the artist attaches to his paints, the poet to his words. Putting children in a rich object world is essential to giving science a chance. At a time when science education is in crisis, giving science its best chance means guiding children to objects they can love. Children will make intimate connections, connections they need to construct on their own.

One of the things that keeps educators and parents from valuing children's object passions is the fear that children will become trapped in objects, the fear that children will prefer the company of objects to that of other children. But even if the objects in the life of a young scientist do begin as objects of reassurance for a lonely child, these objects—from the periodic table of the elements (because it offers an image of perfect and reassuring organization) to Lego blocks (because they offer a way to create perfect and reassuring symmetries) can become points of entry to larger, transformative experiences of understanding and confidence, very often at the point they are shared.

It seems wise to attend to young scientists' romance with objects. If we do so, we are encouraged to make children comfortable with the idea that falling in love with things is part of what we expect of them. We are encouraged to introduce the periodic table as poetry and LEGOs as a form of art.

In *Mindstorms: Children, Computers, and Powerful Ideas*, Seymour Papert writes of falling in love with the gears of a toy car that his father gave him when he was two. Fascination with those gears led to fascination with others. He played with gears in his mind and mathematics began to come alive for him. He fell in love with the gears and he fell in love with science, all at the same time. Papert makes the point that if anyone had tried to measure what was happening to him as this inner explosion of affect and cognition was occurring, they would have found nothing to measure.

I am made optimistic because a conversation about objects reminds us that just because we can't take a measurement doesn't mean that something important is not occurring. Too often when we can't test, we end the conversation. My students' voices make me optimistic because they serve as a reminder that the limit of testing is not the limit of inquiry. It can mark the moment where we turn directly to the child, where we put our deeper intelligence to work. We can learn what motivates and what inspires..

From a practical point of view, we cannot know in advance whether we stand before a child who will use objects as a path to science. If we insist on one-kind-fits-all curricular programming that takes children away from the idiosyncratic objects they are drawn to, we could miss a child who makes Cs and Ds in math and science but goes on to develop an abiding love for designing complex systems because he has connected with LEGOs and a personal computer. We could miss a child who doesn't think of herself as a science student even as she silently absorbs everything she can learn from chemistry experiments that create purple smoke. We might not count as learning the lessons that come with braiding a pony's tail, casting a fly rod, or baking a meringue.

I am reminded daily of these object passions in the students I teach; I am optimistic as I begin to sense the political and philanthropic will that could enable these passions to find their voice in education.

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A New, Environmentally Sustainable Worldview

Given the current array of critical environmental woes—global warming, habitat loss, and species extinctions, among others—one might assume that there is little room for optimism. Nevertheless, I am optimistic, albeit cautiously so, about a profound shift in human attitudes toward the environment.