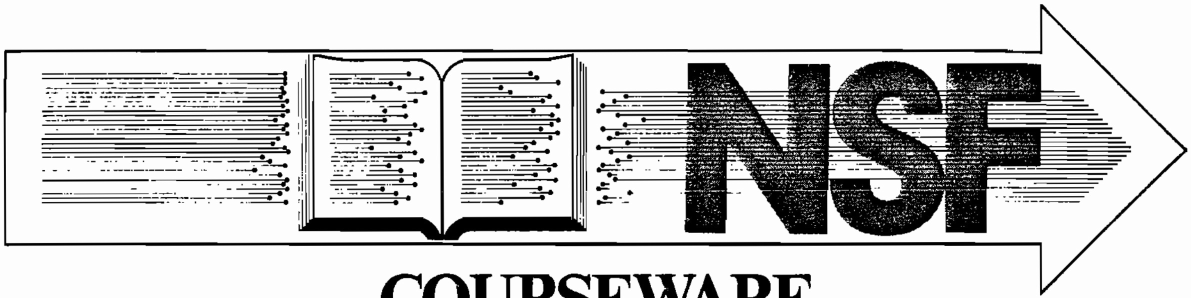
With projected prices of courseware surpassing those of hardware, the NSF must promote software transportability if computer-based instruction is to gain widespread implementation.



COURSEWARE DEVELOPMENT AND THE NSF

Jesse M. Heines
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After reading a prepublication copy of the preceding article, Jesse M. Heines wrote author Joseph I. Lipson, expressing his reservations. Finding Heines's arguments cogent and well-documented, Lipson encouraged him to discuss them with one of the guest editors for this issue, Robert M. Aiken. The result is the following short article. We thank Lipson for encouraging and supporting this contribution, and we appreciate Heines's preparing the article under a very tight deadline.

—Ed.

In the preceding article, "Technology in Science Education: The Next 10 Years," Joseph I. Lipson of the National Science Foundation offers his perceptions of future developments in information technology. He makes several recommendations for taking advantage of these developments to positively influence the future of science education. I have some strong reservations about Lipson's perceptions, especially those about costs. In addition, I feel that some of his recommendations are hollow without a substantial change in NSF policy to assure the transportability of the courseware that Lipson proposes to fund. Here, I explain my points of contention, beginning with a detailed discussion of the cost of courseware development.

The cost of courseware

The biggest problem with Lipson's projections is his assumption in the third paragraph that "the per-pupil-per-year cost (to the school) of acquiring software will be small compared to the cost of supplying the hardware." As manager of a professional computer-based courseware development group, I would project that just the opposite might be true. That is, the cost of acquiring software and courseware will soon be a more significant expense to schools than the cost of acquiring hardware.

Let us analyze these costs further, building on the numbers that Lipson uses in his hardware analysis. He states that "each student should interact with a computer at least 15 minutes per day." In a 180-day school year, that amounts to 2700 minutes of interaction per student per year, or 45 hours of on-line instruction. Note that this 45 hours is only for straight instruction, not branched learning. Some may argue that branched learning, because of the repetitive nature of remediation, would decrease the number of instructional hours needed. But I would argue that branched learning more likely would increase the number of hours, because of the overhead of providing alternative learning paths. So let's compromise and use 45 instructional hours as our basis for further discussion.

How long will it take? The bulk of the literature on courseware development reports that it takes 50-150 hours to develop each hour of on-line instruction. Many newly formed courseware development groups, however, will find that the ratio is closer to 300:1 or even 400:1 until they gain experience and refine their tools and programming aids.

Another major management factor must be considered in a course development project of this scope: man-month productivity is an inverse function of a project's size. That is, the more programmers one puts on a job, the lower the productivity of each individual. In his book *The Mythical Man-Month,* Frederick P. Brook, Jr., reports several studies supporting this statement. One such study found that programmers working alone on projects that require "very few [interpersonal] interactions" can produce about 10,000 deliverable machine instructions in a year. However, when a project becomes large enough to require 25 programmers and "many interactions," productivity can drop as low as 1500 deliverable machine instructions per programmer per year. Brook claims that this drop is caused by the need for communication between the programmers. On large projects their work must be coordinated through meetings, reports, and so on; consequently, a huge amount of productive time is lost. It follows that in a large course development project, this inverse correlation will work to increase the ratio of developmental hours to instructional hours.

As a courseware development group's experience grows, two other forces will also act to increase that ratio: the desire to improve the human engineering of the students' computer environment by programming more capabilities into the courseware and the desire to develop additional materials and documentation to help teachers integrate the courseware into their curricula. Given today's economic picture, I expect that most professional courseware development groups will have to get their ratios down to at least 100:1 if they are going to be successful, but I doubt they will get very far below that and still maintain quality standards. So let's use this 100:1 ratio for further argument.

How much will it cost? What do 100 hours of professional course development cost? At present, a realistic estimate of the cost of course development in an industrial environment (given the overhead costs that exist in all companies) is $35 per man-hour. Unlike that of computer hardware, this cost will surely go up. I estimate that it will move closer to $40 per man-hour in the next two years.

This cost increase will occur primarily because course development is a labor intensive activity and does not respond significantly to advances in technology. Double-digit inflation will drive labor costs higher and higher, no matter how many gates we manage to squeeze on a chip. To support this argument, I draw the reader's attention to the recent price increases announced by the major computer manufacturers since January 1980: hardware prices generally rose 5-10 percent, while software prices generally rose 15-20 percent. The reason for this differential is that much of hardware manufacturing can be automated and made more efficient with new technologies, while software development and support, like course development, remain labor intensive activities.

A possible additional cost should be mentioned: the cost of developing and producing course materials on videodisks will be two or three times the figures quoted above, due to the large numbers of people needed to do the production. In support of this argument, I ask readers to count the number of people listed in the credits after their favorite television programs.

The man-hour rates discussed above are the *actual* costs to a company for developing courseware. They do *not* include profit. When a company develops courseware on contract for customers, the prices must be marked up for two basic reasons.

First, course development requires a very high front-end investment, and return on this investment is not usually seen for two or three years. With today's high cost of capital due to inflated interest rates, pricing must be based on the concept of a "discounted cash flow." That is, one dollar is worth more today than it will be tomorrow. For this reason alone, a product might have to be marked up 100 percent to realize a 20 percent profit (before taxes) in three years.

Second, prices are marked up to allow for contingencies. Not all products reach their market volume goals. When they fall short, the company loses money; obviously if this trend continues for any length of time, the company goes out of business. The price markup helps to insure against such loss.

What's the bottom line? We are now ready to calculate the cost of developing the computer-based instruction materials that we will need to provide 15 minutes of interaction per student per day.

15 min/day × 180 days/yr = 45 instructional hrs/yr
45 inst hrs × 100 development hrs/inst hr = 4500 dev hrs
4500 dev hrs × $35/dev hr = $157.5K

This is the cost of developing the CBI material needed for a single grade level for one year. This $157.5K includes labor, fringe benefits, computer time, etc. It does not include final production, distribution, and marketing. These costs, especially national marketing, could easily total another $100-200K. For the sake of argument, let's use a figure of $142.5K so that the figure rounds nicely to $300K as the actual cost to a corporation to develop, produce, market, and distribute the 45 hours of instruction that Lipson recommends. I believe that $300K is extremely conservative, but it will suffice to make my point.

But we're not finished—we have to mark up the actual cost to provide a profit margin as discussed above. Markups typically run around 100-200 percent, but let's be very conservative and place ours at 100 percent or $300K, so that the company has enough money to at least partially fund the next development cycle. That makes a round total of $600K that the company would like to gross during the life of the product.

But what's the cost to a school? In determining the school's cost of acquiring this courseware, we have to estimate the size of the potential market and the life of the product. This is a tricky business. First, we certainly know that one copy of the materials will be used to train more than one student because the programs themselves are nonconsumable. In addition, even though all software that I know of is sold as a single CPU license, it is virtually impossible to stop schools from copying the software and using it on multiple systems, particularly where microcomputers are involved. Both of these factors tend to depress the market very sharply. I therefore feel that pricing would have to be set on an estimate that not more than 1000 copies of the courseware would be sold. The life of the product may be even more difficult to estimate. For the sake of argument, let's call it five years because this is the time over which Lipson proposes to amortize the hardware.

Thus, the price per copy will be around $600, which, when spread over 20 students (the number who could use the computer for 15 minutes each in one five-hour school day) and amortized over five years, yields a cost to a school of $6 per student per year. This cost is definitely not small compared to Lipson's estimate of $10 per student per year for the hardware. Even if my figures are off by 100 percent, the cost of $3 per student per year is still very significant. But I believe that my estimates are conservative and that in the next 10 years we will see the cost of professional courseware actually exceed the cost of hardware.

A critique of Lipson's recommendations

Recommendation 1. In regard to "Unique and accepted government functions," I have a question: Does the setting of standards to foster transportability fall within the NSF's domain? Or does the NSF believe that standards will stifle their grantees' research rights? I feel that the NSF's unwillingness to use its influence to encourage the transportability of materials developed with federal funds is appalling. Millions of dollars were pumped into PLATO and TICCIT, but the number of programs written for one system that could be easily translated to run on the other can probably be counted on the fingers of one hand.

I feel that the NSF's unwillingness to use its influence to encourage the transportability of materials developed with federal funds is appalling.

Recommendation 3. The array of projects currently sponsored by the NSF continues to be the epitome of "the right hand not knowing what the left hand is doing" syndrome. Frankly, I find it hard to believe that Lipson wrote the paragraph under "Recommendation 3: Dissemination" without mentioning this issue. It is useless for the foundation to "develop programs to prepare teachers to use the new technologies in science education. . . and participate in the development of the educational uses of the new technologies" without setting standards for the materials to be developed.

Recommendation 5. As to "Breaking the software and course materials bottleneck," I firmly believe that the key bottleneck is not, as Lipson says, "The lack of excellent course materials and software. . . ." The Huntington Project materials are excellent—far-ranging and well-documented—and have been around for longer than 10 years. The bottleneck is transportability, plain and simple. If any company could develop software that would run on every computer, I, for one, would be glad to buy its stock, because its potential market would be incredible.

Lipson accurately identifies the chicken and the egg problem of developing markets and attracting industry investment. However, I have mixed feelings about his desire for the NSF to do the "pump priming" necessary to develop potential markets. This has to be done very selectively or we will only prolong the current state of the art as a cottage industry—everyone doing his own thing. That is the antithesis of my plea for transportability. I have heard PLATO referred to as "a hardware dinosaur" and "a software albatross," but its critics must give it credit for being large enough to provide the "critical mass" needed to develop many hours of coordinated, transportable courseware. (I believe that if Control Data, distributor of the current PLATO system, can flow with the microcomputer tide, the company can come out on top because it still has much of the best courseware available.)

So when the NSF selects projects to be funded, I suggest that it choose those large enough to make a significant contribution to the overall market, and that it insist that the courseware developed be produced in multiple formats, which can be transported directly (i.e., "immediately," not "easily" or "with minor revisions") to all major systems currently in use in our schools.

Courseware quality and the role of teachers

So far, I have assumed that the courseware to be developed will be similar in quality to materials available today. But this level of quality may not be high enough to meet the needs of our society. In fact, what we need is a level of quality that can compete directly with commercial television for our students' time.

We have the instructional media and computer technology to accomplish this goal. What we lack is the front-end investment to develop the product and the time to cultivate market acceptance. Teachers still see this technology as a threat to their jobs. Rather than soliciting their help in solving the relevant educational problems, we have alienated them needlessly by implying that computer-based instruction will eliminate the need for their services. This is simply untrue. Teachers are needed to develop and produce new, better, instructional materials. The process of wide-scale implementation of computer-based instruction is evolution, not revolution. ■

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Federal activity in key areas can help ensure the successful application of the microcomputer and the videodisk to science education.

TECHNOLOGY IN SCIENCE EDUCATION: THE NEXT 10 YEARS

Joseph I. Lipson
National Science Foundation

In 1978 the Science Education Directorate of the National Science Foundation convened a conference to set policy for its activities in applying information technology to science education. This article is a distillation of the ideas and advice offered by the participants—those interested in more detailed arguments should consult the participants' papers, collected in "Technology in Science Education: The Next Ten Years—Perspectives and Recommendations."[26]

Probable developments

J.C.R. Licklider[13] of the Massachusetts Institute of Technology dealt with possible future developments and the impact of technology on society and science education. The increase in computational power and memory for a fixed price has been approximately exponential over time. Cost-effectiveness doubles every two years—this means, for example, that the cost-effectiveness of computing has increased by a factor of more than a million since World War II. It seems likely that this doubling will continue through the 1980's. One crucial factor has been the astonishing increase in the number of active elements on a single silicon chip. Such developments are moving us rapidly into the information age, and, as a result of this transition, the use of information technology is flourishing everywhere except in the field of education. Education is not just missing an opportunity; it is failing to discharge a crucial responsibility.

Because computer cost-effectiveness will double every two years, educators who wish to use computers in science education should plan for end-of-the-decade devices that will be about 30 times more powerful than their equivalents today. If we can find ways to allocate to computer hardware and software a small but not negligible fraction of our educational budget (say between 10 and 50 dollars per year per student), we would have an adequate base for sophisticated educational applications. The figure of $10 per student per year is calculated by assuming that each student should interact with a computer at least 15 minutes per day. This means that a single computer terminal can handle about 20 students in a five-hour school day. If we assume that a microcomputer costs $200 per year including maintenance, we divide $200 by 20 and arrive at $10 per student per year. I derived the $200-per-year figure by amortizing a $1000 microcomputer over a five-year period and assuming that the amortization schedule includes maintenance. This calculation also assumes that the per-pupil-per-year cost (to the school) of acquiring software will be small compared to the cost of supplying the hardware. Differing views about these costs would yield differing final figures, of course.

The videodisk represents an important companion technology for educational computer applications. In effect, it provides a huge (read only) memory capability. A single videodisk can store 108,000 television picture frames. The frames can be considered as independent color pictures (i.e., a collection of slides) or as elements of a motion picture sequence. If the 108,000 frames are run as a motion sequence, the disk can store a one-hour motion picture. The two modes can also be mixed; i.e., one can have a mixture of "still frames" and motion sequences. The cost per frame for videodisk systems is about 100 times cheaper than printing.[13] Thus, the economics of the videodisk for educational publishing should become attractive during this decade.[8,10,18]

Even more exciting is the idea of the intelligent videodisk, i.e., a computer combined with a videodisk. The logical capability of such a device may make possible interactive lessons combining

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color, motion, animation, line drawings, multiple sound messages, computer modified graphics, and other creative elements. The question is whether humans whose creative patterns are based on the limitations of existing media can respond to the new opportunity.

Using information technology to improve science education

The promise of advanced technology stems not merely from its cost-effectiveness, but also from the opportunities it provides to improve the *quality* of education. The following are but a few of the ways new technologies can augment the educational environment:

Computer-conducted drill and practice. The most prosaic application, drill and practice, can ensure that all students develop the basic tools needed for more complex intellectual skills such as comprehension and problem solving.

Computer-assisted instruction. The widespread availability of powerful stand-alone computers at low cost has renewed interest in CAI. The availability of new programming languages, the videodisk, a deeper understanding of the learning process, and an understanding of the limitations of computers should permit us to integrate CAI into the classroom and possibly the home.

The computer can foster the learning of ideas that are otherwise difficult to comprehend.

Computer-managed instruction. It is probable that management uses will be integrated with educational uses; i.e., computers will help select lessons, schedule presentations, assess student achievement, and maintain records (especially diagnostic profiles).

Fully computerized instruction. As long as we acknowledge human conversation as an important element of instruction, fully computerized instruction will have a useful role primarily for isolated students, for courses with no available instructor, and for large courses that require a high degree of individual progress.

Computer-assisted problem solving. Many thousands of college and high school students use computers to solve science-related problems. The increasing use of computers by younger students will significantly change the character of early education. By eliminating the drudgery of numerical calculations and by facilitating correction and editing of results, the computer will allow students and teachers to focus on the synthesis of ideas and skills that leads to the solution of problems.

Computer-assisted concept understanding. The computer can foster the discovery and organization of ideas. Through computers students can interact creatively with and model certain classes of ideas that otherwise are difficult to learn.

A "dynamic library." A learning environment based on information technology can give the student a broad scope for exploration and initiative. Emphasizing the student's initiative rather than the teacher's, the computer can provide a dynamic library that the student can explore according to his own interests. Information on almost any subject can be called up, manipulated, and modified.

Such a dynamic library, if it is to transform education, will require a major advance in the representation of knowledge. Thus, the way the computer encourages us to explore the representation of concepts may be as important to education as the computer itself.

Simulation. The computer can give the student "worlds to explore" and become skilled in. The prime example of such real-world simulation is the computer-based aircraft simulator, which, although very expensive, is also very cost-effective. We are now learning whether such gaming and simulation can develop knowledge as well as cognitive and psychomotor skills.

Learning by teaching via the computer. Teachers often observe that they did not really understand a subject until they had to teach it. By having students prepare computer-based tutorial programs, we can add new dimensions to the educational process.

Learning by teaching computers. By writing computer programs that permit the computer to process certain kinds of information (e.g., whether a chemical compound can be formed under certain conditions), the student in effect teaches the computer. Such programming requires precision of thought and understanding of the information to be handled—abilities that should be valuable in themselves.

Every pervasive and powerful technology transforms society and the individuals in that society. Because we do not fully understand the sources of human behavior, we may be unable to direct the way technology will change us. Once a new technology such as television is widespread, it is almost impossible to alter the system to undo the damage of prior decisions. For example, the tendency to develop computer products that deliver a quick profit (e.g., certain kinds of electronic games) may contaminate the potential of computers in education. Low-quality software that does trivial or undesirable things efficiently may give computers a bad reputation and destroy interest and investment in more creative applications.

Fundamental research in technology applied to science education

As the list above shows, there are great potential benefits—and dangers—in using computers in science education. Viewing such benefits and dangers, John Seely Brown[3] of the Xerox Palo Alto Research Center argues that there is a need for basic research that combines the study of educational technology with the discipline of cognitive science. We need to make explicit what is meant by such ideas as "understanding," "common sense reasoning," and "tacit and intuitive knowledge." What is the difference between the way the novice organizes and uses knowledge and the way the expert does it, when each is faced by a similar problem or task? How does one's world view affect the way a decision or problem is attacked? In order to build a computer-based learning environment that is appealing, significant, and effective, we need cognitive theories (i.e., theories of complex human thinking) that have a degree of completeness, precision, and specificity unprecedented in psychology and educational theory. Thus, the attempt to build a computer-based learning environment forces us, first, to be serious about cognitive theories, and second, to use the learning environments we develop as test-beds for the theories.

Brown says:

> Such educational systems require a complete representation of all the tacit knowledge required to perform a skill, together with a cognitive theory of how this knowledge is learned, stored, and distorted. With such a representation it is possible to build an automatic tutorial assistant that can construct an accurate diagnostic model of a student's underlying misconceptions from the symptoms manifested in his work. The same technique can be used to construct adaptive tests that can differentially diagnose a student's misconceptions in optimal fashion. While we have the necessary representations for arithmetic skills, representations for even slight extensions, such as fractions or high school algebra, are still incomplete. Thus, a great deal more cognitive research is needed for modeling even the relatively well-understood and formal domains of mathematics and the physical sciences. However, with the right kind of research, the forthcoming models can yield substantial payoffs in education.

Technological research issues. If we are to use computers effectively, they must operate in various ways—sometimes simulating a human tutor, other times simulating a physical situation. Much human conversation and teaching is possible because people share, to a degree, a world view. We know what an isolated sentence means because of the relationships of its words one to another and because of our general understanding of the world. Because the computer has no world view, interaction with it often frustrates the student. The computer has no way to infer that a statement by a student is correct if it is not the statement programmed as correct. Humans make such adjustments easily. Moreover, when people do not share some aspect of their world views, they can talk with one another and clarify the similarities and differences. They can accommodate their models of how the world works to the models of others.

How can we give computers enough of a world view in a particular subject like physics or chemistry so that the student can learn by "talking" with the computer? What kind of activities and tools can we embed in the computer to allow the student to extend his knowledge and skills and possibly even modify the programs?

People learn many of the properties of the world by active exploration—by "learning the territory." How can we provide hypothetical "microworlds" that students can explore to gain skills in areas such as logic, statistics, and social dynamics? Such microworlds can teach things as they are and even as they could be—the student can create his own world based on his model of how things work or find out how the world would be if some law were systematically modified.

Methodological considerations. In developing a computer-based learning environment, the research scientist needs to be able to modify programs, presentation modes, languages, etc. In addition, since research and development take place over time and since computers are evolving so quickly, the developer should aim for a final device that is quite different from anything available when the project starts.

Projects should not be forced to prove educational effectiveness prematurely. In the early stages of an idea, it is more important to use formative evaluation to understand the underlying strengths and weaknesses of a given approach. As Brown states, ". . . just as one worries about cost-effective instruction, one must also worry about research environments that foster cost-effective mistakes!"

Programming will probably become the fourth "R."

New Content. As computers become more embedded in the workings of society, computer literacy and computer competence will become important elements of the curriculum. Programming will probably become the fourth "R," after reading, writing, and arithmetic. The concepts of processes, information processors, programming, and debugging can become powerful analogies for thinking about human thinking and learning. More important, as noted above, the enhancement of human thinking by computers implies that we can teach subjects, new as well as old, that would have been impossible to consider previously. The computer raises once again the curriculum question: What knowledge is most worth having and when should it be taught?[18]

Technology and the US educational system

Arthur Luehrmann of the Lawrence Hall of Science, University of California, Berkeley, suggests that there is a fundamental incompatibility between the US educational system and most proposed educational technology systems.[14] People in school systems view educational technology as a threat rather than as a way to improve the quality of the learning environment. Hence, we need to explore ways of introducing educational computing through nonschool institutions such as the home, the museum, the library, and the work place, and we must devise an effective and nonthreatening technology for school use.

To fit the present environment of declining enrollments, any process of change should expect to accomplish its goals through in-service training of a somewhat stable teacher population, by using technology to help schools teach basic skills that can be applied and used in more advanced study, and by using technology to deal with the increasing need for individualized instruction. In addition, computer-based education can find acceptance in the growing market for adult retraining and lifelong learning.

The small, low-cost, intelligent videodisk is flexible and unthreatening enough to be compatible with the present character of teachers and schools. However, past projects have overlooked one dimension that could promote CAI's entry into and use by schools. The widespread use of computers, as noted above, will generate a computer-related curriculum since schools will increasingly feel the need to offer one. This computer curriculum requires basic computer education, vocational and professional training in computer skills, and teacher training.

The computer may not be seen as a threat in certain situations: remedial instruction, computer management of class records, and the special instructional arrangements needed for the mainstreaming of handicapped students.

Needed research and development. To accomplish these goals Luehrmann calls for work in five areas of research and development:

- Basic computer skills curricula.
- In-service training of teachers, so that they can teach the computer skills curricula and use the computer in teaching science, math, and other subjects.
- Creation of curriculum development centers to help establish a critical mass of talented people. Such centers would need daily access to students, as well as mechanisms such as visiting appointments to assure a steady flow of creative professionals who would return to their home institutions and promote change.
- Model community learning centers that employ computer-based learning systems.
- Intelligent videodisk personal learning systems. While several government and nongovernment projects are working on this, much work needs to be done on engineering problems, authoring systems, and distribution systems. Only then would major courseware development for the intelligent videodisk be justified.

Recommendations

Federal activity may be justified in a number of areas:

- Videodisks. The advent of the videodisk justifies a new round of research and development in the field of computer-based videodisk technology.
- Basic philosophy. New developments in cognitive science in particular, and science education research in general, suggest that we can avoid the mistakes of past simplistic applications of computers to education.
- Computer literacy. The economic position of the United States requires a computer-literate population, a work-force skilled in the use of computers, and teams of talented computer professionals in both academic and nonacademic organizations. In addition, the computer can improve productivity by contributing to the general level of educational attainment.
- Access for all groups. Unless computer literacy and skills are taught to minority and other academically disadvantaged students, the nation's drive for educational equality cannot be realized. The jobs of the future will go increasingly to those who have computer skills. The rich already have access to computers. Unless such access is provided to the poor, the educational gap will widen.
- Computer-enhanced learning. Such assistance can contribute to improved motivation and amplify the teacher's ability to offer individualized instruction to those most needing such attention.

To promote orderly and cost-effective development in these areas, the conference made the recommendations below. They can be considered as items appropriate for federal and NSF action.

Recommendation 1: Unique and accepted government functions. There are a variety of activities and functions expected of the federal government. If properly organized, activities such as the following can facilitate the development of the new information technologies:

- Setting telecommunications policy (e.g., hardware standards, copyright laws for software, patent laws, tax incentives and tax funds targeted for curriculum development) to encourage the development and use of new technologies for educational purposes.
- Stimulating the creation of a new industrial and commercial market through government purchasing decisions, equipment support to schools,

use of new technologies in government training programs, etc.

- Undertaking an assessment of the impact of new technologies on the individual, society, education, and our position in the world community.
- Periodically measuring the state of science education.
- Working with educational agencies to properly accredit the achievements of students who use new technologies in novel ways.

Recommendation 2: New talent. The lack of special academic, artistic, and instructional design talent to exploit new displays and systems will limit their application in educational settings. It has been observed repeatedly that technology has outrun our imagination and skill in using it. For this reason, the NSF should continue its programs to develop the new talent needed to capitalize on the science education potential of information technology.

Recommendation 3: Dissemination. In order to assure the timely, widespread, and proper use of new technologies, including new course materials, the federal government should assist in the dissemination of information about them. As part of a general federal dissemination effort, the NSF should develop programs to prepare teachers to use the new technologies in science education, teach computer skills to students, and participate in the development of the educational uses of the new technologies. The teacher preparation effort should be coupled to a program of support for the purchase of computers for schools. Experiments and demonstrations with microcomputers, and with new imaging devices such as videocassette and videodisk players, will serve an important dissemination function.

Recommendation 4: An informed public. Only with an informed public can the nation move into the computer age with the speed and sense of purpose required. The adoption of a new technology as far-reaching as the computer technology is an incredibly complex task. Almost every stage involves public attitudes and understanding. Investments, markets, legislative positions, enrollments in courses, and selections of careers will all vary with public awareness and knowledge.

We recommend that the foundation, in cooperation with other federal agencies, initiate a program using the mass media to alert the public to the issues. In addition, specialized media to reach specific audiences should be used.

Recommendation 5: Breaking the software and course materials bottleneck. The lack of excellent course materials and software will hinder the application of computers to science education. Moreover, this lack will slow the development of hardware designed for educational applications, since hardware manufacturers will be reluctant to develop models with educational features unless there are excellent course materials to attract buyers. Conversely, publishers will not invest in the development of materials unless there is an established market for school-oriented hardware. Thus, federal support of software and courseware development will act as a catalyst for commercial development. After a period of pump priming, the commercial sector should be able to take over.

We must break the software and courseware bottleneck.

We recommend that the federal government support the development of innovative materials that allow for future trends in information technology. Anticipation of future trends is critical, since the field moves so rapidly that projects based only on present capabilities can be obsolete by the time they are completed. We also recommend that the government facilitate the authoring and production of educational materials. Specific projects in this area include prototype science course materials, special authoring facilities that utilize computer simulation, electronic editing and production facilities, and prototype student environments incorporating state-of-the-art technology.

Recommendation 6: The research challenge. Our concept of how the person acquires knowledge, understanding, and skill is too limited to allow us to fully exploit today's technology. Systems have outrun existing theories about human learning and human interaction with computer-based environments. Thus, we recommend a broad, sustained attack on urgent research questions by the foundation and by other agencies.

Recommendation 7: Equipment support. A program supporting the placement of microcomputer technology in the classroom will complement the research, development, and dissemination programs recommended above. In addition, equipment demonstration during the early phases of a project can generate valuable feedback about the innovation involved, as well as serve as a compelling demonstration to educators everywhere. Luehrmann has suggested that computer power in the schools be considered a utility like water or electricity. We recommend that the federal government support the carefully controlled introduction of microcomputers into the schools. Such a program is needed to assure the strength and leadership of the United States in the computer industry. Any program of equipment support must involve teachers trained in and committed to the use of the equipment. Support to each school should provide enough microcomputers to serve an entire class at a time.

The recommendations above were developed not as definitive solutions to the problems of the next 10 years, but as a basis for a continuing dialogue. Comments and suggestions are welcome. ■

Acknowledgments

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