Revolutionizing Learning in the Digital Age

Mitchel Resnick

First, the good news: in the years ahead, the declining cost of computation will make digital technology accessible to nearly everyone, from inner-city neighborhoods in the United States to rural villages in developing nations. These technological advances have the potential to fundamentally transform how and what people learn throughout their lives. Just as advances in biotechnology made possible the "green revolution" in agriculture, new digital technology can make possible a "learning revolution" in education.

Now, the bad news: while digital technology could make a learning revolution possible, it certainly does not guarantee it. Early results are not encouraging. In most places where digital technology is used in education, it is used simply to reinforce outmoded approaches to learning. Even as scientific and technological advances are transforming agriculture, medicine, and industry, the ideas and approaches to teaching and learning remain mostly unchanged.

To take full advantage of new technology, we need to fundamentally rethink our approaches to learning and education and our ideas of how new technology can support them.

Beyond Information

Education and learning are often considered in terms of information: What information is most important for people to know? What are the best ways to transmit that information from one person (a teacher) to another (a student)? What are the best ways to represent and display information so that it is both understandable and learnable?

It's not surprising that people see a connection between computers and education. Computers enable transmission, accessibility, representation, and manipulation of information in many ways. Because education and computers are both associated with information, the two seem to make a perfect marriage.

This focus on information, however, is limiting and distorting, both for education and for computers. If we want to take full advantage of new computational technology and help people become better thinkers and learners, we need to move beyond these information-centric views of computing and learning.

Over the past 50 years, psychologists and educational researchers, building on the pioneering work of Jean Piaget have come to understand that learning is not a simple matter of information transmission.[1] Teachers cannot simply pour information into the heads of learners. Rather, learning is an active process in which students construct new understanding of the world around them through active exploration, experimentation, discussion, and reflection. In short, people don't *get* ideas; they *make* them.

Despite the common use of the phrase "information technology," or IT, computers are more than simply information machines. Of course, computers are wonderful for transmitting and accessing information. Furthermore, they are a new medium through which people can create and express themselves. If we use computers to simply deliver information to students, we will fail to take advantage of the revolutionary potential of new technology for transforming learning and education.

Consider the following three things: computers, television, finger paint. Which of the three doesn't belong? For most people, the answer seems obvious: "finger paint." After all, computers and televisions were both invented in the twentieth century, both involve electronic technology, and both can deliver information to large numbers of people. None of that is true for finger paint.

Until we start to think of computers more like finger paint and less like television, computers will not live up to their full potential. Like finger paint (and unlike television), computers can be used for designing and creating things. In addition to accessing existing Web pages, people can create their own. In addition to downloading MP3 music files, people can compose their own music. In addition to playing *SimCity*, people can create their own simulated worlds.

It is through design activities that computers offer the greatest new learning opportunities. Research has shown that many of the best learning experiences come when engaged in designing and creating things, especially things that are meaningful either to us or to those around us.[2] For example, when children create pictures with finger paint, they learn how colors mix. When they build houses and castles with building blocks, they learn about structure and stability. When they make bracelets with colored beads, they learn about symmetry and pattern.

Like finger paint, blocks, and beads, computers can also be used as a "material" for making things—and not just by children, but by everyone. Indeed, the computer is the most extraordinary construction material ever invented, enabling people to create a variety of things, from music videos to scientific simulations to robotic creatures. Computers can be seen as a universal construction material, greatly expanding what people can create and what they can learn in the process.[3]

Digital Fluency

Unfortunately, most people don't use computers that way today. When people are introduced to computers, they are typically taught how to look up information on the Web, how to use a word processor, and how to send e-mail. But they don't become *fluent* in the technology.

What does it mean to be digitally fluent? Consider the analogy with learning a foreign language. If someone learned a few phrases so that he could read menus in restaurants and ask for directions on the street, would you consider him fluent in that language? Certainly not. That type of phrase-book knowledge is equivalent to the way most people use computers today. This knowledge is useful, but it is not fluency.

To be truly fluent in a foreign language, one must be able to articulate a complex idea or tell an engaging story. In other words, one must be able to "make things" with language. Similarly, being digitally fluent involves not only knowing how to use digital technology, but also knowing how to construct things of significance with digital technology.[4]

Fluency with language not only has great utilitarian value in everyday life, it also has a catalytic effect on learning. When one learns to read and write, one is in a better position to learn many other things. This is also true with digital fluency. In the years ahead, digital fluency will become a prerequisite for obtaining jobs, for participating meaningfully in society, and for learning throughout a lifetime.

Today, discussions about the "digital divide" typically focus on the differences in access to computers. That will change. As the costs of computing decline, people everywhere will gain better access to digital technology. However, there is a real risk that only a small handful will be able to use the technology fluently. In short, the "access gap" will shrink, but a "fluency gap" could remain.

Computer Clubhouses

To provide more young people with the opportunity to become digitally fluent, the Massachusetts Institute of Technology (MIT) Media Lab and the Boston Museum of Science have established a network of learning centers in economically disadvantaged communities. At these centers, called Computer Clubhouses, young people become designers and creators using digital technology. Clubhouse members create their own artwork, animations, simulations, multimedia presentations, musical compositions, Web sites, and robotic constructions using leading-edge software.[5]

The first Computer Clubhouse opened in 1993 in Boston, serving youth between the ages of 10 and 18. Based on the success of the initial Clubhouse, Computer Clubhouses opened in a dozen more communities over the next six years. In 2000, Intel announced that it would provide support to open an additional 100 Computer Clubhouses around the world over the ensuing five years. Now there are Clubhouses in India, Ireland, Israel, Colombia, Germany, the Philippines, and the United States, with new ones planned for 2002 in China, Costa Rica, Mexico, South Africa, and Taiwan.

Computer Clubhouses are very different from most telecenters and community technology centers. The latter typically fall into one of two categories: Some centers merely provide access for people to do whatever they want—play games, surf the Web, or use online chat rooms. Others offer structured courses teaching basic computer skills (such as keyboarding) and basic application usage (such as word processing and spreadsheets).

Computer Clubhouses offer a different path with different goals and a different approach. The aim is not simply to teach basic skills, but to help young people learn to express themselves and gain confidence as learners. If they are interested in video games, they don't come to the Clubhouse to play games; rather, they come to create their own games. They don't download videos from the Web; they create their own videos. In the process, participating youth learn the heuristics of being a good designer: how to conceptualize a project, how to make use of the materials available, how to persist and find alternatives when things go wrong, how to collaborate with others, and how to view a project through the eyes of others. In short, they learn how to manage a complex project from start to finish.

The Computer Clubhouse approach strikes a balance between structure and freedom in the learning process. As youths work on projects based on their own interests, they receive a great deal of support from other members of the Clubhouse community (staff members, volunteer mentors, and peers). A large collection of sample projects are on display on the walls, shelves, and hard drives of the Clubhouses; these provide a sense of the many possible entry points. The goal is to allow enough freedom to enable Clubhouse members to follow their fantasies, but also to provide enough support to help them turn those fantasies into realities.

There is no doubt that the lives of many members have been transformed by their time at the Clubhouses. Consider Mike

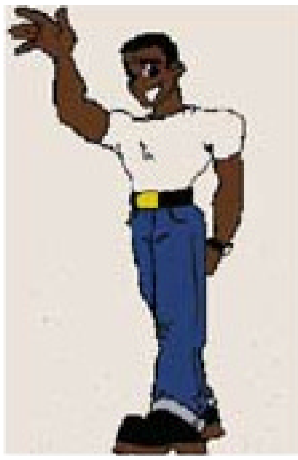


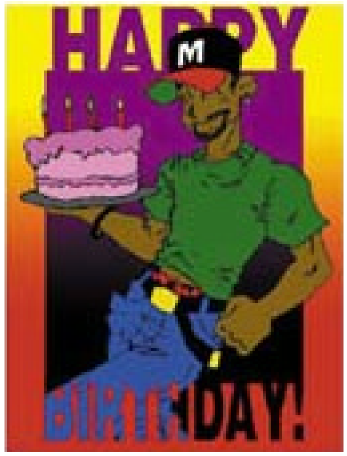
Figure 1 (left). Early comic book self-image created by Mike Lee at the Computer Clubhouse.

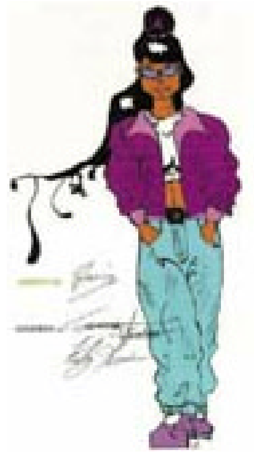
Figure 2 (near right). An example of Mike Lee's use of more advanced computer techniques.

Figure 3 (far right). Artwork by Mike Lee displayed at the Computer Clubhouse.

Lee, who spent time at the original Computer Clubhouse in Boston. Mike first came to the Clubhouse after he had dropped out of high school. His true passion was drawing. He filled up notebook after notebook with sketches of cartoon characters. At the Clubhouse, he developed a new method for his artwork. First, he would draw black-and-white sketches by hand. Then, he would scan the sketches into the computer and use the computer to color them. As shown in Figure 1, his work often involved comic-book images of himself and his friends.

Figure 2 shows how Mike learned to use more advanced computer techniques in his artwork. Everyone in the Clubhouse was impressed with his creations, and others started coming to him for advice. Some members explicitly mimicked Mike's artistic style. Before long, a collection of "Mike Lee style" artwork filled the bulletin boards of the Clubhouse. Fig-





ure 3 is an example of what he displayed. "It's kind of flattering," declared Mike.

For the first time in Mike's life, other people looked up to him. He began to feel a new sense of responsibility. He decided to stop using guns in his artwork, feeling that it was a bad influence on the younger Clubhouse members. "My own personal artwork is more hard core, about street violence. I had a close friend who was shot and died," Mike explained. "But I don't want to bring that here. I have an extra responsibility. Kids don't understand about guns; they think it's cool. They see a fight, it's natural they want to go see it. They don't understand. They're just kids."

Mike began working at the Clubhouse on collaborative projects, resulting in an online art gallery. Once a week, the group met with a local artist who agreed to be a mentor for the project. After a year, their online art show was accepted as an exhi-

Figure 4. Digital collage created by Mike Lee.

bition at Siggraph, the world's premiere computer-graphics conference.

As Mike worked with others at the Clubhouse, he began to experiment with new artistic techniques. Figure 4 illustrates how he added more computer effects and began working on digital collages, combining photographs and graphics while still maintaining his distinctive style. Mike explored how he might use his artwork as a form of social commentary and political expression, as shown in Figure 5.

Through his experience, Mike clearly learned a lot about computers and about graphic design. But he also began to de-

Figure 5. Form of social commentary created by Mike Lee using digital technology.

velop his own ideas about teaching and learning: "At the Clubhouse, I was free to do what I wanted, learn what I wanted. Whatever I did was just for me. If I had taken computer courses [in school], there would have been all those assignments. Here I could be totally creative." Mike remembers—and appreciates—how the staff members treated him when he first started. They asked him to design the sign for the entrance to the Clubhouse. They never thought of him as a "high school dropout" but as an artist.

Mike's artwork still has the same distinctive style, even as he became more fluent in expressing himself in computer-based media. Describing his current work, Mike talks about "dither nightmares" and "antialiasing problems"—concepts that were alien to him a few years ago. He says that his artwork is "ten times better than last year."

Rethinking Technology

In addition to rethinking our approaches to learning and education, we also need to rethink the technology that we provide to young people.

Most of today's computers were primarily designed for use by adults in the workplace. We need to develop a new generation of computer technology focusing on the next generation of children. It's not enough just to make computers faster; we need to develop new types of computers that provide the hardware and software that will enable children to do more with computers.

These new computers might look very different from current computers. For example, my research group has developed a family of "programmable bricks": tiny computers embedded inside children's building blocks.[6,7] Children can build computational power directly into their physical-world constructions, using the programmable bricks to control motors, receive information from sensors, and even communicate with one another. The LEGO Company now sells a commercial version of these programmable bricks under the name LEGO *MindStorms*.

Children have used our programmable bricks to build a variety of creations, including a rollerblade odometer, using a magnetic sensor to count wheel rotations; a diary-security system, using a touch sensor to detect if anyone tried to open the diary; and an automated hamster cage, using a light sensor to monitor the hamster's movements.

Jenny, an 11-year-old girl, was very interested in birds. She decided to use the programmable bricks to build a new type of bird feeder. She started by making a wooden lever that served as a perch for the birds. When a bird landed, it would trigger a touch sensor, sending a signal to a programmable brick that activated a LEGO mechanism, pushing the shutter of a camera and taking a picture of the bird.

The design-oriented nature of the project was clearly very important for Jenny. As she described it, "The fun part is knowing that *you* made it; *my* machine can take pictures of birds." At the same time, the project served as a rich context for engaging in scientific inquiry and learning. Jenny developed a deeper understanding of some concepts, such as mechanical advantage, which she had previously studied in school but had never really applied. She also began to work with some engineering concepts related to feedback and control that are traditionally taught only at the university level.[8]

The programmable bricks provided Jenny with "design leverage," enabling her to create things that would have been difficult for her to create otherwise. At the same time, they provided Jenny with "conceptual leverage," enabling her to master concepts that would have been difficult for her to understand in the past.

Computers can be embedded in a wide variety of objects used by students of all ages. BitBalls, for example, are rubbery balls about the size of a baseball. Tiny computers inside BitBalls can send and receive infrared signals and communicate with other BitBalls and electronic devices, as well as receive programs downloaded from a desktop computer. BitBalls also include an accelerometer and a set of light-emitting diodes.

The balls can be used in scientific investigations for a deeper understanding of kinematics. One group of university students threw a BitBall in the air and graphed the acceleration data to find the top of the trajectory. They discovered that there was no change in acceleration while the ball is in flight, so it was impossible to determine the top of the trajectory from acceleration data alone. The students had previously studied gravity and acceleration, but they were unable to apply their classroom knowledge to this real-world context. In this example, concrete experience with the BitBall helped students develop an understanding of acceleration.

Reforming Educational Reform

Nations are increasingly recognizing that improving education is the best way to generate wealth, enhance health, and maintain peace. However, there is little consensus on how to achieve an educated population, or even what it means to have one. Can progress toward an educated population be measured by counting the number of people in school? By the number of years spent in school? By assessing grades on standardized tests?

Every country in the world, it seems, has plans for educational reform. But, in most cases, such initiatives are superficial and incremental and do not get at the heart of the problem. These initiatives often introduce new forms of testing and assessment but leave in place (or make only small incremental changes to) existing curricula and existing teaching strategies. We need to reform educational reform.

Rethink How People Learn

We need to fundamentally reorganize classrooms. Instead of a centralized-control model (with one teacher delivering information to a roomful of students), we should use a more entrepreneurial approach to learning. Students can become more active and independent learners, with the teacher serving as a consultant, not as a chief executive.

Instead of dividing up the curriculum into separate disciplines (math, science, social studies, language), we should focus on themes and projects that cut across the disciplines, taking advantage of the rich connections between different domains of knowledge. Instead of dividing students according to age, we should encourage students of all ages to work together on projects, enabling them to learn from one another. Instead of dividing the day into hour-long slices of classes and lectures, we should let students work on projects for extended periods of time, enabling them to follow through on the ideas that arise in the course of their work.

Rethink What People Learn

Much of what students learn today was designed for the era of paper and pencil. We need to update curricula for the digital age. One reason is obvious: we must prepare students with the new skills and ideas needed for living and working in a digital society.

There is a second, subtler reason: New technology is changing not only what students *should* learn, but also what they *can* learn. Many ideas and topics have always been important but were omitted from traditional school curricula because they were too difficult to teach and learn with only paper, pencil, books, and blackboard. Some of these ideas are now accessible through creative use of digital technology. For example, students can use computer simulations to explore the workings of systems in the world (everything from ecosystems to economic systems to immune systems) in ways that were previously not possible. Also, some ideas traditionally introduced only at the university level can, and should, be learned much earlier. Technology can make that happen.

Finally, and perhaps most importantly, we need to transform curricula so that they focus less on "things to know" and more on "strategies for learning the things you don't know." As technology continues to quicken the pace of change in all parts of our lives, learning to become a better learner is far more important than learning to multiply fractions or memorizing the capitals of the world.

Rethink Where and When People Learn

Most education-reform initiatives appear to assume that learning takes place only in the classroom, lab, or lecture hall. However, schools are only one part of a broader learning ecosystem. In the digital age, learning must become a daylong and lifelong experience. National education initiatives should aim to improve learning opportunities not only in schools, but also in homes, community centers, museums, and workplaces. In Denmark, for example, the Ministry of Education has joined with the Ministry of Business and Industry to create Learning Lab Denmark, a new research lab that studies learning in all settings and stages of life. In the years ahead, the Internet will open up new learning opportunities, enabling new types of "knowledge-building communities" in which children and adults around the globe collaborate on projects and learn from one another.

Towards the Creative Society

In the 1980s, there was much talk about the transition from the "Industrial Society" to the "Information Society." No longer would natural resources and manufacturing be the driving forces in our economies and societies. Information was the new king.

In the 1990s, people began to talk about the "Knowledge Society." They began to realize that information itself would not bring about important change. Rather, the key was how information was transformed into knowledge and how that knowledge was managed.

The shift in focus from "information" to "knowledge" is an improvement. But I prefer a different concept: the "Creative Society." As I see it, success in the future will be based not on how much we know, but on our ability to think and act creatively.

The proliferation of digital technology has accentuated the need for creative thinking in all aspects of our lives and has provided tools that can help us improve and reinvent ourselves. Throughout the world, computing and communications technology is sparking a new entrepreneurial spirit, the creation of innovative products and services, and increased productivity. The importance of a well-educated, creative society is greater than ever before.

Children should play a central role in this transition to the Creative Society. Childhood is one of the most creative periods of our lives. We must make sure that this creativity is nourished, developed, extended, and refined so that it persists and grows throughout life.

To achieve these goals will require new approaches to education and learning, and new technology to support those new approaches. The ultimate goal is a society of creative individuals who are constantly inventing new possibilities for themselves and their communities.

ACKNOWLEDGMENTS

Many people have contributed to the projects and ideas described in this paper. I am particularly grateful to Robbie Berg, Rick Borovoy, Gail Breslow, Stina Cooke, John Galinato, Fred Martin, Bakhtiar Mikhak, Seymour Papert, Natalie Rusk, Brian Silverman, and Claudia Urrea. The projects described in this paper have received generous support from many sponsors of the MIT Media Lab, most notably the LEGO Company, Intel Corporation, and the National Science Foundation. The ideas about the Creative Society were developed through my participation in the Next Generation Forum. An earlier version of this paper was published in 2002 as "Rethinking Learning in the Digital Age," in *The Global Information Technology Report: Readiness for the Networked World*, edited by G. Kirkman and published by the Oxford University Press, UK, pp. 32–37.

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Mitchel Resnick is an associate professor in the Epistemology and Learning Group at the MIT Media Lab.