Quick, Where do the Computers Go?

History has dealt computer and information science a special role in the inevitable restructuring of the educational system in the United States. In the coming decade computing and information technology will be the backbone of the most significant change in education in over 100 years. Rather than being an adjunct to learning and teaching, technology is facilitating a fundamental rethinking of what should be learned and how. Such changes present the Communications *readership with a unique opportunity and a serious responsibility. Toward meeting this challenge, in this column I will address some key issues in education and technology. For example, this first column examines how our basic notion of what needs to be learned is changing, and how this affects the ways in which technology is used. Subsequent columns will explore topics such as "programming's role in learning," "multi-media, and nationwide, computer-based," testing.*

My intent in this column is to provoke—to confront the folk wisdoms and myths that we all harbor about education. The dialogues that I sincerely hope this column will engender are critically important: the winds of change in education are blowing, and something *will be done; For that something to be proactive and not reactive, for that something to reflect the desires of the people, communities such as ours must participate in serious discussion of the issues. Reflective decision making is, afterall, what education is all about.*

It is no longer news that the educational system in the United States is not working. Report after report documents and decries how America's greatest institution—public education—is falling apart. Graduating students today simply are not prepared to take advantage of the opportunities in the workplace. Even worse, the 1990s are a time when these opportunities are beginning to dwindle. There is unquestionable danger to society in a situation where youth feels its future is being foreclosed on them.

There *is* hope. We as a people are beginning to recognize the sorry state of the educational infrastructure; even the politicians are finally getting the message! In order to put forth a concrete plan for rebuilding that infrastructure, we need to first identify what is wrong with the schools today. The place to start, it seems to me, is at the core: what do those directing our educational system assume needs to be learned? The answer to this question is critical, since it is those assumptions that determine how learning and schooling take place.

Nowhere is the assumption of what needs to be learned more evident than on tests: afterall, what becomes valued is what one is tested on. Schools test students on how much knowledge they have accumulated. The assumption is that there is a core set of knowledge that all students need to acquire. Learning, then, is just knowledge transfer: teachers have it, students need to get it. In effect, students are viewed as empty vessels into which knowledge needs to be poured.

BY
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Accumulation of a core of knowledge as the goal of education comes out of the 19th century. The world then was more circumscribed: change took place over generations, and thus what you knew was useful for a significant period of time. Correspondingly, the majority of today's classrooms appear much as they did back in the 19th century: teachers still use one stone to write on another stone; there are specific subjects (History, Geometry, Science) taught at specific times of the day for specific periods of time.

In contrast, just ask yourself: how has your job changed over the last 10 years? How much of your time on the job is spent learning things you need to know in order to

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do your job? Would you put up with having seven to nine meetings every day, where each meeting lasts exactly 50 minutes? Aren't you being rewarded for solving problems that require the (1) integration of knowledge from diverse disciplines, (2) the uncovering of new information, and (3) the ability to work cooperatively with your colleagues? The ability to *cope well with change* may actually be the key to success in your work.

Our society is rapidly moving out of the Industrial Age and into the Information Age. Significant change occurs within a generation—and it happens over and over again. Without question, students need to know certain "things," but in order to effectively cope with our ever-changing world, it is critically important that students learn how to learn. As Herbert Simon, Nobel Laureate and a founder of contemporary psychology, has pointed out, it may well be more important to learn "how" than to learn "what."

The Techie Fantasy: Fixing Education

Here it comes . . . get ready . . .

> Computers will make everything better; give each student and each teacher a computer and the students will be motivated to learn better/more, and teachers will immediately see how to harness the computer for educational purposes, and, . . .

Put that baldly, no one seriously can defend such a position. In the privacy of your own thoughts, however, recalling those wonderful experiences you have had with technology, ask yourself again: Do you really believe that computers genuinely do have the power to make things better or is it only a matter of degree? Such incorrigible optimism is not a bug—it is a necessary feature that helps us to persevere.

The problem, of course, is not technology per se. Rather, it is how technology is used. By and large, computers in education have been used to implement the accumulation model of learning: with technology we can transfer "stuff" to students faster; with technology we can deliver instruction more effectively—as if ideas were just bags of potatoes in need of transportation. *That* model has not worked—and it will not work, even if we add multimedia to the instruction being delivered. What is needed is a more incisive model of learning, one that can help us cope with changing times and changing needs. So armed, we can then roll in those computers!

Don't Just Sit There, Do Something!

We need not search far for an alternative to the accumulation model of learning: along with Plato and Dewey, your mother knew it quite well when she said to you: "don't just sit there, do something." What your mother knew intuitively, and what the academics are now providing scientific evidence for, is this: learning is not a passive process where one receives information; rather, learning requires an individual to be active, to be engaged in constructing an understanding that ties new ideas to old. Moreover, one learns by *building artifacts*—whether they be formal reports, private scribblings, Lego choo-choo trains, or computer programs, the path to learning is strewn with *things*, with externalizations. You know that if you keep something to yourself the ideas do not progress; expose the ideas to others via some sort of artifact, and the discussion and feedback provide the impetus to move to that next level of understanding. The reason stepwise refinement works is precisely because the steps result in externalization that can be commented on; the comments then generate the next step.

Now, such *learning by doing* cannot be reduced to a simplistic *hands-on* learning approach. I as well as millions of others have tried to measure Avogadro's Number. I was hundreds of orders of magnitude off—but it did not matter, since everyone already knew the number. Rather, hands-on learning must be in the context of some legitimate inquiry; there has to be a real task in which the learner has some personal interest and investment.

In the old days, apprentices gathered around a master, who attempted to provide the former with experiences that would lead to the acquisition of expertise. A master was able to break down real-tasks into accessible pieces, and scaffold the tasks so that the apprentices would not blow themselves up. Frankly, such an active, meaningful, learning model would be hard to carry out in a classroom of 30 students and one teacher—a typical set-up in U. S. schools. The accumulation model of learning is better suited to such a classroom structure.

I should point out that this master/apprentice model of learning was expressed to me by a high school principal in Ann Arbor who is trying to promote the active learning model in his school—as soon as he can. Thus, while there is clearly a strong back-to-basics contingent, there is a growing recognition that learning is about more than just acquiring facts. What role, then, can technology play in helping to realize the principal's vision?

You Have Not Seen This Movie Before

Up until now, the computer-based environments—computer assisted instruction (CAI) and intelligent tutoring systems (ITS) have been used to support *instruction*, the delivery of information. In contrast, the types of systems that are now becoming available, which we call *interactive learning environments* (ILEs) are used by the students for *construction*—that is, ILEs are computer-aided design environments that facilitate the building of artifacts, (from book reports to mini robots), which in turn facilitate the learning of concepts and processes.

These CAD systems go beyond simply framing the task and provide *scaffolding* to support those apprentices as they learn. A student need not confront every hurdle at the outset; rather, an ILE attempts to smooth over those rough areas via scaffolding designed expressly for that purpose. As the learner progresses, the scaffolding can fade away to allow the learner to confront more of the subtleties of the task. Here, then, are some examples of ILEs that are being used in today's classrooms.

Proving Theorems in Geometry: Making the Search Process Explicit

I, for one, recall sitting in geometry class, watching the teacher go through a proof on the board, and nodding my head at each step. At home, however, when confronted with a similar proof, I had no idea what to do. Afterall, the teacher did the proof on the board in a sequential manner, step by step. So, I should have been able to do that, right? Well, no one bothered to tell me that no one really proves theorems in such a simplistic, linear fashion. Rather, proving a theorem is very much a search process, a non-linear activity in which one works with the givens, with the theorem to be proved, or even somewhere in between. The textbook and the teacher proved the theorem in a didactic, lecture-style mode; they provided no hints on how one knows when to pull in Angle-side-angle.

Anderson and Boyle at Carnegie-Mellon University have developed a program, called the Geometry Tutor, that runs on a 512K Mac. The screen dump from a typical proof tells a clear story: the Geometry Tutor (see Figure 1) makes the search process explicit; the student can work on various branches of the proof, and receive hints when he/she requests them. The interface supports the active construction of the proof. Does the Geometry Tutor work? Anderson and Boyle have shown that students who have used this program can

. . . earlier . . . economic transformations were accompanied by major public investments in the creation of new infrastructures such as canals, railroads, electric lines, and highways. In the transformation taking place . . . an educated population is the most critical infrastructure of the emerging economy. . . . The challenge of this generation is how to effectively create this infrastructure.
(Office of Technology Report, 1988)

"Technology and the American Economic Transition: Choice for the Future," OTA, U.S. Congress, Wash. DC., 1988

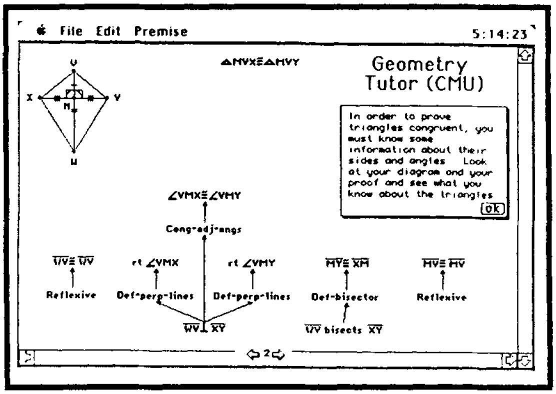

FIGURE 1.
Typical Screen from the Anderson and Boyle Geometry Tutor

improve test scores on standardized geometry tests (i.e., those that require the two-column proof method) one standard deviation! Not too shabby.

Students Doing Scientific Investigation

Ten thousand students around the United States are currently doing serious scientific research on Acid Rain. They collect water samples from puddles in their neighborhood, analyze them in class, and use telecommunications to broadcast their "findings" to others around the world. These students are not replicating Avogadro's Number experiment; rather, they are engaged in a legitimate inquiry that will produce information that is not available and that is relevant to their own lives. Moreover, by interacting with others around the globe they come to an appreciation of central ideas in science and society today. In effect "think globally, act locally."

FIGURE 2.
Student Showing Off Lego-Logo Design

More broadly, there is a new generation of laboratory instruments;—micro-computer based labs—coming on the scene. Sensors are connected directly to the computer; data is automatically input to the computer; and students can immediately use word processors, databases, and spreadsheets to explore the data, write reports (integrating data into their reports), and share their observations with other students. The computer is providing lab support that was simply not possible 10 years ago. The push-back on this technology comes from the educational system itself: teachers do not feel comfortable leading students in long term, multi-concept, multi-activity projects; administrators are not responding to needs of projects in terms of classroom space and class scheduling. While the technology is here now to support genuine exploration and investigation, the biggest problem is, as usual, a people problem.

Writing for Learning

In the Acid Rain project, students write messages and reports, that students, scientists, as well as teachers will actually read and comment on. Writing is a view supporting all sorts of learning: learning science content, learning science process, learning writing. The only time other students ever saw *my* math or science papers in high school was when we exchanged papers for grading.

Writing is a design activity; as such it deserves a CAD system. Moreover, writing in the context of an Acid Rain-like project is a collaborative activity. That too deserves technological support. Systems such as EarthLab and CSILE are exploring how to scaffold learners as they engage in such writing activities [3, 7]. For example, CSILE presents on-screen templates that provide a framework for students writing lab reports, as well as on-screen buttons that provide explicit coaching, e.g., in order to help students better index their reports so they are more accessible to other students, one such button raises the question "How will other people want to look for your document?" Such technological support surely goes beyond the "stone on stone" situation!

Combining the Abstract with the Concrete: Lego-Logo

With all this talk of technology, we should not forget that we still do live in a real, tactile, kinesthetic world. Enter Lego-Logo, brought to you by Papert and crew of the MIT Lab. This is a brilliant integration of the abstract with the concrete. Children build whatevers (see Figure 2) using colorful Lego pieces, motors, and gears; hook up their creations via a box, to the computer; and control the movements of the motorized Lego constructions through Logo programming; robot 1, forward 10; robot 2, move forward and stay on the white line, and so forth. It is 8-year olds building moving toys and writing parallel programs. Now, be honest, would *you* like to get such a Lego-Logo setup for your birthday?

The Bottom-Line: CAD for Kids

Technology has changed the way we, outside of the school, go about our day-to-day business: graphics designers, electrical engineers or architects would be lost without their computer-aided design (CAD) systems. Similarly, technology is the backbone that will support the transition from didactic, talking-heads instruction to a project-based curriculum. As the examples illustrate, technology can facilitate a new kind of learning experience: childern engaged in the active construction and use of knowledge, not passive receivers of decontextualized facts. In turn, these experiences provide the wherewithall for children to deal with real problems in their daily lives.

Education is all about hope; education is the means for bettering one's lot. This is quite the challenge! Given that technology's role in education has never been greater, our community in particular needs to confront the questions that are being raised and play an active role in shaping how computing technology impacts education.

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