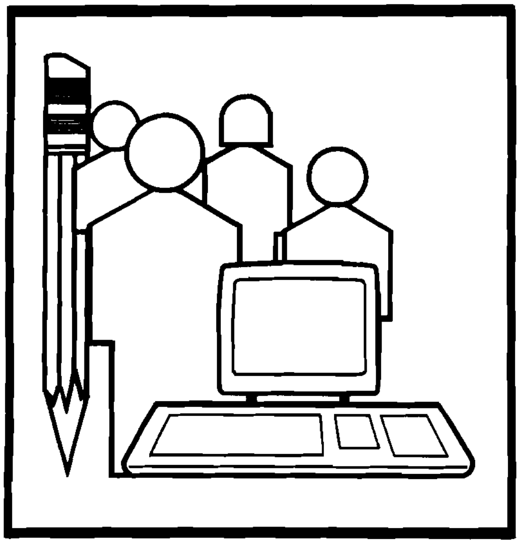

TECHNICAL REPORT

COURSEWARE DEVELOPMENT AND THE NSF

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COURSEWARE DEVELOPMENT AND THE NSF

A commentary on Dr. Joseph Lipson's perceptions of "Technology in Science Education: The Next Ten Years"

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ABSTRACT

Dr. Joseph I. Lipson has made several recommendations for the use of National Science Foundation (NSF) funds to take advantage of developments of information technology in the field of education. These recommendations are based on several assumptions, one of which deals with the cost of courseware. In this area, the author feels that Dr. Lipson's assumptions are incorrect. In the areas covered by some of Dr. Lipson's specific recommendations, the author feels that Dr. Lipson's proposed policies overlook some of the basic needs of the educational field, most importantly the need for transportability. This paper enumerates the reasons for the author's disagreements with Dr. Lipson. [A copy of Dr. Lipson's original article is included in this Technical Report.]

This paper was published in the July 1980 issue of <u>Computer</u> magazine.

Elsewhere in this issue Dr. Joseph I. Lipson of the National Science Foundation offers his perceptions of future developments in information technology. [Dr. Lipson's article is included in this Technical Report.] He then makes several recommendations for taking advantage of these developments to positively influence the future of science education. I have some strong reservations about Dr. Lipson's perceptions, especially those that deal with 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 Dr. Lipson proposes to fund. This paper enumerates my points of contention, beginning with a detailed discussion of the cost of courseware development.

THE COST OF COURSEWARE

The biggest problem with Dr. 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 this further building on the numbers that Dr. Lipson used in his hardware analysis. Dr. Lipson stated that "each student should have at least 15 minutes per day interacting with a computer". In a 180 day school year, this translates 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 would decrease the number of instructional hours needed due to the repetitive nature of remediation. I would argue that branched learning would more likely increase the number of hours due to the overhead involved in 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 project management factor must also 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 quotes several studies which show that this fact will work to increase the ratio of development hours to instructional hours. One such study, as reported by Brook, 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, and subsequently a huge amount of productive time is "lost".

As a courseware development group's experience grows, two other forces will also act to increase the ratio of hours of development to hours of instruction: the desire to program more capabilities to improve the human engineering of the students' computer environment, and the desire to develop additional teacher support materials and documentation ,to make it easier for teachers to 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 the cost of computer hardware, this number will surely go up. I estimate that it will be closer to $40 per man-hour in the next two years.

These cost increases are due primarily to the fact that course development is a labor intensive activity and production does not respond significantly to advances in technology. Double digit inflation will quickly 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%, while software prices generally rose 15-20%. 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, continue to remain labor intensive activities.

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 external customers, the prices must be marked up for two basic reasons.

The first reason is that course development requires a very high front end investment, and return on this investment is not usually seen for two to 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, $1 is worth more today than it will be tomorrow. For this reason alone, a product might have to be marked up 100% to realize a 20% profit (before taxes) in three years.

The second reason that prices are marked up is to allow for contingencies. Not all products reach their market volume goals. When they fall short, the company loses money and obviously if this trend continues for any length of time the company goes out of business. The reader should also realize that the cost of developing and producing course materials for video disks 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 involved as they watch the credits roll after their favorite television programs.

What's the Bottom Line?

We are now ready to calculate the cost of developing the computer-based instruction (CBI) materials that we will need for providing 15 minutes of interaction per student per day.

15 min/day x 180 days/yr = 45 instructional hrs/yr
45 inst hrs x 100 development hrs/inst hr = 4500 dev hrs
4500 dev hrs x $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. Let's use a figure of $142.5K so that the figure rounds nicely to $300K for the sake of argument as the actual cost to a corporation to develop, produce, market, and distribute the 45 hours of instruction that Dr. Lipson recommends. I personally believe that this $300K figure is extremely conservative, but it will suffice to make my point.

But we're not finished: we have to mark up the actual costs to provide a profit margin as discussed above. Mark ups typically run around 100-200%, but let's be very conservative and place our mark up at 100% ($300K) so that we have enough money to at least partially fund the next development cycle and to make another 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 cost to the school 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 non-consumable. 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 Dr. Lipson proposes to amortize the hardware.

This makes the price per copy around $600 which, when spread over 20 students and amortized over five years, yields a cost to a school for courseware of $6 per student per year. This cost is definitely not small compared to Dr. Lipson's estimate of $10 per student per year for the hardware. Even if my figures are off by 100%, the cost of $3 per student per year is still very significant. But I sincerely feel that my estimates are conservative and that in the next ten years we will see the cost of acquiring professional educational courseware actually exceed the cost of acquiring hardware.

CRITIQUE OF DR. LIPSON'S RECOMMENDATIONS

Dr. Lipson's Recommendation 1

In regards 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 consider that standards will stifle their grantees' research rights? I feel that the NSF's lack of willingness 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.

Dr. Lipson's Recommendation 3

The array of projects currently sponsored by the NSF continues to demonstrate the epitome of "the right hand not knowing what the left hand's doing" syndrome. I find it hard to believe that Dr. 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.

Dr. Lipson's Recommendation 5

In regards to "Breaking the Software and Course Materials Bottleneck", I believe that the key bottleneck is not "the lack of excellent course materials and software". The Huntington Project materials are truly excellent; they are far-ranging, 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 their stock, because their potential market would be incredible.

Dr. Lipson accurately identifies the "chicken and the egg" problem in 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 serve to prolong the current state of the art as a cottage industry. This state, in which everyone is doing his or her own thing, 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 establish the "critical mass" needed to develop a large number of hours of coordinated, transportable courseware. (I believe that if Control Data, distributor of the current PLATO system, can flow with the microcomputer tide they can come out on top because they still have much of the best courseware available.)

So when the NSF selects projects to be funded, I suggest that they choose those that are large enough to make a significant contribution to the overall market and insist that the courseware developed be produced in multiple formats so that it can be transported directly (that's "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

This paper assumes that the courseware to be developed will be similar in quality to materials that are available today. This level of quality may not be satisfactory 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' services are needed to develop and produce newer and better instructional materials. The process of wide-scale implementation of computer-based instruction is evolution, not revolution.

TECHNOLOGY IN SCIENCE EDUCATION: THE NEXT TEN YEARS

Joseph I. Lipson, Ph.D.

INTRODUCTION

This article is the result of a conference convened by the Science Foundation Directorate of the National Science Foundation. The purpose of the conference and the resulting papers was to help the Foundation set policy for its activities in the application of information technology to the improvement of science education. Of necessity the ideas and advice offered by the participants is a distillation of all their scholarly work and experience. The reader who is interested in more detailed arguments to back up the ideas and recommendations is urged to request the parent document, Technology in Science Education: The Next Ten Years, from the National Science Foundation at the below address. In addition, a great deal of supporting data and evidence is supplied in the documents cited and the references listed at the end of this article.

PROBABLE FUTURE DEVELOPMENTS

Dr. J.C.R. Licklider of the Massachusetts Institute of Technology (Licklider, 1979) prepared the conference paper on potential future developments, the impact of technology on society and, therefore, on science education. The increase in computational power and memory for a fixed price has been approximately exponential in time. Cost-effectiveness doubles every two years. As an example, the cost-effectiveness of computing increased by a factor of more than a million since World War II. It seems likely that the doubling of cost-effectiveness will continue through the 1980s. Once factor that has been crucial in resent developments has been the astonishing increase in the number of active elements on a single silicon chip. The world is rapidly moving into the information or knowledge age, and as a result of the transition, the use of information technology is flourishing everywhere except in the field of education. Education is, thereby, not only missing an opportunity, it is failing to discharge a crucial responsibility.

At the time this article was written, Dr. Lipson was Director of the Division of Science Education Development and Research at the National Science Foundation, Washington, D.C.

As a result of the doubling of computer cost-effectiveness every two years, educators who plan for the use of computers in science education should plan for devices that will be about 30 times more powerful by the end of the decade than today. If we can find ways to allocate a small but not negligible (say between $10 and $50 per year per student) fraction of our educational budget on computer hardware and software, we would have an adequate base for very sophisticated educational applications. The figure of $10 per student per year is calculated by assuming that each student should have at least 15 minutes per day interacting with a computer. 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 arrive at $200/20 = $10 per student per year. If you adjust the assumptions, you can arrive at your own figure. I arrived at the $200 per year figures by amortizing a $1,000 microcomputer over a five year period and assuming that this amortization schedule includes maintenance costs. 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.

The videodisc is an important companion technology for educational computer applications. In effect it provides a huge (read only) memory capability. A single videodisc can store 108,000 television picture frames. The frames can be considered as independent color pictures (e.g., a collection of slides) or as elements of a motion picture sequence. The two modes can also be mixed, i.e., one can have a mixture "still frames" and motion sequences. A single disc then has the capacity to store 108,000 individual pictures or to supply one hour of television motion picture. The cost per frame is about 100 times cheaper than printing (Licklider, 1979, p. 5). Thus the economics of the videodisc for educational publication should become a significant attractive feature sometime during this decade. (Fletcher, 1979; Hawkins, 1979; Molnar, 1979.)

Even more exciting is the idea of the computer combined with the videodisc (the intelligent videodisc). The logical capability of the computer combined with the image and information storage capacity of the videodisc offers the possibility of interactive lessons that combine 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 past limitations of media can respond to the new opportunity.

Using Information Technology to Improve Science Education

As the last paragraph implies, the promise of advanced technology for science education lies, not merely in its cost-effectiveness, but also in the opportunities to improve the *quality* of education. The following are but a few of the ways the new technologies can augment the educational environment:

- Computer conducted drill and practice. The most prosaic application, drill and practice, can insure that all students have the basic skills such as comprehension and problem-solving.

- Computer Assisted Instruction (CAI). The widespread availability of powerful stand-alone computers at low cost has renewed interest in this approach. The availability of new programming languages, the videodisc, a deeper understanding of the learning process and an understanding of the limitations of computers should permit us to effectively integrate CAI into the classroom and possibly the home.

- Computer Managed Instruction (CMI). It is probable that the use of the computer as a management tool will be integrated with other, educational, uses (help select lessons, schedule presentations, assess student achievement, and maintain records -- especially diagnostic profiles).

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

- Use of computers in solving problems. Many thousands of college students and high school students use computers in the solution of 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, by facilitating correction and editing of results the computer will allow students and teachers to focus on the deeper aspects of scholarship that are encountered when one tries to synthesize ideas and skills in the solution of problems.

- Use of computer and programming concepts to foster discovery and organization of ideas. Through computers students can creatively interact with and model certain classes of ideas that otherwise are very difficult to learn.

- Learning in an information-technology-based-environment that gives the student broad scope for exploration and initiative. This concept emphasizes the student's initiative rather than the teacher's or the computer's.

The computer can provide a dynamic library, as it were, that the student can explore following her/his own interests. Information on almost any subject can be called up, manipulated and modified.

The development of such a dynamic library, if it is to transform education, will required a major advance in the representation of knowledge. Thus the way the computer encourages us to explore the way concept networks can be represented may be as important to education as the computer itself.

- <u>Practice that simulates a real-world task</u>. The computer can give the student "worlds to explore" and become skilled in. The prime example of such simulation is the computer-based aircraft simulator which, although very expensive, is very cost effective. We are in the process of finding out whether such gaming and simulation can develop knowledge as well as cognitive and psychomotor skills.

- <u>Learning by teaching other students via programming</u>. Teachers often observe that they did not really understand a subject until they had to teach it. By giving students the task of preparing computer-based tutorial programs, we can add new dimensions to the educational process.

- <u>Learning by teaching computers</u>. 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 a precision of thought, and understanding of the knowledge base being addressed that should be valuable in itself. This idea will be discussed below as the challenge to those who will carry out research in the applications of technology to science education.

Every pervasive and powerful technology transforms society and the individuals in that society. Because we do not fully understand the sources of human behavior, a new technology may alter us in undesirable ways. 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

Because of the great potential benefits and dangers suggested above, John Seely Brown of Xerox, Palo Alto Research Center (Brown, 1979) argues that there is a need for basic research that combines the constraints and challenge 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" in a particular situation. How is knowledge organized and used by the expert and the novice when each is faced by a similar problem or task? How does one 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 (theories of complex human thinking) that have a degree of completeness, precision and specificity unprecedented in psychology and educational theory. Thus the attempt to use our theory to build a computer-based learning environment forces us to be serious about those theories and the resulting educational system provides the educational medium for testing 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 (Brown, 1968). Thus, a great deal more cognitive research is needed for modeling even the relatively well understood and formal domains of mathematics and the physical science. However, with the right kind of research, the forth coming models can yield substantial payoffs in education.

Technological Research Issues

If we are to use computers effectively, we need to be able to have them operate in various ways -- sometimes simulating a human tutor to a degree, 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 its context and our general understanding of what the world is like. Because the computer has no world view, interaction is often frustrating to the student. The computer has no way to infer a statement by a student that is correct, but not the one programmed as correct. Humans make such adjustments easily. Also, when people do not share some aspect of their world views, they can engage in a discussion that clarifies the similarities and differences. They can negotiate the differences in their models of how the world works.

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

People learn many of the properties of the world by active exploration -- learning the territory. How can we provide general hypothetical "microworlds" that students can explore to give them intuition and skill in various kinds of domains of knowledge such as logic, relativity, statistics, social dynamics, etc. Such microworlds can both teach things as they are and also encourage a deeper understanding by allowing the student to either create his own world based on his model of how things work or to 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 flexibly modify and change programs, presentation modes, languages, etc. In addition, since research and development take place over time and since computers are evolving so dynamically, the developer should aim for a final device that is quite different from anything available when work starts on a project.

Projects should not be driven into proving educational effectiveness prematurely. In the early stages of an idea it is more important to use formative evaluation to understand the underlying causes of the 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!"

New Content

As computers become more and 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 become powerful analogical concepts for thinking about human thinking and learning. More important, as noted above, the augmentation of human thinking possible with computer 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 (Molnar, 1979)?

TECHNOLOGY AND THE U.S. EDUCATIONAL SYSTEM

Dr. Luehrmann of the Lawrence Hall of Science, University of California, Berkeley (Luehrmann, 1979) suggests that there is a fundamental incompatibility between the U.S. educational system and most of proposed systems of educational technology. The result is that people in the school system view educational technology as a threat rather than as a way to improve the quality of the learning environment. If this analysis is accepted, we need to (a) explore ways of introducing educational computing through such non-school institutions as the home, the museum, the library and the work place, and (b) devise and appropriate technology for school use that is effective and non-threatening.

In order to be suitable for the present condition of declining enrollments, any process of change should expect to accomplish its goals (a) through in-service training of a somewhat stable teacher population, (b) by using technology to help the schools teach the basic skills in such a way that those skills can be applied and used in more advanced study, and (c) by using technology to deal with the increasing need and demand 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 microcomputer combined with the videodisc offers the flexibility and the unthreatening character to be compatible with the character of present teachers and schools. However, past CAI projects have overlooked one dimension of computers that can promote its entry into and use by schools. The widespread use of computers, as noted above, generates the computer related curriculum that schools will increasingly feel the need to offer. This computer curriculum requires the following: basic computer education, vocational and professional training in computer skills, and teacher training.

In certain situations the computer may not be felt as a threat: 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 three areas of research and development:

- Development of the basic computer skills curricula.
- In service training of teachers so that they can teach the computer skills curricula and use of the computer in teaching science, math, and other subjects.
- Creation of curriculum development centers to establish and use a critical mass of talented people. Such centers would need daily access to students and mechanisms such as visiting appointments to assure a steady flow of creative professionals who would return to their home institutions and promote change.
- Development of a variety of models of community learning centers that employ the computer-based learning systems.
- Development of an "intelligent videodisc" personal learning system. While several government and non-government 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 videodisc be justified.

RECOMMENDATIONS

Several factors justify serious consideration for government activity in the field of computer-based educational technology:

- The dramatic changes in computer technology and the advent of the videodisc justify a new round of research and development in the field of computer-based and intelligent videodisc technology.
- New developments in cognitive science in particular and science education research in general suggest that, with some care, we can avoid the mistakes of past simplistic applications of computers to education.

- 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 non-academic organizations. In addition, the computer has the potential to improve productivity by contributing to the general level of educational attainment.

- Unless computer literacy and computer skills are taught by the schools that teach minorities and other academically disadvantaged students, the nation's drive for educational equality cannot be realized. The jobs of the future will increasingly go to those who have such skills. The rich already have access to computers. Unless such access is provided to the poor, the educational gap will be widened.

  Computer enhanced learning can contribute to improved motivation and amplify the teacher's ability to offer extended, detailed individualized instruc tion to those that need such attention the most.

To promote orderly and cost-effective development, the following recommendations are suggested. These highlight important leverage points for Federal action in general, and the National Science Foundation in particular.

<u>Recommendation 1: Unique and Accepted Government Functions</u>

There are a variety of activities and functions that are widely accepted and expected of the Federal Government. Properly organized, such activities as the following can facilitate the development of the new information technologies:

- Set telecommunications policy (e.g., hardware standards, copyright for software laws, patent laws, tax incentives and tax funds targeted for curriculum development) to encourage the proper development and use of the new technologies for important educational purposes.

- Aggregate and stimulate the creation of a new industrial and commercial market through government purchasing decisions, equipment support to schools, use of the new technologies in government training programs and other mechanisms.

- Undertake an assessment of the impact of these new technologies on the individual, society, education, and our position in the world community.

- Commission periodic measurement of the state of science education.

- Work with other educational agencies to assure that the achievement of students who use the new technologies in novel ways can be properly accredited.

Recommendation 2: New Talent

A severe limitation on the successful educational uses of new technologies lies in the lack of special academic, artistic and instructional design talent to exploit the new displays and systems. It has been observed repeatedly that the technologies have outrun our imagination and skill in using them. For this reason the National Science Foundation should support a variety of programs to discover and develop the new talent needed to capitalize on the science education potential of the computer and other information technologies. (Note: In the past two years a significant start has been made in this regard.)

Recommendation 3: Dissemination

In order to assure the timely, widespread and proper use of the 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 Foundation 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 new image devices such as the video-cassette and videodisc players, will serve an important dissemination function.

Recommendation 4: An Informed Public

Only with an informed public can the nation hope to move into the computer age with the speed and sense of purpose required. The adoption of a new technology as far-reaching as computer technology is incredibly complex. At almost every stage there is strong interaction with public attitudes and public understanding. Investments, markets, legislative positions, enrollment in courses, and selection 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 about the issues. In addition, use of specialized media to reach specific publics should be used.

Recommendation 5: Breaking the Software and Course Materials Bottleneck

A key bottleneck is the lack of excellent course materials and software. Furthermore, excellent materials are one prerequisite to commercial investment in the educational uses of new technologies. Hardware manufacturers are 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 represented by large numbers of devices in the schools or in homes. Thus, federal support of development of software and courseware will act as an important catalyst for commercial development. After an initial period of pump-priming the commercial cycle should take over.

We recommend that the Federal Government support the development of innovative materials that allow for future trends in the information technologies. Anticipation of future developments is critical since the field moves so rapidly that projects based only on present capabilities will be obsolete by completion time. We also recommend the funding of key technical developments to facilitate the authoring and production of educational materials. Examples of specific projects to be supported include: prototype science course materials; special authoring facilities including computer simulation, electronic editing and production facilities; and prototype student environments that demonstrate the technological features that will soon be available.

Recommendation 6: The Research Challenge

Our conceptions regarding the representation and growth of knowledge, understanding, and skill, are not adequate for the effective use of today's technology. Current systems have outrun our existing concepts of human learning and human interaction with computer-based environments. Thus we recommend a broad sustained attack by the Foundation and other agencies on urgent and promising research questions.

Recommendation 7: Equipment Support

A program of carefully designed support for the placement of microcomputer technology in the classroom will complement and make more effective the research, development and dissemination programs recommended. In a sense, equipment demonstration during the early phases of implementation can serve as a model to generate communications about the innovative idea, and provide a compelling demonstration to educators as a whole. Dr. Luehrmann has suggested that computer power in the schools should come to be thought of as a utility like water or electricity. We recommend that the Federal Government provide support for the carefully controlled introduction of microcomputers into the schools. The program is needed as an incentive to assure the strength and leadership of the United States in the computer industry. Any program of equipment support should be tied to evidence that a teacher is trained and committed to the use of the equipment and to the school's record of effective use of innovative technology. Support to teach school should provide sufficient numbers of microcomputers to serve a class of students learning to use them.

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

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