

Computers, Networks and Education

Globally networked, easy-to-use computers can enhance learning, but only within an educational environment that encourages students to question "facts" and seek challenges

by Alan C. Kay

The physicist Murray Gell-Mann has remarked that education in the 20th century is like being taken to the world's greatest restaurant and being fed the menu. He meant that representations of ideas have replaced the ideas themselves; students are taught superficially about great discoveries instead of being helped to learn deeply for themselves.

In the near future, all the representations that human beings have invented will be instantly accessible anywhere in the world on intimate, notebook-size computers. But will we be able to get from the menu to the food? Or will we no longer understand the difference between the two? Worse, will we lose even the ability to read the menu and be satisfied just to recognize that it is one?

There has always been confusion between carriers and contents. Pianists know that music is not in the piano. It begins inside human beings as special urges to communicate feelings. But many children are forced to "take piano" before their musical impulses de-

velop; then they turn away from music for life. The piano at its best can only be an amplifier of existing feelings, bringing forth multiple notes in harmony and polyphony that the unaided voice cannot produce.

The computer is the greatest "piano" ever invented, for it is the master carrier of representations of every kind. Now there is a rush to have people, especially schoolchildren, "take computer." Computers can amplify yearnings in ways even more profound than can musical instruments. But if teachers do not nourish the romance of learning and expressing, any external mandate for a new "literacy" becomes as much a crushing burden as being forced to perform Beethoven's sonatas while having no sense of their beauty. Instant access to the world's information will probably have an effect opposite to what is hoped: students will become numb instead of enlightened.

In addition to the notion that the mere presence of computers will improve learning, several other misconceptions about learning often hinder modern education. Stronger ideas need to replace them before any teaching aid, be it a computer or pencil and paper, will be of most service. One misconception might be called the fluidic theory of education: students are empty vessels that must be given knowledge drop by drop from the full teacher-vessel. A related idea is that education is a bitter pill that can be made palatable only by sugarcoating—a view that misses the deep joy brought by learning itself.

Another mistaken view holds that humans, like other animals, have to make do only with nature's mental bricks, or innate ways of thinking, in the construction of our minds. Equally worrisome is the naive idea that reality

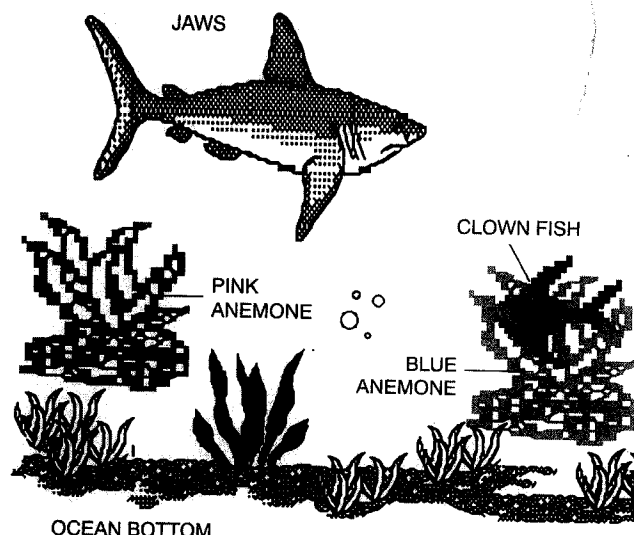
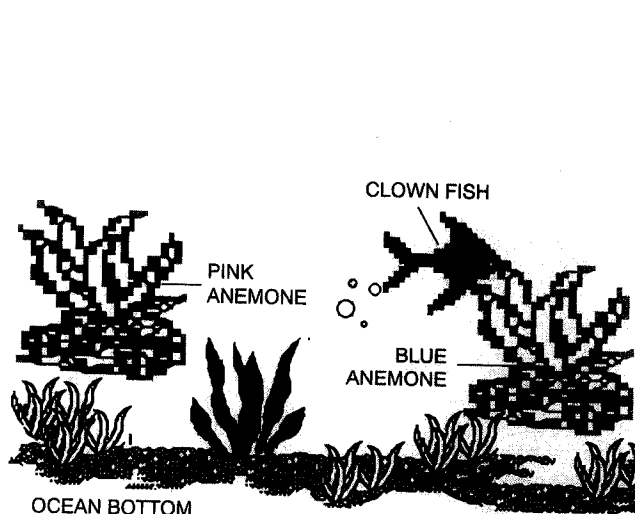
is solely what the senses reveal. Finally, and perhaps most misguided, is the view that the mind is unitary, that it has a seamless "I"-ness.

Quite the contrary. Minds are far from unitary: they consist of a patchwork of different mentalities. Jerome S.



STUDENTS at the Open School: Center for Individualization, in Los Angeles, are creating a dynamic simulation of ocean life (right) and doing math (above) with the help of Macintosh computers, which are set unobtrusively into the desks. In the Open School, which already had a strong curriculum before it obtained computers, the machines do not substitute for teachers. They are thought of as "just another material," like books, paints and clay, that can support the children's activities. In the next few years, notebook-size computers are expected to become available; then children will be able to carry their computers anywhere they go.

ALAN C. KAY has been a fellow of Apple Computer Inc. since 1984. Before joining Apple, he was a founder and fellow of the Xerox Palo Alto Research Center and, later, chief scientist of Atari. One of the pioneers of personal computing, he is the original designer of the overlapping-window user interface and Smalltalk, the first completely object-oriented language. Kay has worked with children for most of his career because, he says, "the media that powerfully shape our ways of thinking must be made accessible as early in life as possible." His interests outside of computing include musical performance and instrument design and "trying to learn more about the world in which we find ourselves." He also plays tennis whenever he can.



CLOWN FISH IS FEATURED in an ocean simulation constructed by nine- and 10-year-olds at the Open School. The fish repeatedly brushes up against an individual sea anemone (left panel) to build immunity to its poisonous stings. After immunity is established (right panel), the fish can take refuge among the anemone's tentacles whenever a predator (here a

shark named Jaws) is near. By constructing simulations, the children learn more about the challenges of being a clown fish and the benefits of symbiosis than they would if they engaged only in more passive activities—such as reading books and observing a fish tank. The author argues that adults, too, learn best when they can test ideas through simulation.

Bruner of New York University has suggested that we have a number of ways to know and think about the world, including doing, seeing and manipulating symbols. What is more, each of us has to construct our own version of reality by main force, literally to make ourselves. And we are quite capable of devising new mental bricks, new ways of thinking, that can enormously expand the understandings we can attain. The bricks we develop become new technologies for thinking.

Many of the most valuable structures devised from our newer bricks may require considerable effort to acquire. Music, mathematics, science and human rights are just a few of the systems of thought that must be built up layer by layer and integrated. Although understanding or creating such constructions is difficult, the need for struggle should not be grounds for avoidance. Difficulty should be sought out, as a spur to delving more deeply into an interesting area. An educational system that tries to make everything easy and pleasurable will prevent much important learning from happening.

It is also important to realize that many systems of thought, particularly those in science, are quite at odds with common sense. As the writer Susan Sontag once said, "All understanding begins with our not accepting the world as it appears." Most science, in fact, is quite literally non-sense. This idea became strikingly obvious when such instruments as the telescope and micro-

scope revealed that the universe consists of much that is outside the reach of our naive reality.

Humans are predisposed by biology to live in the barbarism of the deep past. Only by an effort of will and through use of our invented representations can we bring ourselves into the present and peek into the future. Our educational systems must find ways to help children meet that challenge.

In the past few decades the task before children—before all of us—has become harder. Change has accelerated so rapidly that what one generation learns in childhood no longer applies 20 years later in adulthood. In other words, each generation must be able to quickly learn new paradigms, or ways of viewing the world; the old ways do not remain usable for long. Even scientists have problems making such transitions. As Thomas S. Kuhn notes dryly in *The Structure of Scientific Revolutions*, a paradigm shift takes about 25 years to occur—because the original defenders have to die off.

Much of the learning that will go on in the future will necessarily be concerned with complexity. On one hand, humans strive to make the complex more simple; categories in language and universal theories in science have emerged from such efforts. On the other hand, we also need to appreciate that many apparently simple situations are actually complex, and we have to be able to view situations in their larger contexts. For example, burning down

parts of a rain forest might be the most obvious way to get arable land, but the environmental effects suggest that burning is not the best solution for humankind.

Up to now, the contexts that give meaning and limitation to our various knowledges have been all but invisible. To make contexts visible, make them objects of discourse and make them explicitly reshapable and inventable are strong aspirations very much in harmony with the pressing needs and on-rushing changes of our own time. It is therefore the duty of a well-conceived environment for learning to be contentious and even disturbing, seek contrasts rather than absolutes, aim for quality over quantity and acknowledge the need for will and effort. I do not think it goes too far to say that these requirements are at odds with the prevailing values in American life today.

If the music is not in the "piano," to what use should media be put, in the classroom and elsewhere? Part of the answer depends on knowing the pitfalls of existing media.

It is not what is in front of us that counts in our books, televisions and computers but what gets into our heads and why we want to learn it. Yet as Marshall H. McLuhan, the philosopher of communications, has pointed out, the form is much of what does get into our heads; we become what we behold. The form of the carrier of information is not neutral; it both dictates

the kind of information conveyed and affects thinking processes.

This property applies to all media, not just the new high-tech ones. Socrates complained about writing. He felt it forced one to follow an argument rather than participate in it, and he disliked both its alienation and its persistence. He was unsettled by the idea that a manuscript traveled without the author, with whom no argument was possible. Worse, the author could die and never be talked away from the position taken in the writing.

Users of media need to be aware, too, that technology often forces us to choose between quality and convenience. Compare the emotions evoked by great paintings and illuminated manuscripts with those evoked by excellent photographs of the originals. The feelings are quite different. For the majority of people who cannot make such comparisons directly, there is an understandable tendency to accept the substitution as though nothing were lost. Consequently, little protest has been made over replacing high-resolution photographs of great art (which themselves do not capture the real thing) with lower-resolution videodisc images (which distort both light and space even further). The result is that recognition, not reverie, is the main goal in life and also in school, where recognition is the highest act to which most students are asked to aspire.

When convenience is valued over quality in education, we are led directly to "junk" learning. This is quite analogous to other junk phenomena, pale substitutions masquerading for the real thing. Junk learning leads to junk living. As Neil M. Postman of New York University says, whether a medium carries junk is not important, since all media have junk possibilities. But one needs to be sure that media incapable of carrying important kinds of discourse—for example, television—do not displace those that can.

Media can also lure us into thinking we are creating by design when in fact we are just tinkering. Consider the difficulty of transforming clay—a perfectly malleable and responsive substance—into anything aesthetically satisfying. Perfect "debugability," or malleability, does not make up for lack of an internal image and shaping skills. Unfortunately, computers lend themselves to such "clay pushing"; they tempt users to try to debug constructions into existence by trial and error.

Finally, as McLuhan noted, the instant communication offered by today's media leads to fragmentation. Sequence and exposition are replaced by isolated,



WALKWAY through a garden (*top*) outside the Open School was designed by the third graders, who chose a herringbone pattern to ensure easy access to all plots. The children settled on the pattern after creating and debating many models, often with the help of their computers. The garden is part of the Life Lab project, in which children plan, plant, tend and enjoy the fruits of their own garden (*bottom*) as a way of learning about the interaction of living things with the environment.

context-free factoids, often presented simply because they are recent. Two hundred years ago the Federalist papers—essays by James Madison, Alexander Hamilton and John Jay arguing for ratification of the U.S. Constitution—were published in newspapers in the 13 colonies. Fifty years later the telegraph and its network shifted the goals of news from depth to currency, and the newspapers changed in response. Approximately 100 years after that, television started shifting the emphasis of news from currency to visual immediacy.

Computers have the same drawbacks as other media, and yet they also offer opportunities for counteracting the inherent deficits. Where would the authors of the Constitution publish the Federalist papers today? Not in a book;

not enough people read books. Not in newspapers; each essay is too long. Not on the television; it cannot deal with thoughtful content. On computer networks? Well, computer displays, though getting better every year, are not good enough for reading extended prose; the tendency is to show pictures, diagrams and short “bumper sticker” sentences, because that is what displays do well.

But the late 20th century provides an interesting answer to the question: transmitting over computer networks a simulation of the proposed structure and processes of the new Constitution. The receivers not only could run the model but also could change assumptions and even the model itself to test the ideas. The model could be hyperlinked to the sources of the design, such as the constitution of Virginia, so

that “readers” might readily compare the new ideas against the old. (Hyperlinking extends any document to include related information from many diverse sources.) Now the receivers would have something stronger than static essays. And feedback about the proposals—again by network—could be timely and relevant.

Five years ago, intent on studying firsthand the strengths and weaknesses of computers as amplifiers for learning, my colleague Ann Marion and I, in collaboration with the Open School: Center for Individualization, in Los Angeles, set up a research project called the Apple Vivarium Program. We and the principal, Roberta Blatt, were not trying to improve the already excellent school by introducing technology. We were trying to better understand the value computers might have as supporting media.

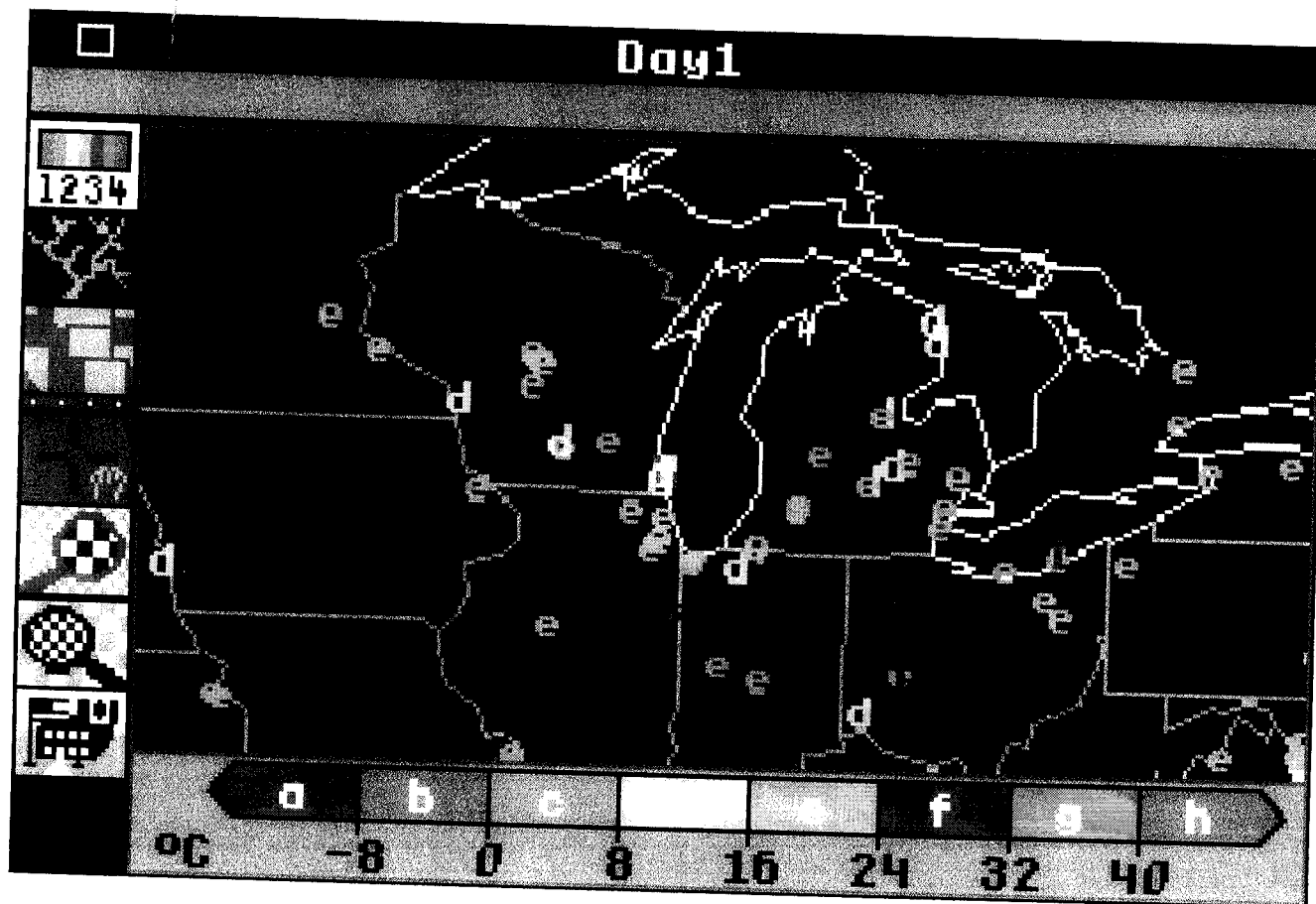
Children are bused in and, as is the case with other busing schools in Los Angeles, are selected by lot so that the racial balance is roughly in accord with that of the city as a whole. Parents have to be interested enough in their children and the school’s teaching approach to put their children on the list for consideration. Parental interest and involvement are key factors that have made the school a success. One could even argue that the educational approach in a classroom is not nearly as important as the set of values about learning found in the home. If those exist, almost any process will work, although some may be more enjoyable and enriching than others.

We particularly wanted to investigate how children can be helped to understand that animals, people and situations are parts of larger systems that influence one another. We therefore focused much of our work on the study of biology and ecology. Studies of the design and functioning of large cities also give children an awareness of such complexity. Doreen Nelson of the California Polytechnic Institute has been teaching city design to children for many years; on the basis of her work, our study group introduced a large-scale city-building project for the third graders. We also helped the school develop a major theater program, so the children might see how art and systems work from the inside.

What does it mean to learn about biology as it relates to us and our world? All creatures consist of and are part of many systems that range from the molecular to the planetary. A weak way to approach this romance—in which we are at once part of the scenery, bit



MODEL CITY was built by third graders at the Open School after months of planning. Although the children erected the buildings by hand, they turned to their computers for assistance on a number of jobs. For instance, the computers helped the students simulate the formation of smog in their city.



PLOT OF TEMPERATURES in the Great Lakes region of the U.S. is part of an international map created from data collected by students in hundreds of schools. The children took measurements at the same time of day and pooled them through a

network. Making such maps is part of the *Weather in Action* unit of the National Geographic Kids Network curriculum. It is also an example of how networks can enhance scientific collaboration—for children as much as for adults.

players, star-crossed lovers, heroes and villains—would be a well-meaning attempt to use books, computers or other representational media as “delivery vehicles.” There could be videodiscs showing plant and animal growth, and the students could have network access to data about crop yields, taxonomies of animals and plants, and so forth. But why substitute a “music appreciation” approach for the excitement of direct play? Why teach “science and math appreciation,” when the children can more happily (and to better effect) actually create whole worlds?

What is great in biology and humankind’s other grand investigations cannot be “delivered.” But it can be learned—by giving students direct contact with “the great chain of being,” so that they can internally generate the structures needed to hold powerful ideas. Media of all kinds can now be used to amplify the learning experience, whereas before they acted as a barrier to the “good stuff.”

The Open School is nothing if not straightforward. Because “things that grow” is the essence of what is called

the Life Lab program, the children made a garden, tearing up part of their asphalt playground to get good clean dirt. The third graders, while in the midst of their city-building project, spent months modeling and debating designs for the garden. They ultimately arrived at a practical, child-scaled pattern featuring a herringbone-shaped walkway that puts every plot in reach.

Not surprisingly, the children found that the simulation capability of their computers helped them examine the merits of many different walkway designs. Like modern-day architects, they used the computer to help construct models of their ideas. Teachers Dolores Patton and Leslie Barclay facilitated the process, but it was the children who came up with the ideas.

There are many Life Lab schools in California. Because they are engaged in similar pursuits, they have things to say to one another. For them, networks serve as much more than a conduit for retrieving fixed data; they allow students to develop knowledge of their own collaboratively. For example, it is easy to make one’s own weather maps

on the basis of simultaneous recordings of temperature and barometric pressure and the like and to argue via network about what the maps mean.

Computer animation can be used to ponder the patterns more readily. A fairly easy inference is that pressure changes seem to go from west to east. Could this have anything to do with the rotation of the earth? The directions of winds are more complicated, since they are more affected by features of the terrain. Do they match up with pressure changes?

We can go still deeper. Children are capable of much depth and attention to quality when they are thinking about questions that seem important to them. Why do animals do what they do? Why do humans do what we do? These are vital issues. Close observation, theories and role-playing help. Reading books about animal behavior helps. The teacher can even explain some ideas of the Nobel laureate Niko Tinbergen, such as the suggestion that animal behavior is organized into modules of innate patterns.

But these are just words. Now the children can make dynamic models of animal behavior patterns to test Tinbergen's concepts themselves.

Can nine- and 10-year-old children actually capture and understand the mentality of a complex organism, such as a fish? Teacher B. J. Allen-Conn spent several summers learning about intricate ecological relations in the oceans. She searched for ways to express how an individual's behavior is altered by interactions with many other animals. At the same time, Michael Travers, a graduate student from the Media Laboratory at the Massachusetts Institute of Technology who was working with us, built several animal simulations, among them fish behaviors described by Tinbergen. Then Scott Wallace and others in our group turned these various ideas into Playground, a simulation construction kit for children.

Children are particularly enthralled by the clown fish, which exhibits all expected fishlike behaviors (such as feeding, mating and fleeing from predators) but also displays a fascinating way of protecting itself. It chooses a single sea anemone and gradually acclimates to the anemone's poison over a period of several days. When acclimation is complete, the clown fish has a safe haven where it can hide if a predator comes hunting.

It is fairly easy to build a simple behavior in Playground, and so the children produce simulations that reflect how the fish acts when it gets hungry, seeks food, acclimates to an anemone and escapes from predators. Later they can explore what happens when scripts conflict. What happens if the animal is very hungry yet there is a predator near the food? If the animal is hungry enough, will it start eyeing the predator as possible food? Do the fish as a group fare best when each animal is out for itself, or does a touch of altruism help the species overall?

For an adult, the children's work would be called Artificial Intelligence Programming Using a Rule-Based Expert Systems Language. We researchers and the teachers and children see the dynamic simulations as a way of finding out whether theories of animal behavior apply to the real world.

Computers in the Open School are not rescuing the school from a weak curriculum, any more than putting pianos in every classroom would rescue a flawed music program. Wonderful learning can occur without computers or even paper. But once the teachers and children are enfranchised as explorers, computers, like pianos, can serve as powerful amplifiers, extending the reach and depth of the learners.

Many educators have been slow to

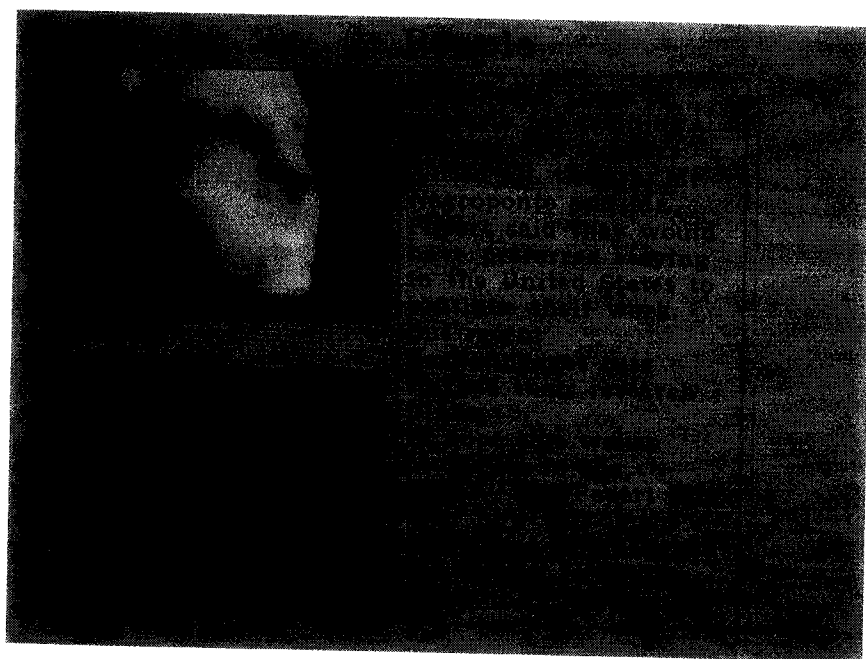
recognize this concept of knowledge ownership and to realize that children, like adults, have a psychological need for a personal franchise in the culture's knowledge base. Most schools force students to learn somebody else's knowledge. Yet, as John Holt, the teacher and philosopher of education, once said, mathematics and science would probably be learned better if they were made illegal. Children learn in the same way as adults, in that they learn best when they can ask their own questions, seek answers in many places, consider different perspectives, exchange views with others and add their own findings to existing understandings.

Ten years from now, powerful, intimate computers will become as ubiquitous as television and will be connected to interlinked networks that span the globe more comprehensively than telephones do today. My group's experience with the Open School has given us insight into the potential benefits of this technology for facilitating learning.

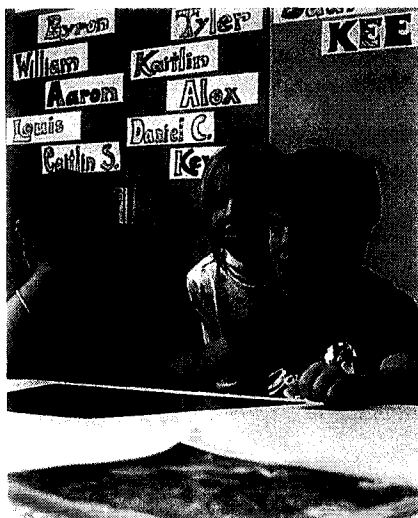
The first benefit is great interactivity. Initially the computers will be reactive, like a musical instrument, as they are today. Soon they will take initiatives as well, behaving like a personal assistant. Computers can be fitted to every sense. For instance, there can be displays for vision; pointing devices and keyboards for responding to gesture; speakers, piano-type keyboards and microphones for sound—even television cameras to recognize and respond to the user's facial expressions. Some displays will be worn as magic glasses and force-feedback gloves that together create a virtual reality, putting the user inside the computer to see and touch this new world. The surface of an enzyme can be felt as it catalyzes a reaction between two amino acids; relativistic distortions can be directly experienced by turning the user into an electron traveling at close to the speed of light.

A second value is the ability of the computers to become any and all existing media, including books and musical instruments. This feature means people will be able (and now be required) to choose the kinds of media through which they want to receive and communicate ideas. Constructions such as texts, images, sounds and movies, which have been almost intractable in conventional media, are now manipulatable by word processors, desktop publishing, and illustrative and multimedia systems.

Third, and more important, information can be presented from many different perspectives. Marvin L. Minsky



EXCERPT FROM A NEWSCLIP is part of a newspaper tailored to the interests of a single individual; the text was produced several years ago by the software program NewsPeek, which the author and Walter Bender designed when they were at the Massachusetts Institute of Technology. The program is an early prototype for one kind of "agent," a system that can learn a user's goals and retrieve relevant information on the person's behalf. Such agents will one day be essential for navigating through the mass of information that will be available on networks.



CHILDREN AT A COMPUTER in the Open School are clearly engrossed in their work. If used properly, the author notes, computers can be "powerful amplifiers, extending the reach and depth of the learners."

of M.I.T. likes to say that you do not understand anything until you understand it in more than one way. Computers can be programmed so that "facts" retrieved in one window on a screen will automatically cause supporting and opposing arguments to be retrieved in a halo of surrounding windows. An idea can be shown in prose, as an image, viewed from the back and the front, inside or out. Important concepts from many different sources can be collected in one place.

Fourth, the heart of computing is building a dynamic model of an idea through simulation. Computers can go beyond static representations that can at best argue; they can deliver sprightly simulations that portray and test conflicting theories. The ability to "see" with these stronger representations of the world will be as important an advance as was the transition to language, mathematics and science from images and common sense.

A fifth benefit is that computers can be engineered to be reflective. The model-building capabilities of the computer should enable mindlike processes to be built and should allow designers to create flexible "agents." These agents will take on their owner's goals, confer about strategies (asking questions of users as well as answering their queries) and, by reasoning, fabricate goals of their own.

Finally, pervasively networked computers will soon become a universal library, the age-old dream of those who love knowledge. Resources now beyond individual means, such as supercom-

puters for heavy-duty simulation, satellites and huge compilations of data, will be potentially accessible to anyone.

For children, the enfranchising effects of these benefits could be especially exciting. The educator John Dewey noted that urban children in the 20th century can participate only in the form, not the content, of most adult activities; compare the understanding gained by a city girl playing nurse with her doll to that gained by a girl caring for a live calf on a farm. Computers are already helping children to participate in content to some extent. How students from preschool to graduate school use their computers is similar to how computer professionals use theirs. They interact, simulate, contrast and criticize, and they create knowledge to share with others.

When massively interconnected, intimate computers become commonplace, the relation of humans to their information carriers will once again change qualitatively. As ever more information becomes available, much of it conflicting, the ability to critically assess the value and validity of many different points of view and to recognize the contexts out of which they arise will become increasingly crucial. This facility has been extremely important since books became widely available, but making comparisons has been quite difficult. Now comparing should become easier, if people take advantage of the positive values computers offer.

Computer designers can help as well. Networked computer media will initially substitute convenience for verisimilitude, and quantity and speed for exposition and thoughtfulness. Yet well-designed systems can also retain and expand on the profound ideas of the past, making available revolutionary ways to think about the world. As Postman has pointed out, what is required is a kind of guerilla warfare, not to stamp out new media (or old) but to create a parallel consciousness about media—one that gently whispers the debits and credits of any representation and points the way to the "food."

For example, naive acceptance of on-screen information can be combated by designs that automatically gather both the requested information and instances in which a displayed "fact" does not seem to hold.

An on-line library that retrieves only what it is requested produces tunnel vision and misses the point of libraries; by wandering in the stacks, people inevitably find gems they did not know enough to seek. Software could easily

provide for browsing and other serendipitous ventures.

Today facts are often divorced from their original context. This fragmentation can be countered by programs that put separately retrieved ideas into sequences that lead from one thought to the next. And the temptation to "clay push," to create things or collect information by trial and error, can be fought by organizational tools that help people form goals for their searches. If computer users begin with a strong image of what they want to accomplish, they can drive in a fairly straightforward way through their initial construction and rely on subsequent passes to criticize, debug and change.

If the personally owned book was one of the main shapers of the Renaissance notion of the individual, then the pervasively networked computer of the future should shape humans who are healthy skeptics from an early age. Any argument can be tested against the arguments of others and by appeal to simulation. Philip Morrison, a learned physicist, has a fine vision of a skeptical world: "...genuine trust implies the opportunity of checking wherever it may be wanted.... That is why it is the evidence, the experience itself and the argument that gives it order, that we need to share with one another, and not just the unsupported final claim."

I have no doubt that as pervasively networked intimate computers become common, many of us will enlarge our points of view. When enough people change, modern culture will once again be transformed, as it was during the Renaissance. But given the current state of educational values, I fear that, just as in the 1500s, great numbers of people will not avail themselves of the opportunity for growth and will be left behind. Can society afford to let that happen again?

FURTHER READING

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