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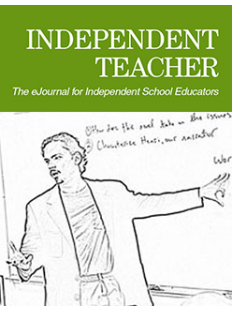

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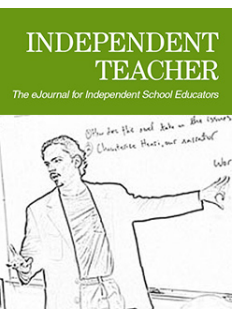

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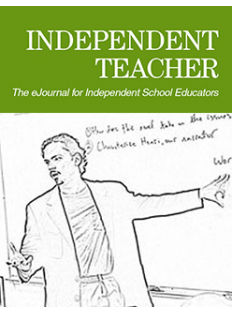

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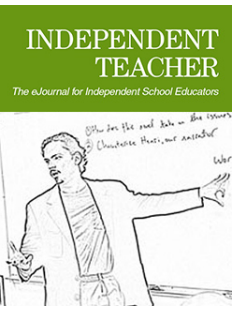

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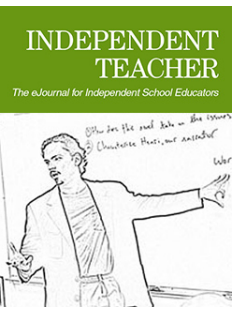

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Outside the Skinner Box

January 01, 2015

The phrase "technology and education" usually means inventing new gadgets to teach the same old stuff in a thinly disguised version of the same old way. Moreover, if the gadgets are computers, the same old teaching becomes incredibly more expensive and biased towards its dumbest parts, namely the kind of rote learning in which measurable results can be obtained by treating the children like pigeons in a Skinner box.[1]

- Seymour Papert and Cynthia Solomon

Sadly, this quote from a paper written more than 40 years ago by two educational technology pioneers still reflects the state of affairs in many schools. Only the reference to B.F. Skinner and his behavioral experiments is dated. By any objective measure, one could conclude that the effort to inject computers in schools has been a costly disaster. Consider the following evidence:

- Despite ubiquitous access, too many students possess low-levels of technological fluency and too few teachers know how to perform simple tasks using computational technology.
- A quarter century after schools first embraced 1:1 computing (a laptop for every student), such efforts at student empowerment remain controversial. In too many schools, computers have yet to become personal.
- Thirty-five years after schools began purchasing microcomputers, teachers still need to be bribed, tricked, coerced, cajoled, or threatened to use them. Nearly two generations of students have missed powerful learning opportunities due to the inaction of adults.
- An infinitesimal percentage of young people are taught any computer science in schools despite the intellectual rigor, creative potential, and vocational opportunities afforded by programming.
- Hysterical policies and cumbersome network obstacles make teachers less inclined to use computers.
- Schools increasingly invest in "devices" with less and less computing power. iPads and other consumption technologies are outpacing computer sales.
- Educational computing has come to be equated with the low-hanging fruit of "information access," note taking, and purposes of even less value.

Two Myths

There are two commonly repeated tropes about educational technology impeding progress and clouding our judgment. The first such myth is that *technology is neutral*. This is untrue. All technology was designed to influence behavior; the fact that a handful of people can stretch a technology beyond its normal trajectory does not change this fundamental truth.

It is not uncommon for a school committed to progressive learner-centered education to undermine its mission by investing in a well-intentioned school-to-home communication package that allows Dad to sit at his office desk and day-trade his eight-year-old when the expectation of continuous numerical reporting is offered by such a system. Similarly, I have encountered many independent schools committed to whole language development that then contradict their missions by using phonics software on iPads for no other reason than, “There’s an app for that.”

In schools, all hardware and software bestow agency on one of three parties: the system, the teacher, or the learner. Typically, two of these actors lose their power as the technology benefits the third. Ask a group of colleagues to create a three-column table and brainstorm the hardware or software in your school and who is granted agency by each. Management software, school-wide grade-book programs, integrated learning systems, school-to-home communication packages, massive open online courses (MOOCs), and other cost-cutting technologies grant maximum benefit to the system. Interactive whiteboards, worksheet generators, projectors, whole-class simulations, plagiarism software, and so on, benefit the teacher. Personal laptops, programming languages, creativity software, cameras, MIDI keyboards, microcontrollers, fabrication equipment, and personal web space primarily benefit (bestow agency to) the learner.

The second oft-recited myth is that *technology changes constantly*. If only this were the case in schools. Regrettably, much of what schools do with technology is exactly the same, or less than, what they did 25 years ago. Wordles, note taking, looking stuff up, word-processing essays, and making PowerPoint presentations on topics students don’t care about for audiences they’ll never encounter represent the state-of-the-art in far too many classrooms. We can do better.

I enjoyed the great fortune of leading professional development at the world’s first laptop schools nearly a quarter century ago. Those Australian schools never saw laptops as an experiment or pilot project. For them, laptops represented a way to rescue kids explicitly from a failing hierarchical bureaucracy. Every student learned to program from every teacher as a means to encounter powerful ideas, express oneself, and change the nature of the educational experience.

When teachers saw what was possible through the eyes and the screens of their children, they demanded rapid changes to scheduling, assessment, classroom furniture, and even school architecture. They blurred the artificial boundaries between subject areas, shared expertise, challenged peers, and transformed many schools to benefit the children they served. Those early "laptop teachers" often viewed themselves in new and powerful ways. An amazing number of them went on to become school principals, Ph.D.s, policy makers, and entrepreneurs. A school like Methodist Ladies' College in Melbourne, Australia, changed the world *with its existing teaching staff* through a coherent vision articulated clearly by a bold, charismatic leader, David Loader, who focused on benefiting the largest number of stakeholders in any school community: the students.[2]

Making the Future

We live in a historic moment in which new technologies, with enormous potential for giving agency back to the learner, are emerging. In the book I coauthored with Sylvia Libow Martinez, *Invent To Learn: Making, Tinkering, and Engineering in the Classroom* (2013), [3] we identify three game-changing technologies: personal fabrication, physical computing, and computer programming.

At the core, these technologies connect timeless craft traditions (learning-by-doing) and remarkable technological progress in a fashion accessible to learners of all ages and affordable for schools. These innovative materials, hardware, and software fuel the global Maker Movement and provide students unprecedented learning opportunities.

The satisfaction, personal efficacy, and knowledge construction resulting from the act of making something is well established. New technologies - such as 3-D printers and computer-controlled precision cutters, microcontrollers, and programming languages - are designed for children to kick things up a notch by allowing them to make things *work*! There is no greater sense of exhilaration than when the machine you built or the program you wrote performs as you hoped it would. Even bugs elicit shrieks of joy when things go terribly wrong (at least for the moment). Such bugs are an invitation to make small refinements or chart a different course. Success inspires improvements, decoration, or the testing of a larger hypothesis.

For too long, models, simulations, and rhetoric limited schools to abstraction. Schools embracing the energy, tools, and passion of the Maker Movement recognize that, for the first time in history, kids can make real things - and, as a result, their learning is that much more authentic. Best of all, these new technologies carry the seeds of education reform dreamed of for a century. Seymour Papert said that John Dewey's educational vision was sound but impossible with the technology of his day. In the

early- to mid-20th century, the humanities could be taught in a project-based, hands-on fashion, but the technology would not afford similarly authentic opportunities in mathematics, science, and engineering. This is no longer the case.

Personal Fabrication

Increasingly affordable 3-D printers, laser cutters, and computer numerical control (CNC) machines allow laypeople to design and produce real objects on their computers. The revolution is not in having seventh-graders 3-D print identical Yoda key chains, but in providing children with access to the Z-axis for the first time. Usable 3-D design software allows students to engage with powerful mathematical ideas while producing an aesthetically pleasing artifact. Most important, the emerging fabrication technologies point to a day when we will use technology to produce the objects we need to solve specific problems.

Physical Computing

The ability to embed intelligence and interactivity into an everyday system via conductive thread or paint, Circuit Stickers (*chibitronics.com*), and all manner of microcontrollers enable students to invent machines that respond to their surroundings. The low-cost and powerful open-source Arduino microcontrollers can respond to stimuli from the real world (captured via sensors) and then be programmed by students in ways only limited by one's imagination. Hobbyists and professionals alike are using Arduino boards to run experiments, power robots, and control other machinery. The LilyPad and FLORA microcontrollers allow students to make machine-washable wearable computers with switches, sensors, lights, sound generation, and speakers, all connected via conductive thread. A necklace that alerts you when your least-favorite teacher approaches, a singing stuffed animal, or a bicycle jacket with light-up turn signals sewn into its back offers new entry points to engineering experiences for a greater diversity of students.

littleBits, a "toy" construction set composed of magnetic elements representing different kinds of circuitry, just added the cloudBit to its collection. When you add a cloudBit to your littleBits toy, the impossible becomes child's play. You can push a button to send a tweet, turn on a fan when a stock price falls, or send an automatic text message response to your mother when she texts you. The Arduino bit allows kid inventors to program their littleBits creations using the Arduino programming environment. Today's toy was an MIT research project just a few years ago.

Programming

Programming is a liberal art that should be part of every child's formal education. The impact of computer science has been felt in nearly every discipline and, if you believe Bill Gates, being able to program has significant vocational benefits as well. However, the primary reason why every child must learn to program is to answer the question Papert began asking in the mid-1960s, "Does the child program the computer or does the computer program the child?" This is a fundamental matter of exerting agency over an increasingly complex, technologically sophisticated world.

You can make things on a computer by programming in the same spirit of making tangible artifacts. Sometimes, your physical creations are brought to life by programming.

Programming environments like Scratch (*scratch.mit.edu*), SNAP! (*snap.berkeley.edu*), Turtle Art (*turtleart.org*), and MicroWorlds (*microworlds.com*) are designed to be used by children to not only produce computer programs, but to learn powerful ideas from mathematics and computer science along the way. The Scratch website contains more than six million projects shared by users. Each of these projects may be opened up, studied, remixed, and reused in new projects. Increasingly, students are using environments like Scratch to control external devices such as LEGO WeDo, the Hummingbird Robotics Kit (hummingbirdkit.com), and microcontrollers. This extends the power of physical computing to younger tinkerers and engineers.

A Bold Vision for the Future of Computers in Schools

The future of schools is not found in a shopping list of devices and programs, no matter how interesting or revolutionary the technology may be. In order for schools to seize the power of computers as intellectual laboratories and vehicles for self-expression, the following traits need to be in place.

Awareness

Educators, parents, and policy makers need to understand that, currently, their investment in technology is not maximizing its promise to amplify the human potential of each student. Alternative models must be made available.

Governance

Too many schools conflate instructional and noninstructional technology. Such an inability to reconcile often-competing priorities harms the educational enterprise of a school. One role is of the plumber and the other of a philosopher; both are important functions, but you would never consciously surrender the setting of graduation

standards to your maintenance department. Why, then, is educational policy so greatly impacted by IT personnel?

Vision

Schools need a bolder concept of what computing can mean in the creative and intellectual development of young people. Such a vision must be consistent with the educational ideals of a school. In far too many cases, technology is used in ways contrary to the stated mission of the school. At no point should technology be used as a substitute for competent educators or to narrow educational experiences. The vision should not be rigid, but needs to embrace the serendipitous discoveries and emerging technologies that expand the power of our goals.

Consistent leadership

Once a vision of educational technology use is established, school leadership needs to model that approach, enact rituals and practices designed to reinforce it, and lend a coherent voice leading the entire community in a fashion consistent with its vision to improve the lives of young people.

Great leaders recognize the forces that water down innovation and enact safeguards to minimize such inertia.

Professional development for professionals

You cannot be expected to teach 21st-century learners if you have not learned in this century. Professional development strategies need to focus on creating the sorts of rich constructive learning experiences schools desire for students, not on using computers to perform clerical tasks. We must refrain from purchasing “teacher-proof” curricula or technology and then acting surprised when teachers fail to embrace it. PD needs to stop rewarding helplessness and embrace the competence of educators.

High Expectations and Big Dreams

When we abandon our prejudices and superstitions in order to create the conditions in which anything is possible, teachers and children alike will exceed our expectations.

Some people are excited by using technology to teach what we have always wanted kids to know, perhaps with greater efficiency, efficacy, or comprehension. I am not interested in using computers to improve education by 0.02 percent. Incrementalism is the enemy of progress. My work is driven by the actualization of young people

learning and doing in ways unimaginable just a few years ago.

This is not a fantasy; it's happening in schools today. Here are a few vignettes from my own work.

Learning by Doing

A fifth-grade class seemed to be struggling with fractions, as expressed by the teacher spending nearly an entire school year asking the class to memorize the terms "numerator" and "denominator." One day, I challenged the class to write a program in MicroWorlds EX that would take any fraction as input and draw a graphical representation of that fraction as parts of a circle. Two days later, three girls handed me a working program. All the curriculum asked of the kids was to memorize two vocabulary words, but without context such a simple task took months to achieve. In two days, the very same students demonstrated not only an understanding of numerator and denominator, but variable, radius, angle, decimals, percent, and a host of computer science issues.

I met two 10-year-old boys in a Vermont school who had built a working marimba inspired by Blue Man Group. Their perfectly tuned instrument was a nice piece of carpentry and engineering. What impressed me the most was their use of computer programming. The boys explained that there is a complex calculation required to determine the precise length for each PVC pipe and that while they were capable of performing that calculation, some of their classmates would struggle. So they wrote a program in Scratch that asked for the diameter of the pipe and the frequency they wished to play. The program then told the user how long to cut the pipe. This functional use of computer science is powerful and underrepresented in school. You can write a program to solve other problems, not merely to create a software product.

Teachers at our annual Constructing Modern Knowledge summer institute (*constructingmodernknowledge.com*) often create projects in four days that would have earned a TED talk two years ago and a Ph.D. five years ago. Each summer, our minds are blown by what educators accomplish without direct instruction. Last July, a team of educators from all over the world, representing a variety of grade levels and subject areas, decided to tackle the invention of an automatic plant-watering system. Each success led to a more ambitious iteration of the teachers' design. Eventually, they built a probe made of two nails capable of determining soil moisture based on electrical resistance, a LEGO robot that poured a specific quantity of water, and a light sensor that would only activate the system when it was dark outside. LEGO construction, electronics, overcoming various engineering challenges, and Arduino programming were all required. My favorite part of the project was that once the

group members determined the correct distance between the two nails, they sketched in Tinkercad (*tinkercad.com*) and 3-D printed a custom "nail separator" to act as their moisture probe. All of this was accomplished in a few days by a team of strangers who admitted virtually no previous experience with any of the technologies.

The whole was much greater than the sum of the parts, and 3-D design was just an incidental utility they conquered along the way.

These uses of technology far surpass what passes for technology integration in many schools. Yet they are consistent with the engaging, intellectual challenges that young people need to learn - the things our society deems important. They also reinforce my belief in the ability of teachers and children.

Making prepares students to solve problems their teachers never anticipated. When faced with a new challenge, makers possess the confidence and competence to overcome the obstacle, even if only to discover that there is much more to learn. In the past, schools overvalued learning with one's head. The future requires a recalibration - beginning with valuing learning with one's hands, heart, and head equally.

Parents Are Enthusiastic About Making

Attend one of the more than 100 Maker Faires held annually around the globe and you will run into families learning and making together. Last fall, I organized two Saturday morning "Invent to Learn" making workshops for families at the American School of Bombay. Parents were so delighted by their children's enthusiasm, engagement, and ingenuity that they insisted that making permeate every corner of their children's school. Similar reactions have occurred in other schools where I've led family workshops.

In December 2012, I was helping an independent school fifth-grade class make digital gingerbread houses. Students used graham crackers, icing, motors, lights, sensors, candy, sprinkles, cookies, and computer programming to bring gingerbread houses to life. They then added music, twinkling lights, spinning trees, and more to this traditional craft project. Unannounced, an admissions tour consisting of several dozen prospective parents visited, observed, and talked to the kids about their work. Later that day, the director of admissions reported to me that she needed to convince the prospective parents that the digital gingerbread project was not staged for their benefit. That reminded me that perhaps parents are less concerned about beating Finland in long division than in their kids coming home from school happy and with a tale to tell about something they learned while making something they cared about.

Papert said, “If you can make things with technology, then you can make more interesting things and you can learn a lot more by making them.” Schools should be in the business of making meaning and memories. Constructive technology use goes a long way toward achieving those aims.

Notes

1. Seymour Papert and Cynthia Solomon, “Twenty Things to Do With a Computer,” *Artificial Intelligence Memo #248*. Cambridge, MA: Massachusetts Institute of Technology (1971).

2. Bob Johnstone, *Never Mind the Laptops: Kids, Computers, and the Transformation of Learning*. Seattle: iUniverse (2003).

3. Sylvia Libow Martinez and Gary Stager, *Invent To Learn: Making, Tinkering, and Engineering in the Classroom*. Constructing Modern Knowledge Press (2013).

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