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# Computer as Paintbrush: Technology, Play, and the Creative Society

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## Introduction

Let's start with a familiar children's game: Which of these things is not like the other? Which of these things just doesn't belong?

Television. Computer. Paintbrush.

For many people, the answer seems obvious: the paintbrush doesn't belong. After all, the television and the computer were both invented in the 20th century, both involve electronic technology, and both can deliver large amounts of information to large numbers of people. None of that is true for the paintbrush.

But, in my view, computers will not live up to their potential until we start to think of them less like televisions and more like paintbrushes. That is, we need to start seeing computers not simply as information machines, but also as a new medium for creative design and expression.

In recent years, a growing number of educators and psychologists have expressed concern that computers are stifling children's learning and creativity, engaging children in mindless interaction and passive consumption (Cordes and Miller, 2000; Oppenheimer, 2003). They have a point: today, many computers *are* used in that way. But that needn't be the case. This paper presents an alternate vision of how children might use computers, in which children use computers more like paintbrushes and less like televisions, opening new opportunities for children to playfully explore, experiment, design, and invent. My goal in this paper is not to provide conclusive evidence but rather, through illustrative examples, to provoke a rethinking of the roles that computers can play in children's lives.

## An Example: Alexandra's Marble Machine

To provide a clearer sense of how computers can serve as paintbrushes, this section tells the story of Alexandra, an 11-year-old girl who used a tiny computer called a Cricket as a new medium for expression, experimentation, and exploration.

Alexandra wasn't very excited about school, but she loved coming to the Computer Clubhouse in her neighborhood in Boston. Alexandra's local Clubhouse was part of a worldwide network of after-school centers established to help young people (ages 10-18) from low-income communities learn to express themselves creatively with new technologies (Resnick, Rusk, & Cooke, 1998). At Computer Clubhouses, young people become actively engaged in designing with new technologies, creating their own graphic animations, musical compositions, and robotic constructions. Alexandra became particularly excited when two volunteer mentors (from a local university) organized a Clubhouse workshop for building "marble machines" – whimsical contraptions in which marbles careen down a series of ramps and raceways, bouncing off bells and bumpers.

The mentors, Karen Wilkinson and Mike Petrich, brought a variety of craft materials to the Clubhouse: pegboard, wooden slats, bells, string, marbles. They also brought a collection of tiny computers called Crickets, small enough to fit inside a child's hand (Resnick et al., 1996; Martin, Mikhak, & Silverman, 2000; Resnick, Berg, & Eisenberg, 2000). Crickets can be programmed to control motors and lights, receive information from sensors, and communicate with one another via infrared light. Children can use Crickets to make their constructions come alive – for example, making a motor turn on whenever a touch sensor is pressed, or whenever a shadow is cast over a light sensor.

Alexandra became interested in the marble-machine project right away. She cut wooden slats to serve as ramps, and inserted the ramps into a pegboard. She began playfully rolling marbles from one ramp to another, trying to create interesting patterns of motion, without the marbles dropping off. As the marbles dropped from one ramp to another, Alexandra giggled with delight.

Next, Alexandra created a Cricket-controlled conveyor belt with a small basket on top. Her plan: the marble should roll down a ramp into the basket, ride along the conveyor belt inside the basket, then drop onto the next ramp when the basket tipped over at the end of the conveyor belt. How would the conveyor belt know when to start moving? Alexandra programmed the conveyor-belt Cricket to listen for a signal from another Cricket higher up on the pegboard, alerting it that the marble was on its way. The conveyor-belt Cricket waited two seconds, to make sure the marble had arrived safely in the basket, before starting to move the conveyor belt and basket.

Alexandra worked on her project for several weeks, experimenting with many different configurations of the ramps, and adjusting the timing of the conveyor belt. She playfully tried out new features – for example, putting bells on the ramps, so that the marbles would make jingling sounds as they rolled past.

Alexandra decided to enter her marble machine into her school's science fair. But when she talked to her classroom teacher about it, the teacher said that the marble machine was not acceptable as a science-fair project. The teacher explained that a science-fair project must use the "scientific method": the student must start with a hypothesis, then gather data in an effort to prove or disprove the hypothesis. The marble machine, said the teacher, didn't follow this approach.

Alexandra was determined to enter her marble machine in the science fair. With support from mentors at the Clubhouse, she put together a sequence of photographs showing different phases of the marble-machine construction. Even though Alexandra never wrote a hypothesis for her project, her teacher ultimately relented and allowed her to enter the marble machine in the school science fair. Much to Alexandra's delight, she was awarded one of the top two prizes for the entire school.

What did Alexandra learn through her marble-machine project? A great deal. Although Alexandra's teacher was concerned that the project did not use the scientific method, the project is, in fact, a wonderful example of the scientific method. True, Alexandra did not start with a single overarching hypothesis. But as she playfully experimented with her marble machine, Alexandra was continually coming up with new design ideas, testing them out, and iterating based on the results. Each of these design ideas can be viewed as a "mini-hypothesis" for which Alexandra gathered data. Over the course of her project, she investigated literally dozens of these mini-hypotheses. While positioning the ramps, for example, Alexandra tested different angles to try to find the maximum range for the marble. Alexandra also experimented to find the right timing for the conveyor belt. She modified the conveyor-belt program so that the basket would make one complete revolution, returning to its original location, properly positioned for the next marble.

Through her playful experiments, Alexandra not only improved the workings of her marble machine but also developed a better understanding and appreciation of the process of scientific investigation. In the spirit of John Dewey's "theory of inquiry" (1910), Alexandra began to develop a scientific frame of mind through her playful yet systematic efforts to solve practical problems that arose in her marble-machine project.

## Edutainment versus Playful Learning

The story of Alexandra's marble machine highlights how new technologies can support playful learning – and how playful activities can help children understand and make full use of new technologies. Of course, the idea of mixing play, technology, and learning is hardly new. In establishing the first kindergarten in 1837, Friedrich Froebel used the technology of his time to develop a set of toys (which became known as "Froebel's gifts") with the explicit goal of helping young children learn important concepts such as number, size, shape, and color (Brosterman, 1997). Other educators, such as Maria Montessori (1912), have built on Froebel's ideas, creating a wide range of manipulative materials that engage children in learning through playful explorations.

More recently, there has been a surge of computer-based products that claim to integrate play and learning, under the banner of "edutainment." But these edutainment products often miss the spirit of playful learning. Often, the creators of edutainment products view education as a bitter medicine that needs the sugarcoating of entertainment to become palatable. They provide entertainment as a reward if you are willing to suffer through a little education. Or they boast that you will have so much fun using their products that you won't even realize that you are learning – as if learning were the most unpleasant experience in the world.

Part of the problem is with word *edutainment* itself. When people think about *education* and *entertainment*, they tend to think of them as services that someone else provides for you. Studios, directors, and actors provide you with entertainment; schools and teachers provide you with education. New edutainment companies try to provide you with both. In all of these cases, you are viewed as a passive recipient. But that's not the way most learning happens. In fact, you are likely to learn the most, and enjoy the most, if you are engaged as an active participant, not a passive recipient (e.g., Bruner, 1963).

The terms *play* and *learning* (things that you do) offer a different perspective from *entertainment* and *education* (things that others provide for you). Thus the phrase *playful learning*, as opposed to *edutainment*, conveys a stronger sense of active participation. It might seem like a small change, but the words we use can make a big difference in how we think and what we do.

Alexandra's playful explorations with her marble machine were not a sugarcoating for science experiments; rather, play and learning were fully integrated in her project. Alexandra experimented with ramp angles and conveyor-belt timing not to get a reward or a grade, but as an integral part of her play experience. In other words, Alexandra was driven by "intrinsic motivation," not external rewards. That distinction is critical. Research has found that "self-motivation, rather than external motivation, is at the heart of creativity, responsibility, healthy behavior, and lasting change" (Deci, 1995). Indeed, in our studies, we have found many examples of youth who had short attention spans in traditional school classrooms but displayed great concentration when engaged in projects that interested them.

Alexandra's project was far from easy: she worked very hard on it, and parts of the project were very difficult for her. But the challenge of the project was one of the attractions. Too often, designers and educators try to make things "easy" for learners, thinking that people are attracted to things that are easy to do. But that is not the case. Mihaly Csikszentmihályi (1991) has found that people become most deeply engaged in activities that are challenging, but not overwhelming. Similarly, Seymour Papert has found that learners become deeply engaged by "hard fun" – in other words, learners don't mind activities that are hard as long as the activities connect deeply with their interests and passions (Papert, 1993).

## Learning through Designing

Unfortunately, projects like Alexandra's marble machine are the exception, not the rule, in children's use of new technologies. Children have many opportunities to *interact* with new technologies – in the form of video games, electronic storybooks, and "intelligent" stuffed animals. But rarely do children have the opportunity to *create* with new technologies, as Alexandra did with the Crickets in her marble machine.

Research has shown that many of children's best learning experiences come when they are engaged not simply in interacting with materials but in designing, creating, and inventing with them (Papert, 1980; Resnick, 2002). In the process of designing and creating – making sculptures out of clay or towers with wooden blocks – children try out their ideas. If their creations don't turn out as they expected or hoped, they can revise their ideas and create something new. It's an iterative cycle: new ideas, new creations, new ideas, new creations.

This design cycle can be seen as a type of play: children play out their ideas with each new creation. In design activities, as in play, children test the boundaries, experiment with ideas, explore what's possible. As children design and create, they also learn new concepts. When they create pictures with a paintbrush, for example, they learn how colors mix together. When they build houses and castles with wooden blocks, they learn about structures and stability. When they make bracelets with colored beads, they learn about symmetries and patterns.

In my research group at the MIT Media Lab, our goal is to develop new technologies that follow in the tradition of paintbrushes, wooden blocks, and colored beads, expanding the range of what children can create, design, and learn. Our Programmable Brick technology, for example, is a natural extension of the LEGO brick. The original LEGO brick, developed in the 1950s, enabled children to build structures like houses and castles. In the 1970s, the LEGO Company expanded its construction kits to include gears, pulleys, and other mechanical parts, enabling children to build their own mechanisms. Programmable Bricks, which we developed in the 1990s in collaboration with the LEGO Company, represent a third generation. With these new bricks, children can program their LEGO creations to move, sense, interact, and communicate. Now, children can build not only structures and mechanisms but also behaviors.

Programmable Bricks are commercially available as part of a robotics kit called LEGO Mindstorms. Over the past decade, there have been hundreds of different robotic toys on the market, but Mindstorms is fundamentally different. With most robotic toys, children simply interact with a pre-built robot. With Mindstorms, children create their own robots: they use gears, axles, pulleys, and cams to build the mechanisms, connect motors to drive the motion, attach sensors to detect conditions in the world (temperature, light levels, etc.), and write computer programs to guide the robot's behavior (turning motors on and off based on inputs from the sensors).

By creating their own robots, children gain a deeper understanding of the ideas underlying the workings of robots. In one fifth-grade class, for example, students used a Programmable Brick to create a LEGO dinosaur that was attracted to flashes of light, like one of the dinosaurs in Jurassic Park. To make the dinosaur move toward the light, the students needed to understand basic ideas about feedback and control. They wrote a program that compared readings from the dinosaur's two light-sensor "eyes." If the dinosaur drifted too far to the left (i.e., more light in the right eye), the program made it veer back to the right; if the dinosaur went too far right (more light in the left eye), the program corrected it toward the left. This classic feedback strategy is typically not taught until university-level courses. But with the right tools, fifth graders were able to explore these ideas (Resnick, Bruckman, & Martin, 1996).

## Crickets and Crafts

In her marble machine, Alexandra used a new version of Programmable Brick called the Cricket. While the Programmable Bricks in LEGO Mindstorms were designed primarily for controlling robots, the Crickets are designed for more artistic and expressive projects. The Crickets can control not only motors but also multi-colored lights and music-synthesis devices, so children can use Crickets to build their own musical instruments and light sculptures. The Crickets are also much smaller than previous Programmable Bricks, so they are well-suited for projects that need to be small and mobile, such as electronic jewelry.

The Cricket was designed to feel more like a craft material than an information-processing machine, in hopes that children would see the Cricket as just another object in their bin of construction parts – and use the Cricket just as playfully and creatively as they use traditional craft materials. One indicator of success: when Alexandra described the parts of her marble machine, she listed Crickets right along with all of the other materials: ". . . slopes, stoppers, Crickets, LEGOs, . . ."

To explore the possibilities of integrating Cricket technology with traditional craft activities, my research group co-organized a hands-on workshop (called Digital Dialogues) with Haystack Mountain School of Crafts, an internationally renowned craft center in Maine (Willow, 2004). At the workshop, artists worked alongside technologists and engineers, sharing ideas, techniques, and materials. Sally McCorkle, a sculptor from Penn State University, used a Cricket, a small fan, and a distance sensor to create an interactive sculpture that blew gold dust in interesting patterns whenever anyone approached. Artist Therese Zemlin created a series of handmade paper lanterns with small lights inside, and programmed the lights to change color and intensity based on the movements of the people around the lanterns. Three Media Lab researchers collaborated with blacksmith Tom Joyce to create a vessel that could "talk for itself," telling the story of its own making. When you reached into the vessel, sensors activated videos showing how the metal had been forged and riveted.

We have found that activities integrating computation and craft provide a good context for learning math, science, and engineering ideas – especially for young people who are alienated by traditional approaches to math and science education, which often emphasize abstract concepts and formal systems rather than hands-on design and experimentation. Although screen-based computer applications offer many advantages, Michael and Ann Eisenberg (2000) argued that "something is lost, too, in this move away from the physical – something pleasurable, sensually and intellectually, about the behavior of stuff." Computational crafts, they argue, combine the best of the physical and computational worlds:

> It's a natural desire to employ all one's senses and cognitive powers in the course of a single project. We do not feel that a love of crafts is incompatible with technophilia, nor that an enjoyment of computer applications must detract from time spent in crafting. The world is not, or should not be at any rate, a battleground between the real and the virtual. It is instead a marvelous continuum, a source of wonders that blend and knead together

> the natural and artificial, the traditional and novel, the scientifically objective and the personally expressive, the tangible and the abstract. We anticipate a future in which ever more astonishing things will present themselves to our minds, and ever more astonishing ideas to our hands.

## Supporting Playful Learning (and Learningful Play)

Regardless of how innovative or evocative they are, new technologies can not, on their own, ensure playful-learning experiences. Technologies can always be used in multiple ways – including many ways not intended or desired by their designers. LEGO Mindstorms, for example, was designed as a “robotics invention system,” to encourage people to develop their own robotic inventions. And, certainly, many children (and adults too) have used Mindstorms in creative and inventive ways. But there are also many classrooms where the teacher assigns students to build a particular robot according to pre-designed plans, then grades the students on the performance of their robots.

Our ultimate goal is not creative technologies, but rather technologies that foster creative thinking and creative expression. This section discusses several strategies that we have developed over the years to try to maximize the chances that children will use our technologies in creative, playful, and “learningful” ways.

### *Making It Personal*

We have found that children become most engaged with new technologies, and learn the most in playing with these technologies, when they work on projects growing out of their own personal interests. When children care deeply about the projects they are working on, they are not only more motivated but they also develop deeper understandings and richer connections to knowledge.

Consider the case of Jenny, an 11-year-old girl. Jenny loved watching birds, so when she was introduced to the Cricket, she decided to use it to build a new type of bird feeder. Jenny already had a bird feeder in her backyard, but there was a problem: often, the birds would come while Jenny was away at school, so she didn’t get to see the birds. With the Cricket, Jenny figured she could build a new bird feeder that would collect data about the birds that landed on it.

Jenny started by making a wooden lever that served as a perch for the birds. The long end of the lever was next to a container with food for the birds. At the other end of the lever, Jenny attached a simple homemade touch sensor consisting of two paper clips. Jenny’s idea: When a bird landed near the food, it would push down one end of the lever, causing the two paper clips at the other end to move slightly apart. Jenny connected the paper clips to one of the sensor ports on a Cricket, so that the Cricket could detect whether the paper clips were in contact with one another.

But what should the bird feeder do when a bird landed on it? At a minimum, Jenny wanted to keep track of the number of birds. She also thought about weighing the birds.

But she decided it would be most interesting to take photographs of the birds. She began exploring ways of connecting a camera to her bird feeder, built a motorized LEGO mechanism that moved a small rod up and down, and mounted the mechanism so that the rod was directly above the shutter button of the camera. Finally, Jenny plugged the mechanism into her Cricket and wrote a program for the Cricket. The program waited until the paper clips were no longer touching one another (indicating that a bird had arrived), and then turned on the motorized LEGO mechanism, which moved the rod up and down, depressing the shutter button of the camera. At the end of the day, the camera would have taken pictures of all of the birds that had visited the bird feeder.

Jenny worked on the project for several hours a week over the course of three months. By the end, the sensor and mechanism were working perfectly. But when she placed the bird feeder outside her window at home, she got photographs of squirrels (and of her younger sister), not of birds.

Jenny never succeeded in her original plan to monitor what types of birds would be attracted to what types of bird food. But the activity of building the bird feeder provided a rich collection of learning experiences. While building the lever for the bird feeder, Jenny needed to experiment with different lever designs to achieve the necessary mechanical advantage for triggering the paper-clip touch sensor. Jenny also systematically experimented with the placement of her camera, testing it at different distances from the bird perch in an effort to optimize the focus of the photographs. Thus, the bird feeder activity provided Jenny with an opportunity to make use of scientific concepts in a meaningful and motivating context.

The fact that Jenny built the bird feeder herself put Jenny in closer contact with the technology – and with the scientific concepts related to the technology. Crickets provided Jenny with “design leverage,” enabling her to create things that would have been difficult for her to create in the past. At the same time, the bricks provided Jenny with “conceptual leverage,” enabling her to learn concepts that would have been difficult for her to learn in the past.

Consider Jenny’s touch sensor. In general, touch sensors are based on a very simple concept: they measure whether a circuit is open or closed. People interact with touch sensors (in the form of buttons) all of the time. But because most touch sensors appear in the world as “black boxes” (with their internal working hidden from view), most people don’t understand (or even think about) how they work. In Jenny’s touch sensor, created from two simple paper clips, the completing-the-circuit concept is exposed. Similarly, Jenny’s LEGO mechanism for pushing the shutter of the camera helped demystify the control process of the bird feeder; sending an infrared signal from the Cricket to trigger the camera might have been simpler in some ways, but also less illuminating.

Of course, not everything in Jenny’s bird feeder is transparent. The Cricket itself can be seen as a black box. Jenny certainly did not understand the inner workings of the Cricket electronics. On the other hand, Jenny was able to directly control the rules underlying the functioning of her bird feeder. Through the course of her project, she continually modified the computer program on the Cricket, to extend the functionality of the bird feeder. After finishing the first version of the bird feeder, Jenny recognized a problem: If a bird were to hop up and down on the perch, the bird feeder would take multiple photographs of the bird. Jenny added a `wait` statement to her program, so that the program would pause for a while after taking a photograph, to avoid the "double-bouncing" problem.

This ability to modify and extend her project led Jenny to develop a deep sense of personal involvement and ownership. She compared her bird-feeder project with other science-related projects that she had worked on in school. "This was probably more interesting cause it was like you were doing a test for something more complicated than just what happens if you add this liquid to this powder," she explained. "It was more like how many birds did you get with the machine *you* made with this complex thing you had to program and stuff" [emphasis hers]. Jenny cared about her bird feeder (and the photographs that it took) in large part because she had designed and built it. The "fun part" of the project, she explained, "is knowing that you made it; *my* machine can take pictures of birds" [emphasis hers].

### ***Many Paths, Many Styles***

While developing an early version of the Programmable Brick technology, we tested some prototypes with a fourth-grade class in Boston. We asked the students what types of projects they wanted to work on, and they decided to create an amusement park, with different groups of students working on different rides for the park.

One group of three students worked on a merry-go-round. They carefully drew up plans, then built the structure and mechanisms according to their plans. After they finished building, they wrote a computer program to control the merry-go-round with a touch sensor. Whenever anyone touched the sensor, the merry-go-round would spin for a fixed amount of time. Within a couple hours, their merry-go-round was working.

Another group, also with three students, decided to build a Ferris wheel. But after working half an hour on the basic structure for the Ferris wheel, they put it aside and started building a refreshment stand next to the Ferris wheel. This decision could be viewed as a positive example of students following their interests. But there was a problem: By focusing on the refreshment stand, which did not have any motors or sensors or programming, the students were missing out on some of the important ideas underlying the activity. The students continued to work on structures (as opposed to mechanisms or programming) for several hours. After finishing the refreshment stand, the group built a wall around the amusement park. Then, they created a parking lot, and added lots of little LEGO people walking into the park.

Finally, after the whole amusement-park scene was complete, the students went back and finished building and programming their Ferris wheel. For this group, building the Ferris wheel wasn't interesting until they had developed an entire story and context around it. In the end, their Ferris wheel worked just as well as the first group's merry-go-round. And, like the first group, they learned important lessons about mechanical advantage as they built the gearing system for the Ferris wheel, and they developed their ability to think systematically as they wrote the programs to control the Ferris wheel. But the two groups travelled down very different paths to get to the same result.

These two groups represent two very different styles of playing, designing, and thinking. Turkle and Papert (1992) have described these styles as “hard” (the first group) and “soft” (the second). The hard and soft approaches, they explain, “are each characterized by a cluster of attributes. Some involve organization of work (the hards prefer abstract thinking and systematic planning; the softs prefer a negotiational approach and concrete forms of reasoning); other attributes concern the kind of relationship that the subject forms with computational objects. Hard mastery is characterized by a distanced stance, soft mastery by a closeness to objects.”

In many math and science classrooms, the hard approach is privileged, viewed as superior to the soft approach. Turkle and Papert argue for an “epistemological pluralism” that recognizes the soft approach as different, not inferior. My research group has taken a similar stance in the design of new technologies and activities, putting a high priority on supporting learners of all different styles and approaches. We pay special attention to make sure that our technologies and activities are accessible and appealing to the softs; because math and science activities have traditionally been biased in favor of the hards, we want to work affirmatively to close the gap.

### *Using the Familiar in Unfamiliar Ways*

Over the past five years, my research group has collaborated with a group of museums on an initiative called the Playful Invention and Exploration (PIE) Network. The museums have used Crickets to develop a new generation of hands-on activities that combine art, science, and engineering. By taking a playful approach to invention, and integrating engineering with artistic expression, the PIE museums have engaged a broad and diverse population of people in scientific inquiry and invention (Resnick et al., 2000).

Some of the most popular and successful activities at the PIE museums have been based on the use of familiar objects in unfamiliar ways. At the MIT Museum, for example, Stephanie Hunt and Michael Smith-Welch created workshops in which children turned food into musical instruments. At the core of the activity was a simple Cricket program that measured the electrical resistance of an object and played a musical note based on the resistance. The higher the resistance, the higher the note. Children could put different food items on a plate (with electrical connections to the Cricket), and hear the resistance. A marshmallow (high resistance) would play a high-pitched note, while a pickle (low resistance) would play a low-pitched note. Children could play songs by quickly replacing one piece of food with another.

In one workshop, a 9-year-old named Jonah took several pieces of cantaloupe and lined them up in a row. He attached one wire on the left end of the cantaloupe row, and moved a second wire gradually down the row. The musical notes got higher and higher as he moved down the row. The reason: with more cantaloupe pieces between the two wires, there was more resistance, hence higher notes. And thus the melon xylophone was born. Jonah found a xylophone mallet and connected a wire to it. Then, he could tap the cantaloupe pieces with the mallet to play different melodies, just as on a xylophone. As he worked on this playful project, Jonah learned about the workings of electrical circuits, the nature of electrical resistance and conductivity, and the electrical properties of everyday objects.

Inspired by the food-based musical instruments, another 9-year-old named George came up with an idea for a new type of robot. He attached two wires inside the "mouth" of his robot. When the robot bumped into a piece of food, the two wires formed a circuit with the food and measured its resistance. George programmed the robot so that it could tell one type of food from another, based on differences in resistance. George recorded sound clips for the robot to play when it encountered different food. When the robot bumped into a lemon, it would say: "Yuck, a lemon." When it bumped into a pickle, it would say "Yum, a pickle."

As they ran the musical-food workshops, Stephanie and Michael continued with their own food experiments. They discovered that the resistance of a hot dog changes as you bend it, so a hot dog could be used as a "bend sensor." The more you bend a hot dog, the higher the resistance. They experimented with green beans and string cheese too. "We never had a enough bend sensors," said Stephanie. "It was great to discover that we could make our own."

The musical-food activities led children (and the workshop organizers) to start to think about food in new ways. Typically, people think of food in terms of its color or texture or taste. Through Cricket music activities, children began to realize that food has other properties – in particular, electrical resistance. And resistance became not just an abstract concept learned in science class but a useful tool for creative expression.

Other PIE workshops used other familiar materials: Q-tips, pipe-cleaners, blocks of ice. As they played with familiar materials, children seemed more comfortable experimenting and exploring. At the same time, they were more intrigued when unexpected things happened. If you're playing with unfamiliar or complex materials and something unexpected happens, you're not so surprised. But if you're playing with something simple and familiar (like a hot dog or piece of cantaloupe) and something surprising happens, then you want to find out more. "The familiar doing the unfamiliar stops you in your tracks," said one PIE workshop leader. "It jars you to want to know more."

## The Creative Society

In the 1980s, there was much talk about the transition from the Industrial Society to the Information Society (e.g., Beniger, 1986; Salvaggio, 1989). 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 (e.g., Drucker, 1994). They began to realize that information itself would not bring about important change. Rather, the key was how people transformed information into knowledge, and how they managed and shared that knowledge.

But, as I see it, knowledge alone is not enough. Success in the future – for individuals, for communities, for companies, for nations as a whole – will be based not on what we know or how much we know, but on our ability to think and act creatively. In the 21st century, we are moving toward the Creative Society.

The proliferation of new technologies is quickening the pace of change, accentuating the need for creative thinking in all aspects of our lives. At the same time, some new technologies can foster and support the development of creative thinking. We have seen, for example, how Cricket-based activities at the PIE museums can help children develop as creative thinkers.

In some ways, children can serve as models for the Creative Society. Childhood is one of the most creative periods of our lives. We must make sure that children's creativity is nurtured and developed, providing children with opportunities to exercise, refine, and extend their creative abilities. That will require new approaches to education and learning – and new types of technologies 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.

## A New Alliance

In March 2001, I had one of the most frustrating meetings of my life. Three leaders of the Alliance for Childhood came to visit me at the MIT Media Lab. The previous September, the group had published a report called *Fool's Gold: A Critical Look at Computers in Childhood* (Cordes and Miller, 2000). In reading the report, I found myself agreeing with the authors on many issues. The report emphasized the importance of nurturing children's creative abilities, arguing that "creativity and imagination are prerequisites for innovative thinking, which will never be obsolete in the workplace." I certainly agreed. And the report expressed concern that many new technologies restricted rather than encouraged creative thinking: "A heavy diet of ready-made computer images and programmed toys appear to stunt imaginative thinking." Again, I agreed: Most computer-based products for children are like televisions not paintbrushes, delivering pre-programmed content rather than fostering exploration and expression.

I was pleased that the leaders of the Alliance had asked to visit the Media Lab. I looked forward to showing them some of the projects that children had created with our Cricket technology. I felt that our Cricket research was grounded in the same core values expressed in their report. I wanted to show them that some technologies, rather than stunting imaginative thinking, could actually foster and support the development of creative thinking and creative expression.

But the meeting didn't go according to my expectations. After I showed the visitors Jenny's bird feeder, and told them the story of how Jenny had built and programmed it, one of the visitors turned to me and said: "Don't you think it's a problem to take children away from creative play experiences?" I couldn't believe it. I had just described what I considered to be an extraordinarily playful and creative project, but the visitor from the Alliance didn't see it that way. She saw a project using advanced technology, and immediately assumed that the child could not possibly have been doing anything creative.

The interaction made me aware of how polarized our discussions about children and technology have become. There is no doubt, as the *Fool's Gold* report persuasively argues, that the promoters of new technologies make excessive claims and promises, assuming that all technologies must be worthwhile technologies. But it is equally true that the critics of new technologies are too quick to lump all technologies together and dismiss them collectively.

Although I work at one of the world's leading centers of technological innovation, I often find myself sympathizing more with the techno-critics than with the techno-enthusiasts. I resonated with the *Fool's Gold* report when it asserted (p. 68): "Knowledgeable, caring teachers – not machines – are best able to mediate between young children and the world." I, too, am deeply skeptical about "intelligent tutoring systems" that try to put a computer in the place of a teacher. But in the very next sentence, the *Fool's Gold* report argues: "Low-tech tools like crayons, watercolors, and paper nourish children's inner capacities and encourage the child to freely move in, directly relate to, and understand the real world." Why restrict it to "low-tech" tools? Does the ability to "nourish children's inner capacities" really depend on the level of technology? A century ago, crayons were considered advanced technology. Did that make them less able to nourish children's inner capacities?

We need to move away from generalizations about all computers or all technologies, and consider instead the specifics of each technology and the context of its use. Some technologies, in some contexts, foster creative thinking and creative expression; other technologies, in other contexts, restrict it. Rather than focusing on the division between techno-critics and techno-enthusiasts, we need to focus on the difference between activities that foster creative thinking and creative expression (whether they use high-tech, low-tech, or no-tech) and those that don't.

New alliances are needed. At the Playing for Keeps conference in October 2004, I had the good fortune to meet again with Joan Almon, coordinator and president of the board of U.S. Alliance for Childhood. It was the first time Joan and I had met since the meeting at MIT in 2001. I told Joan how frustrated I had been by the earlier meeting – frustrated not because we disagreed (I disagree with many people) but because we allowed our disagreements to overwhelm and obscure what I thought were deep commonalities. We talked for several hours, and we did, indeed, find many shared values, beliefs, and goals. A few months later, Joan came to MIT and spent two days with my research group. We still have our differences, and I'm sure we always will. But those of us who believe in paintbrushes over televisions need to stick together.

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## References

Beniger, (1986). *The Control Revolution: Technological and Economic Origins of the Information Society*. Cambridge, MA: Harvard University Press.

Brosterman, N. (1997). *Inventing Kindergarten*. New York: Harry N. Abrams Inc.

Bruner, J. (1963). *The Process of Education*. Cambridge, MA: Harvard University Press.

Cordes, C., & Miller, E. (2000). *Fool's Gold: A Critical Look at Computers in Childhood*. College Park, MD: Alliance for Childhood.

Csikszentmihalyi, M. (1991). *Flow: The Psychology of Optimal Experience*. New York: Harper-Collins Publishing.

Deci, E. (1995). *Why We Do What We Do: Understanding Self-Motivation*. New York: Putnam Publishing.

Dewey, J. (1910). *How We Think*. Boston: Heath.

Drucker, P. (1994). *Knowledge Work and Knowledge Society*. Edwin L. Godkin Lecture, John F. Kennedy School of Government, Harvard University, Cambridge, MA.

Eisenberg, M., & Eisenberg, A. (2000). The Developing Scientist As Craftsperson. In N. Roberts, W. Feurzeig, & B. Hunter (Eds.), *Computer Modeling and Simulation in Pre-College Science Education* (pp. 259-281). New York: Springer-Verlag.

Eisenberg, M. (2003). Mindstuff: Educational Technology Beyond the Computer. *Convergence*, *9* (2), 29-53.

Martin, F., Mikhak, B., & Silverman, B. (2000). MetaCricket: A designer's kit for making computational devices. *IBM Systems Journal, 39* (3-4), 795-815.

Montessori, M. (1912). *The Montessori Method*. New York: Frederick Stokes Co.

Oppenheimer, T. (2003). *The Flickering Mind: Saving Education from the False Promise of Technology*. New York: Random House.

Papert, S. (1980). *Mindstorms: Children, Computers, and Powerful Ideas*. New York: Basic Books.

Papert, S. (1993). *The Children's Machine: Rethinking School in the Age of the Computer*. New York: Basic Books.

Resnick, M., Martin, F., Sargent, R., & Silverman, B. (1996). Programmable Bricks: Toys to Think With. *IBM Systems Journal*, *35* (3-4), 443-452.

Resnick, M., Bruckman, A., & Martin, F. (1996). Pianos Not Stereos: Creating Computational Construction Kits. *Interactions*, *3* (6), 41-50.

Resnick, M., Rusk, N., & Cooke, S. (1998). The Computer Clubhouse: Technological Fluency in the Inner City. In D. Schon, B. Sanyal, & W. Mitchell (Eds.), *High Technology and Low-Income Communities* (pp. 266-286). Cambridge, MA: MIT Press.

Resnick, M., Berg, R., & Eisenberg, M. (2000). Beyond Black Boxes: Bringing Transparency and Aesthetics Back to Scientific Investigation. *Journal of the Learning Sciences*, *9* (1), 7-30.

Resnick, M., Mikhak, M., Petrich, M., Rusk, N., Wilkinson, K., & Willow, W. (2000). *The PIE Network: Promoting Science Inquiry and Engineering through Playful Invention and Exploration with New Digital Technologies*. Proposal to the U.S. National Science Foundation (project funded 2001-2004). MIT Media Laboratory, Cambridge, MA.

Resnick, M. (2002). Rethinking Learning in the Digital Age. In G. Kirkman (Ed.), *The Global Information Technology Report: Readiness for the Networked World* (pp. 32-37). Oxford: Oxford University Press.

Salvaggio, J. (1989). *The Information Society: Economic, Social, and Structural Issues*. Mahwah, NJ: Lawrence Erlbaum.

Turkle, S., & Papert, S. (1992). Epistemological Pluralism and the Revaluation of the Concrete. *Journal of Mathematical Behavior*, *11* (1), 3-33.

Willow, D. (Ed.). (2004). *Digital Dialogues: Technology and the Hand*. Haystack Monograph Series, Haystack Mountain School of Crafts, Deer Isle, ME.