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The Evolution of Information Technology: Implications for Curriculum

Schools must change their curriculums to reflect the changes technology is making in the workplace.

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During the next two decades, major changes in the technological base of American society will alter the knowledge, skills, and values we need to be capable workers and citizens. Evolving information technologies will transform the nature of work, and this transformation will in turn affect the design and content of the school curriculum. As jobs change, schools must shift in response.

Technological Evolution

Since World War II, the performance capabilities of computers and telecommunications have been doubling every few years at constant cost. For example, a decade ago $3,500 could buy a new Apple II microcomputer. Today, $6,800—the same amount of purchasing power (adjusted for 10 years of inflation)—can buy a new Macintosh II microcomputer. The Macintosh handles 4 times the information at 16 times the speed, preprogrammed and reprogrammable memory are both about 20 times larger, disk storage is about 90 times larger, and the display has 7 times the resolution and 16 times the number of colors. Comparable figures could be cited for other brands of machines. Equally impressive, users' demands for this power have increased as rapidly as it has become available.

Over the next two decades, data processing and information systems will probably be replaced by sophisticated devices for knowledge creation, capture, transfer, and use. A similar evolution can be forecast for telecommunications: personal videorecorders, optical fiber networks, intelligent telephones, information utilities such as videotex, and digital discs will change the nature of media.

Cognition Enhancers

The concept of "cognition enhancers" can help us understand how we can use these emerging technologies (Dede 1987b). A cognition enhancer combines the complementary strengths of a person and an information technology. Two categories of cognition enhancers will have considerable impact on the workplace: empowering environments and hypermedia.

Empowering Environments

Empowering environments enhance human accomplishment by a division of labor: the machine handles the routine mechanics of a task, while the person is immersed in its higher-order meanings. For example, I once took an oil painting course. My goal was to transfer my mental images to canvas so that viewers could share my experiences and emotions. However, rather than pondering form and composition and aesthetics, I had to spend my time trying to mix colors that remotely resembled my visualizations, trying to keep the paint from running all over the canvas, trying to keep the turpentine out of my hair. Now, I can use a graphics construction set to choose from a huge palette of colors; to alter, pixel by pixel, the contour of an image; to instantly "undo" my mistakes. Now I am involved with the creative aspects of art, while the empowering environment handles the mechanics. (However, my accomplishments as an artist are still ultimately limited by my own talents and knowledge.)

The workplace is adopting many empowering environments: databases for information management, spreadsheets for modeling, computer-aided design systems for manufacturing. And word processors with embedded spelling checkers, thesauruses, outliners, text analyzers, and graphics tools are driving the evolution of a new field: desktop publishing.

Hypermedia

Even with a sophisticated empowering environment for desktop publishing, I can still get writer's block. I can know everything I want to write yet not have my ideas in the linear "stream" required for written or oral communication. I need an "idea processor," a way of creating an external structure that mirrors the concepts and links in my memory. I need a second type of cognition enhancer: hypermedia.

Hypermedia is a framework for creating an interconnected, web-like representation of symbols (text, graphics, images, software codes) in the computer. This representation is similar to human long-term memory: people store information in networks of symbolic, temporal, and visual images related by association. For example, in my memory the word *apple* conjures up religious, corporate, computational, botanic, and gustatory associations.

With my knowledge externalized in a hypermedia system, I can traverse this network along alternative paths through nodes and links, seeking the right sequential stream for my intended content, audience, and goals. The computer allows me to avoid overload in transferring long-term to short-term memory. Also, my access to long-term memory may be enhanced by the process of building and using hypermedia.

Hypermedia documents are beginning to appear in the workplace. For example, automobile mechanics will soon be using hypermedia repair manuals to diagnose problems. The mechanic will trace initial symptoms through a series of linked tests to reach final judgment on what is wrong, then follow a web of nodes that map the different steps of the repair. An educational version of such a manual would incorporate "trails" through the hypermedia network that guide the user through a series of structured, sequenced learning experiences.

The emergence of primitive hypermedia systems on personal computers is inspiring new ideas for their use. For example, a hypermedia version of this paper would place each fundamental concept in a separate node; links would tie related concepts together. Chunking and juxtaposing ideas in this way increases comprehension over the forced linearity of textual presentations. Perhaps different styles of remembering and learning will evolve!

Using cognition enhancers, however, requires more than learning how to activate the machine and issue commands; the style of working must change. For example, as a result of using a word processor, I can no longer write well with paper and pencil. I used to compose a sentence by thinking for a couple of minutes and then setting down a near-final version, because making changes meant cutting and pasting; now, I think for half a minute and type in a sentence, think for another 15 seconds and make a change, make another change a few seconds later, and so on. Now I can concentrate on revision and polishing, without the pressure of having to create a finished product. However, when I try to write with a pencil using this new superior style—disaster! The eraser wears out long before the pencil needs sharpening. Most people who use cognition enhancers experience the same unconscious shift in style.

Shifts in Occupational Skills

In a world of empowering environments, the ways we accomplish tasks will alter. The global marketplace will drive this evolution; in this new economic "ecology," each nation is seeking a specialized niche based on its financial, human, and natural resources. Developed countries, which no longer have easily available natural resources and cheap labor, cannot compete with developing nations in manufacturing industrial commodities (President's Commission on Industrial Competitiveness 1985). Instead, nations with technological expertise, an advanced industrial base, and an educated citizenry are developing economies that use sophisticated workers and information tools to create products tailored to individual consumers' needs (Reich 1988). For example, we now try to match our stylistic preferences and the shape of our feet to the prepackaged shoes in a store; in a decade, a shoe store may have lasers to measure our feet, videodisc images from which to select styles and colors, and assembly machines to make customized shoes while we wait.

One way of understanding the impact of these changes on occupational skills is to contrast how information technology has changed the job roles of the supermarket checker and the typist. Many supermarkets now have bar code readers; rather than finding the price on each item and punching it into the register, the checker need only pass the goods over the scanner. Efficiency and productivity have increased, and the job requires fewer skills.

In contrast, substituting a word processor/information networking device for a typewriter completely alters a secretary's function. To use the information tool to its full capability, the clerical role must shift from "keyboarding" to using database, desktop publishing, communications, and graphics applications. The job now demands higher-order cognitive skills to extract and tailor knowledge from the huge information capacity of the tool, and the occupational role shifts to the new profession of "information manager."

As workstations become more intelligent through embedded coaches and expert decision-aids, the thinking skills required of the human role in the partnership become more sophisticated. Creativity and flexibility become vital, because the standardized aspects of problem-solving skills are absorbed by the machine. However, technology is no panacea; overautomation and excessive reliance on assembly-line metaphors can deskill work and produce job dissatisfaction (Kraft 1987). Moreover, as the routine parts of work are automated, a greater proportion of decisions will require stressful ethical choices.

Computers and people have complementary intellectual strengths; each can supply what the other lacks. How-

New technologies, like these erasable optical data disks, are changing the way we work and learn.

ever, the possible future described above is not meant to imply that this transformation of work will be inevitable or universal. On the contrary, advanced technology eliminates jobs as well as creating them; and, in an automated workplace, many of the occupations that survive may require only low-level skills (Rumberger 1987). In every developed nation, significant uncertainty exists about fundamental questions such as:

- How many jobs will be available in the early part of the next century?
- What will be the mix of skilled and unskilled positions?
- Will sufficient "middle class" occupations be available to prevent a polarization of wealth in society, or will most such jobs be deskilled by intelligent machines?
- How will these technological and economic shifts affect equity?

A reasonable assumption is that, during the next decade, developed countries' economies will evolve so as to generate some knowledge-added occupational roles and many lower-skill jobs. Eventually, however, if the majority of the population is to have interesting, well-paid work roles, educators must help shape the needs of the emerging workplace rather than merely respond to present trends (Levin and Rumberger 1987).

Implications for Curriculum Design and Content

As the American workplace begins to use intelligent devices, the goals, content, and clients of education will alter (Office of Technology Assessment 1988a). The impact of knowledge bases on the content and design of the school curriculum will be profound. To illustrate, here are some potential effects of the widespread use of cognition enhancers (Dede 1988b):

- Human strengths in partnerships between people and cognition enhancers include skills such as creativity, flexibility, decision making with incomplete data, complex pattern recognition, information evaluation/synthesis, and holistic thinking. These higher-order mental attributes might become our new definition of human intelligence, as basic cognitive skills increasingly shift to the tool's portion of the partnership.
- Methods of assessment will alter from measuring mastery of descriptive knowledge to evaluating attainment of higher-order skills. Developing technological methods for collecting and analyzing detailed performance data could greatly improve the assessment of individual learning needs (Office of Technology Assessment 1988b). For example, we could easily collect the exact hesitation time a student took before each problem-solving step in learning subtraction; this could be valuable diagnostic information.
- "Learning-while-doing" will become a more significant component of occupational education, as combined computer and telecommunications technologies allow delivery of instructional services in a decentralized manner. To allow credit for job-based learning, workers' tools may include intelligent devices that act as job performance aids while simultaneously collecting a cognitive audit trail of user skill improvements. For example, a student in a technical writing course could write all week at work on a word processor, then bring a record of his or her performance to class. The instructor could monitor how the student was writing by scanning his or her actions (deletions, revisions, resequencing), looking for patterns of suboptimal performance and evaluating the learner's writing process.[1]
- As the workplace shifts to an emphasis on group task performance and problem solving, collaborative learning will become more important. Information technology tools may increasingly be designed for use by teams rather than individuals working in isolation (Gorry et al. 1988), and new types of interpersonal skills will be needed for occupational roles in which computer-mediated communication is important (Kiesler et al. 1984). In such an economic environment, adults who lack sophisticated experiences in shared machine-enhanced interaction may be at a disadvantage (Reder and Schwab 1988). Students in conventional classroom settings have few opportunities to build skills of cooperation, compromise, and group decision making; shifts in teaching must occur so that computer-supported collaborative learning becomes a major type of student interaction.
- Interlinked "educational information utilities" that supply access to a variety of data, tools, and training might emerge (Dede 1985). For example, a device may soon be marketed that combines the attributes of the

telephone, radio, television, videotape, computer, copier, and printing press. If I heard an item of interest while watching the nightly news, pushing a function key could output articles on that topic from major newspapers. Scanning those might produce keywords of interest; another keystroke would trigger a knowledge base search. From the list of articles that resulted, I might identify the name of a researcher active in this field; yet another command would dial that person's work number. If no one answered, a final keystroke could send an electronic mail message. All this integration may seem merely a gain in speed, but from that perspective the airplane is "just" a faster version of the automobile. Such a device could be inexpensively accessible to a wide range of users, altering the curriculum by shifting emphasis from acquiring data to discussing and synthesizing ideas.

- As discussed earlier, hypermedia would enable a long-standing instructional goal: an integrated curriculum. In a hypertextbook series, the math "book" would contain links to materials in social studies, biology, history, language arts, and physical education. The important interrelationships among different subject areas could be explicitly represented through concept maps; students could modify these webs of linkages to help them learn (Yankelovitch et al. 1985). The curriculum could shift from a subject-centered, disciplinary emphasis to a focus on real-world problem solving using perspectives and tools from multiple fields.

Using Tools Wisely

Some claim that technological advances are driving the emergence of a new era: industrial society is being replaced by a civilization based on knowledge processing. Others disagree that the industrial economy is ending but do see many occupational shifts as people implement new information technologies to aid in their work.

The implications for the school curriculum and instructional practice could be profound: a new definition of human intelligence, more sophisticated methods of assessment, decentralization of teaching into workplace settings, a greater emphasis on collaborative learning, a curricular shift from presenting data to evaluating and synthesizing ideas, a focus on solving real-world problems using concepts and skills from multiple subject areas. The most important barriers to this evolution will not be technical or economic but conceptual and organizational; and, unless controlled, the outcome of these changes may be undesirable. We must begin shaping the use of these emerging tools now if we are to have a bright educational future.□

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[1] For the interested reader, I have written detailed, annotated scenarios of sophisticated "learning-while-doing" task performance aids: an intelligent tutor and coach (Dede 1987a) and a computer-supported cooperative learning environment (Dede 1988a).

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