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ABSTRACT

This report is an analysis of the findings of four workshops exploring the ways interactive technology can be considered an option for improving American education after 25 years of research and development. Sections include: (1) "Manpower Needs and School Problems"; (2) "Science and Technology Option"; (3) "Barriers and Strategy"; and (4) "To Move Forward." The first program element aims to seed the development, distribution and maintenance of sophisticated new software for science and mathematics education. The second program element concerns selected large-scale educational trials aimed at demonstrating substantial improvement in science and mathematics education that require radical departure from traditional school arrangements. The third program element concerns strengthening the nation's applied cognitive science capacity, which is necessary to undergird development of a science and technology option over the long run. Teacher preparation and training is touched upon at the close. Summary reports of the four workshops are appended. (YP)

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New Information Technology Directions for American Education

Improving Science and Mathematics Education

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Final Report
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Final Report*

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* The views expressed here are those of the principal investigators and do not necessarily reflect the policies of the sponsoring agency.

Final Report

New Information Technology Directions for American Education:
Improving Science and Mathematics Education

OVERVIEW

This report is an analysis of the findings of four workshops sponsored by a grant from the National Science Foundation. The workshops aimed to explore in what ways interactive technology can now -- after 25 years of R&D -- be considered an option for improving American education. Summary reports of the workshops can be found in appendices to this report. The analysis is the responsibility of the principal investigators alone.

> *America is in rapid social and economic transition. Changing circumstances are undermining the effectiveness of traditional classroom instruction. A different educational model may be required. rather than marginal reform of the present system.*

The present system of American education has been powerfully determined by two characteristics, traditional classroom instruction and decentralized finance and governance. These characteristics have allowed for the easy growth of elementary-secondary education from some 400,000 students in 1870 to about 40,000,000 today. They may now set unacceptable limits on educational effectiveness in a changing America. A new, culturally heterogeneous student population, a less docile and obedient student, a pervasive TV presence, and a decline in the academic quality of teacher candidates are new conditions (not transitory problems) that challenge the concept of school isolated from the realities of social and economic life. The cost of school practice that clings to a romantic image of the *little red school house* is high. Academically weak students drop out, without learning all that they should; while academically strong students do not learn as much as they could for the time they invest.

America is in rapid economic transition. Technological advances in the 400 years since Watt's invention of the steam engine will be eclipsed by developments in the next 40 years, with profound implications for the world and for American society. New technological frontiers like space, biotechnology and computer intelligence will make new demands on the schools for improved student learning, and for the improvement in human capital necessary for America to compete successfully in an expanding international economy. In these circumstances of new educational demands and changing social and economic conditions, it seems prudent to consider whether the nation's educational requirements can be satisfied by the present lockstep model of classroom instruction, or by a system of educational governance that does not effect a suitable investment in scientific R&D.

Educational practice is not ordained, and history assigns no credit for invention of the classroom. The ease with which this 'production kernel' -

the classroom -- could be reproduced in America's reach for mass education is a vestigial virtue. Presently, there are some 2,000,000 classrooms in the U.S., with an average student-teacher ratio of about 21:1. Regular cries of public dissatisfaction with school performance produce equally regular popular and learned accounts of the need to reduce, or sharply reduce, average student-teacher ratio. It seems everyone suspects that at least one other educational practice -- individual and small group tutoring -- will produce better results than classroom instruction.

In fact, empirical evidence reveals that students can learn in many ways: independently; in small and large groups, with and without a tutor or teacher; and from books, television and computers. The issue is not how best to facilitate student learning, but how best to facilitate the education of all school-age students at a cost society is prepared to pay. There is no evidence that traditional classroom instruction optimizes mass education at current prices for America's school-age population; there is ample evidence that it fails many.

The application of science and technology, which has had such powerful effect in other social and economic sectors, can be the basis of a new instructional model with much improved learner productivity.

The past fifty years have seen the effect of science and technology in almost every sphere of human activity. Uniquely, education lags. Thanks to science and technology, the planet is now able to support a population of 4.7 billion; and life expectancy in advanced industrial nations exceeds 70 years of age, on average. Americans generally have a high expectation that science and technology will continue to expand output and improve the quality of life. But no conception of educational change appears to exist in the public mind comparable to expectations of change, whether well informed or not, in other spheres of activity like the home and transportation, the structure of the economy and the condition of work, space voyage and communication, and so on. In education, the nation seems adjusted to the expectation of only marginal change and improvement. Despite prima facie evidence that every day we almost all learn by reading or watching television -- and an increasing number by computing -- it seems most Americans believe that science and technology have little to say to education.

Empirical evidence supports intuition concerning factors that can strongly affect student learning. A short list, which emphasizes improving how students learn rather than how classroom teachers teach, includes:

suitable course content, carefully developed so that the student can find the answer to most of his questions;

more time for the student to learn, and for each student to spend on learning what he individually needs to learn;

diagnostics that assist the student and teacher to know what the student has successfully learned and so far failed to learn; and, a teacher capable of motivating and tutoring the student, as necessary.

Advances in science and technology -- interactive information technology based on the digital computer, and the new learning science developing from research in cognitive science and artificial intelligence -- have demonstrated the potential for contributing to greatly improved learner productivity. A new organization of educational practice is required that provides the student with increased time for individualized learning and practice, and provides the suitably trained teacher with the time and opportunity to motivate and tutor the student, as necessary. That science and technology which improve learner productivity will require a change in educational practice and organization should not much surprise us. That is the historical experience in agriculture, medicine and every other sphere of human activity, where science and technology have had great impact.

No claim can be made that science and technology will (like a *learning inoculation*) advance all students equally along a royal road that leads from the acquisition of facts, procedures and problem solving skills to a deep conceptual understanding of course content and the development of general analytic abilities. No such claim is necessary. The issue is whether an instructional approach that emphasizes the application of science and technology to the unfolding problems of mass education in America merits development and exploration. The answer, from both the empirical evidence and experienced professional judgement, is unambiguously yes! The hard question is how to advance the process of development and exploration in our decentralized system of education!?

> *Without an inventory of (nearly) full-course computer curriculums, (which should embody the most advanced knowledge about learning from research in cognitive science,) trials of the extensive use of interactive technology in the context of suitably restructured educational practice are not possible. The development of the necessary body of computer curriculums requires a risk investment, a concept alien to our decentralized system of educational finance and governance, which also appears to lie outside the present practice of traditional school publishers.*

A summary of major educational objectives today will include improving student achievement in the basic skills, and in science and mathematics education; controlling rising costs in the face of taxpayer resistance to new educational levies; meeting the special needs of low and high academic achieving students; and providing a full academic program in the absence of qualified teachers, especially in science, mathematics and foreign language instruction. Many experienced school system administrators have interest in exploring the potential of interactive technology, in combination with necessary changes in educational practice and organization, to realize these objectives.

The availability of suitable equipment, which can be acquired at a price between $1,000 and $3000 a unit is not an inhibiting factor. The number of computer units (of all kinds) already in the schools is estimated at around two million. But the absence of a suitable inventory of computer curriculums, requiring a front-end investment between $1 million and $3 million per course and a specialized team of expert developers, effectively forecloses any opportunity for local initiative.

The development cost of an inventory of full-course computer curriculums necessary to allow trials aimed at important educational objectives can amount to some tens of millions of dollars. There is little knowledge or experience among State and local education authorities to manage a development activity of this complexity or scale. State legislatures do not budget for it. American education has relied on school publishers for risk investments like this. In this case, school publishers find the risk too high.

The nation's arrangements for responding to social change with marginal educational reform, which have so far worked well or well enough, are suddenly unavailing. State and local education agencies and school publishers together will not soon effect a suitable investment to develop the necessary computer curriculums. Some institutional improvisation is needed.

> *N.S.F. interest could be decisive in advancing the timely development and exploration of a science and technology option for educational improvement that may otherwise be long delayed.*

Authorized by the U.S. Congress to assure the quality and quantity of U.S. scientific manpower, the National Science Foundation is positioned to finance the development of a suitable inventory of secondary-school computer curriculums in science and mathematics education, at a cost under $20 million. Enterprising school system administrators, alerted to the development schedule, can plan a course of exploratory trials aimed at selected educational objectives. Some trials, involving far reaching reorganization of traditional educational practice, will require a financial supplement over the regular operating budget during the transition period.

In the absence of any institutionalized process for strategic educational planning and reform, these individual initiatives by enterprising school system administrators may be the nation's best approach to testing and developing a science and technology option for meeting the educational requirements of a changing America.

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Final Report

New Information Technology Directions for American Education:
Improving Science and Mathematics Education

INTRODUCTION

This report is an analysis of the findings of four workshops conducted under NSF award #MDR-8652287: Strategic Planning for the Use of Advanced Information Technology to Improve American Education. The workshops aimed to explore in what ways interactive technology can now -- after 25 years of R&D -- be considered an option to achieve a significant improvement in American education, and how best to advance its development and exploration. Although the option was found scientifically and technologically genuine, barriers to its application for school improvement remain. To advance the realization of this latent opportunity to improve science and mathematics education requires:

> federally financed seeding of the first round of science and mathematics software development, in the absence of sufficient private sector investment;
>
> federally financed support of school trials aimed at exploring variations in educational practice and organization necessary for the most effective application of interactive technology; and,
>
> federal support of R&D, and training.

An analysis of these actions, their costs, and the logic underlying them are described in four sections. The first section considers school problems and national manpower needs that are visible on the horizon; the second reviews the history of interactive technology R&D and the potential role of science and technology in improving American education. The third section describes present barriers to the school use of interactive technology to realize a significant improvement in American education, and outlines broad actions necessary to overcome them; and the fourth provides details on steps that can be taken now to develop and explore a science and technology option for improving American education by the close of the century. The report concludes with some personal remarks by the principal investigators.

The four workshops were limited to one day. The first, described in Appendix 1, involved some 20 experts from the fields of cognitive and computer sciences, and interactive technology. The principal findings of this workshop can be summarized.

> Suitable and adequate interactive technology is available; i.e., the 286- and 386-class computer, and equivalent, the analog videodisc and the digital CD-ROM

have the capacity and capability to support all applications presently contemplated by educational experts.

The very recent announcement of this class of equipment assures a stable technological planning framework of from six to ten years, or even longer. No doubt other new equipment with special capabilities will become available in this period that may be educationally useful, but which will not supplant in capacity this newly available class of equipment.

Substantial educational improvement that depends upon student use of interactive technology is strongly time dependent. To provide suitable amounts of learning time using educational technology requires reorganization of traditional school practice.

The second workshop of eight experts aimed to explore issues of educational restructuring. The principal findings of this workshop, described in Appendix 2, are simply stated.

A wide range of options exists for the restructuring of classroom practice and school organization.

The software necessary for the extensive use of interactive technology for individualized learning is not presently available.

The third workshop is briefly described in Appendix 3. Involving twelve representatives of school publishers and other experts, it aimed to learn something of the educational software products that might be available for school acquisition in the planning horizon, and about factors affecting investment decisions by school publishers in educational software development. Three findings emerged.

School publishers are not agents of educational change or school improvement. Rather, they meet the demands of the market as they understand them, and in the matter of educational software believe they are doing so adequately, with products designed primarily for compensatory and remedial education and educational enrichment.

School publishers do not seem to engage in the typical behavior of technology firms, which *get out front* early in order to shape the market and seize market share. School publishers seem to see no profitable business opportunity in developing and marketing substantial bodies of computer curriculum, approaching a full course.

The quality and quantity of educational software presently provided by school publishers will not change much in future, unless there is a change in the incentive system they face.

The fourth and final workshop, involving 29 experts, introduced current school system administrators into the mix of earlier workshop participants. A summary of the discussions appears in Appendix 4. Three findings emerged.

> School system administrators aiming to extend the marginal use of interactive technology are not satisfied with the range and variety of educational software products available to them in the market place.
>
> Practical exploratory trials of the extensive use of interactive technology coupled with the reorganization of school practice necessary in order to realize significant student gains is generally only a modest ambition of school system administrators. Many enterprising school system administrators, sometimes driven by necessity, can nonetheless be expected to experiment, given the availability of the necessary (nearly) full-course computer curriculums.
>
> Many school system administrators will actively participate in federally supported trials aimed at systematically exploring far reaching variations in school practice and organization, which may be necessary for the most beneficial use of interactive technology. Improving secondary-school science and mathematics education can be an early objective of these trials. School system administrators should be expected to tie the conduct of these trials to activities aimed at improving education in other curriculum areas.

The principal investigators for this activity are grateful for the involvement and contributions of all workshop participants. Special thanks are due Prof. Alan Lesgold, who served as rapporteur at two workshops, and to Dr. Lionel Baldwin, Dr. Sylvia Charp, Dr. Linton Deck, Francis Fisher, Esq., Thomas Haver and Dr. Fred Weingarten for their unfailing good advice and counsel.

It should be emphasized that this analysis and all conclusions and findings described in this report are the responsibility of the principal investigators alone.

###

SECTION 1: Manpower Needs and School Problems

The tenth amendment to the Constitution leaves responsibility for education to the States, and with some exceptions, like education for the economically and socially handicapped, and the physically handicapped, there is little national education policy that directly affects the local governance and operation of the nation's schools. Educational R&D funded by agencies of the Federal Government, at increased levels since *Sputnik*, has presumably indirectly affected local decisions on school operation.

In higher education the situation is little different, with federal investment in scientific R&D and the federally guaranteed student loan program representing the principal education policy interventions by national government in the governance and operation of the nation's public and private institutions of higher education.

This constitutionally shaped arrangement that leaves primary responsibility for the finance and governance of education to State and local education agencies has apparently worked well enough so far; Americans seem to like it; and there has been little policy linkage between schooling and the nation's manpower requirements for economic security and national defense. Of course, contingent linkages exist between the quality of education and the quality of the labor force, which have been getting intense scrutiny recently from State governors and the nation's business leaders. There is a growing awareness that the world economy and the U.S. economic position in the world is changing; and that these changes hold implications for the quality of manpower required for continued U.S. economic growth and therefore, for the quality of American education. The Director of the National Science Foundation, Erich Bloch, argued forcefully in a speech before the New York Science Policy Association on January 20, 1987: (1) that economic 'success in the long run requires a well developed and healthy science and engineering base -- that is, the collection of people, institutions, equipment and facilities -- that makes innovation possible'; (2) that people must be a major focus of efforts to improve the base; and (3) that precollege education in the sciences and mathematics, and undergraduate instruction in the sciences and engineering must be improved significantly.

The growing *internationalization* of trade assures that the market price for any product is determined by the lowest price for labor anywhere in the world the product can be produced. Increased low-interest lending by banks assures that the producer goods required for standardized products is available to many developing countries, which can undercut the price of U.S. products with cheaper labor. To compete successfully, the real wages of Americans engaged in the production of these products must decline asymptotically to the wage rates for labor in countries with lower standards of living. This is not a happy situation for the nation to contemplate, or for those Americans who already find themselves *riding the down escalator* to a lower standard of living.

An increase in the number of service jobs paying the minimum hourly wage is not an economically successful solution to this problem. A much preferred solution proposed by concerned public officials and business leaders is that the American economy should increasingly emphasize the production of *high-tech* capital goods and the delivery of special professional and technical services that trade at a higher price in the world economy. This strategy, which requires better educated and trained labor, places an additional demand on American education at a time when U.S. schools face new and special difficulties of their own.

The generous American impulse that aims at universal education; school desegregation laws; the legal and illegal immigration of Hispanic populations; new, previously unknown waves of immigration from Asia and from South America; a pervasive TV presence, which stimulates a life of the feelings; all contribute to a new, less docile, culturally heterogeneous student population that is harder to teach. At the same time, a new and unequal competition has opened between the U.S. economy and the State and local tax base for academically competent individuals, leaving the schools with a shortfall of teachers, particularly in the *hard* subjects like science, mathematics and foreign language instruction. The demographics of the nation's teacher corp threatens a further reduction in the supply of classroom teachers, due to retirement.

Some indicators of these school conditions are evident in the recent record of declining test scores, international comparisons of school science and mathematics achievement, and the increasing cost for college remediation in science and mathematics. Of some 24,000 secondary schools, 7,100 do not presently offer a course in introductory physics, 4,200 do not offer a course in introductory chemistry and 1,900 do not offer a course in introductory biology.

It is pleasant to imagine that this unfavorable educational condition is temporary and will recede; and if persistent and real, that it can be resolved by traditional approaches like smaller classes and higher prices for teachers, which the taxpayer will come to accept. But if only as a precaution, other non-traditional options for improving education should be prepared. It is difficult to credit that Americans presently learn enough in school, on average, to meet the complex demands of modern life. Is there a realistic opportunity for using information technology to improve American education?

It was the purpose of this NSF-sponsored activity to consider whether and how -- after 25 years of R&D -- interactive technology should be considered an option for achieving a significant improvement in American education at a price the taxpayer would be willing to pay; and to determine what steps were necessary to advance the development and exploration of this option.

The remaining sections of this report are concerned with an analysis and discussion of answers to this question that were developed through four one-day workshops of educational experts.

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SECTION 2: Science and Technology Option

The stored-program computer invented by von Neumann for scientific calculation in the late 1940's, which provided for contingent -- in place of pre-wired -- computing, is the conceptual basis for interactive technology. Applied to instruction, this development, in principle, allows the student's input at any point in an interaction with a stored instructional program to be met with a particularized response. This practical opportunity to realize the dream of educators since Dewey for individualized instruction has not been seized.

Initially, computers were too expensive, too large, too cumbersome and generally unsuited to school use. With the development of remote and time-shared computing in the early 1960's and of physically smaller computers with little or no special air-conditioning requirements, these difficulties were sufficiently overcome to allow exploration of educational applications to begin.

Financing was provided from various sources, primarily non-school, like private foundations and public agencies, and some private sector firms. President Johnson's drive to improve educational opportunity in the mid-1960's provided public funding for experimentation in the schools through Title III of the Elementary Secondary Education Act; and in 1967, the National Science Foundation initiated a modest program of R&D support for computer applications at all levels of education.

The 1960's saw various efforts made towards the development of drill-and-practice programs in arithmetic, initial reading skills and the language arts, primarily for compensatory and remedial education. New languages suitable for educational application were developed like BASIC, LOGO and PLANIT. Computer simulations in the physical and social sciences were developed for use by teachers and students, as well as problem sets for solution by students that demanded use of the computer. Although carried out with great enthusiasm and high expectation, these efforts were most often short-term in duration and inadequately financed.

The 1970's saw a large number and wide variety of (more and less formal and expensive) evaluations of the educational use of computers. Some were clearly premature, conducted with prototype software, a victim of the politics of educational R&D funding. Some, like many others in the modern history of educational evaluation, found *no significant educational difference*. And some found either that students learned more (by about 10% to 20%,) or learned faster (by about 30%.)

An evaluative approach to decision making (using statistically matched student samples) that, however conceptually attractive and statistically rigorous, often produces a result of *no significant educational difference* should be suspect. In fact, intensity and duration of computer use by the student is often an explanatory factor distinguishing between studies that found significant educational gains and the others. A deeper reservation concerning those early efforts to use interactive technology in education should be the rough-and-ready approach adopted to the applications development process, in the absence of much scientific knowledge of the mental processes of human learning. Of course, classroom instruction is daily undertaken in the same circumstance.

The 1980's are producing developments in science and technology with important new implications for the opportunity to improve education. There is new knowledge from research in cognitive science and artificial intelligence that should favorably affect the instructional quality of educational software. Developments in intelligent tutoring systems aim to replace a rough parametric model of the student's learning behavior with a more explicit representation of his knowledge. Developments in expert systems are providing designers of intelligent tutoring systems with new techniques for offering the student instructionally effective advice when he is thought to be floundering. In trials of one example of sophisticated new mathematics software recently, a statistical sample of students learned geometry, who most often do not in the traditional classroom.

Since the appearance of the low-cost personal computer around the beginning of the decade, U.S. schools have invested more than $2 billion in their acquisition. This choice, made across the nation in a climate of scarce educational resources generally, is a powerful local vote of confidence in the instructional use of the computer. Recent announcements by equipment vendors promise more powerful hardware with the capacity and capability to support very sophisticated educational applications at a price the schools can afford.

The combination of capital-intensive technology and scientific innovation has been the story of civilization since the Middle Ages. Capital-intensive technology and scientific innovation have worked their effect by creating lower-cost and new goods and services. As a result, a world population, which required more than two million years to grow to a figure of one bil- on in around 1830, is projected to reach six billion around the end of this ntury, only 170 years later. The nation now stands at the threshold of being able to apply science and technology to mass education with great effect, although not by marginal use alone.

The present opportunity for using science-based interactive technology to improve American education is attractive to many and even very attractive to some. But barriers to the development and exploration of this opportunity exist, described in the next section.

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SECTION 3: Barriers and Strategy

The activities of commerce and industry, scientific research, and the civilian and military agencies of government have recently combined to create a national computer culture in which the schools have been able to participate, assisted by the relatively inexpensive price of the personal computer. Since 1982, the schools have acquired some two million units, of all kinds, at a cost exceeding some $2 billion.

Instructional use of this equipment varies widely, including computer programming, computer literacy, compensatory education, enrichment in science and mathematics education, and word processing. Software products used for compensatory and remedial education and educational enrichment often have their roots in pre-personal computer developments and have been suitably modified since to take advantage of new hardware features, like greater memory size, color and graphic displays, digitized speech, and so on.

Although selected by the schools for their educational value, these applications, which introduce the use of computers at the margin of school practice, do not address the strategic problems of American education: a harder-to-teach student population, declining student achievement, and a growing shortage of teachers able to teach the *hard* subjects. To use low-cost interactive technology in an effort to deal with the changing condition of American mass education requires suitable software products, which are not presently available in the market place, and a change in school organization. A reorganization of classroom practice and the use of the school day can also take into account a shortfall in teachers.

So fundamental a change in the schools can only occur over a long period of time, after much local exploration and trial with suitable software. Software products that can satisfy the need for increased individualized learning in the circumstance of a shortfall of suitable teachers must include advanced features based on new knowledge from research in cognitive science and artificial intelligence, and represent the equivalent of a full curriculum that meets course standards defined by current national tests. The hardware necessary to execute this more sophisticated software has recently been announced at higher prices, which will decline steadily in time to little more than today's prices.

Major American school publishers, typically undercapitalized, do not dare risk the substantial investment required to develop and sell software products like these in an uncertain market. In the absence of suitable software, individual school system administrators are unable to consider restructuring options based on a mix of new technology and new organization, which might solve local educational problems and, in time, national manpower problems. If this impasse is to be overcome, some institutional improvisation is necessary.

State and local governments appropriate an annual operating budget for the schools, which does not include an R&D component. State agencies concerned with education have little experience in managing R&D. Some action by an agency of federal government with the necessary experience and budget seems necessary to break the impasse.

Through changed conditions beyond their control, the schools are presently unable to offer a precollege science and mathematics education program that meets the nation's pressing economic requirements. Absent the trained manpower necessary for a healthy science and engineering base, U.S. economic growth must inevitably falter in the face of growing international competition, and a steadily rising American population must grow poorer, on average.

The National Science Foundation (NSF), authorized by the U.S. Congress to assure the quality and quantity of U.S. scientific manpower, can act to provide schools the opportunity to explore restructuring options based on a mix of new technology and new organization, which can improve secondary school science and mathematics education.

A conservative approach would involve *seeding*, at modest cost, a first round of science and mathematics software development a the (junior high and) secondary school level. Although some debate inevitably attends the definition and content of secondary-school science and mathematics, the academic substance and standards for these courses are better established than for most of the school curriculum. Voluntary trials elected by school system administrators of restructuring at the secondary-school level will be less constrained by considerations of custodial care than for younger students in earlier grades.

Nonetheless, hemmed in by inevitable criticism over any departure from traditional school practice, the choice of restructuring trials with interactive technology by school system administrators may represent only a modest departure from traditional educational practice. External funding -- for necessary changes in physical plant, for necessary equipment, and to cover the cost of returning to the *status quo ante* in the event of a real or perceived failure -- can be expected to make a difference in the local climate of opinion, and aid school system administrators in electing more radical but educationally justified departures from common practice, with potentially greater educational benefits. In an expanded program of support, the National Science Foundation (NSF) could act to provide financial support for the design and implementation of selected large-scale school trials aimed at demonstrating substantial improvement in science and mathematics education. School system administrators should be expected to tie the conduct of such demonstration trials with activities aimed at improving education in other curriculum areas.

These actions would make strong demands on the still small academic community concerned with educational applications of cognitive science, which needs to be expanded and strengthened.

A program of activities, including software development and selected large-scale school trials, which could affect large numbers of school-age Americans, can be completed by the end of the c tury. The odds are favorable that it would generate new options for e ucational practice and organization that Americans will soon find necessary or think desirable, and affect all school-age Americans. The cost of a pilot program -- described in the next section -- is tiny, relative to the annual operating budget of American schools.

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SECTION 4: To Move Forward

The pilot program described here aims to improve science and mathematics education for many secondary junior high and secondary school students in the near term, and to advance the exploration and development of a science and technology option for improving American education, which could soon affect all students. Exploratory trials by school system administrators of the extensive use of interactive technology for individualized learning, which requires restructuring of traditional classroom practice and school organization, are presently inhibited by the absence of suitable, advanced software products. The first program element aims to *seed* the development, distribution and maintenance of sophisticated new software for science and mathematics education.

The second program element concerns selected large-scale educational trials aimed at demonstrating substantial improvement in science and mathematics education that require radical departure from traditional school arrangements. The nature and expense of these trials make their election by school system administrators unlikely in the absence of some external support.

The third program element concerns strengthening the nation's applied cognitive science capacity, which is necessary to undergird development of a *science and technology option* over the long run. Schematic descriptions of these program elements include rough cost estimates and identify factors that strongly influence cost. Annual budgets and rates of expenditure will depend upon specific operational designs. Teacher preparation and training, a necessary component of any successful educational innovation, is touched upon at the close.

I. *SEEDING* the DEVELOPMENT, DISTRIBUTION and MAINTENANCE of SOPHISTICATED NEW SOFTWARE

This program element aims to develop advanced software suitable for school trials of the extensive use of interactive technology; and to *seed* a market for this new class of software. Representing the equivalent of a full course, the nature and style of this software will vary widely from course to course, depending upon current knowledge from R&D. Science software will tend to emphasize simulations and the use of construction sets, and mathematics software to depend more on the algorithmic nature of the subject, symbolic and computational. Some course software will emphasize learner control in the form of intelligent tools and others will emphasize program control in the form of intelligent tutors, depending upon knowledge and experience from current R&D. This design and development issue must be decided on a case-by-case basis, and is not considered further here.

How many courses

Current efforts to improve American education by raising graduation standards aims at the requirement of two science and mathematics courses per year for students in secondary school. This suggests an initial target of eight computer curriculums, divided equally between science and mathematics, a figure that should satisfy both the immediate and strategic purposes of this program element (which can be extended to the junior high school by the addition of two to four more curriculums.)

Software course development cost

There is little experience on which to base an estimate of the development cost for this class of software. An informal poll of experts produced figures ranging from $1 million to $4 million a course, weighted in the direction of the lower figure. A mean figure of $2 million, which does not include the cost of distribution and maintenance, will be used in representative calculations here.

Who does development

While the necessary underlying knowledge exists, the organized capacity to develop these computer curriculums does not presently, and will have to be stimulated. Suitable development teams will include experts in course content, software development and applied cognitive science. Existing sources of expertise include the academic community, private-sector firms and the schools. The formation of teams can be stimulated through a staged design process that provides the necessary time and opportunity for teams to form.

Distribution and maintenance

An incentive system should be structured to attract existing private sector firms to the task of distribution and maintenance or to create new institutional capacity for this purpose. Distribution can be by mail, using magnetic or optical media, or electronically, by modem. A system should be established to receive feedback from schools and teachers on problems of content. pedagogy and operation. The opportunity to learn at low cost from this first round of publicly-financed software development is one element of an incentive system that should attract private sector firms to the task. A second can be a modest fee paid by schools for software updates.

How to proceed

Two critical issues that have to be faced in order to proceed are: (1) what precisely is the advanced software product; and (2) how can the development capacity to produce it be organized. The first issue concerns things like the topics which will be represented in the computer curriculum; the curriculum pedagogy, including the nature of the program interaction (mentioned earlier,) and the nature and degree of teacher assistance necessary for successful learning by the student; how the student's learning will be tested; the demands of the curriculum representation and program interaction on hardware; and so on.

The second issue represents the empirically testable hypothesis that traditional school publishers, conditioned to operating in a technologically non-progressive sector, are not the natural competitive producers of this new product, although their knowledge of school culture and operation could prove decisive in its successful trial and adoption. A resolution of both issues can be achieved with a design and development process made up of several competitive stages.

For any course, whether pre-calculus mathematics or biology, the government will solicit preliminary proposals, with the intention of funding a small number of proposers for the preparation of a detailed design. An important dimension of variation distinguishing 'winners' of this first phase competition might be the amount and nature of teacher assistance they anticipated for successful use of the computer curriculum by the student. Based on a review of the small number of detailed designs, the government will select the developer. The design products should include plans for pilot test of the software, and for the financing and organization of its distribution and maintenance.

This staged process with its structured incentives is intended to produce a clear description of the proposed computer curriculum by a strong design and development team capable of producing it. The team members can be attracted to this opportunity from any institutional source. The process also provides entre to existing private sector firms in a primary or supporting role at various points in the process.

The period for the preliminary proposal can be six to nine months, with twelve to fifteen months for preparation of the detailed design, and two years for the development and pilot test of the computer curriculum.

Who pays and who gets

o The government

The principal cost to the government is the development cost of $2 million per course, or $16 million total. (This figure will be reduced if preliminary proposals reveal existing experimental software materials previously funded by the government that can be appropriated.) The investment can be spread out over four or five years. Front-end design costs can add $4 million to the total. Distribution and maintenance costs, possibly up to 25% of the development cost, can be allocated to the schools through a user fee.

o The schools

The total cost to schools is made up of two components: equipment; and user fees for software updates. Assuming a hardware unit to *run* this new, more complex software has an acquisition cost of $3000 -- the range of variation estimated by experts is $2000 to $4000 -- and an expected life cycle of four years, and that three students can use a unit daily (with effectively no waiting time,) then the annualized cost per student of a unit is $250.; if five students, $150.

At 25% of $2 million, the total distribution and maintenance cost per course is $500,000, or $100,000 per year spread out over five years. If 40% of the nation's 25,000 secondary schools participate, the annual user fee per school can be as low as $10.00 per course. At a distribution and maintenance cost of 50% and at a school participation rate of 20%, the annual user fee per school is $40. If a profit of 100% is found necessary to stimulate the development of institutional capacity for distribution and maintenance, the annual user fee per school per course is $80.

The annualized imputed cost per school for course development, using the same assumptions of $2 million per course, a life cycle for the software of five years, and 10,000 participating secondary schools, is $40.; if only 5,000 participating schools, $80.

o The nation

A successful program would:

generate working examples of new classroom practice and school organization, which are found by enterprising school system administrators to solve local problems in science and mathematics education;

develop a school market for sophisticated new software for science and mathematics education;

develop new capacity for the development, distribution and maintenance of sophisticated new software; and,

improve science and mathematics achievement for students involved in sustained trials of this software.

II. TRIALS OF RADICAL EDUCATIONAL RESTRUCTURING

Small departures from school practice using interactive technology will not long suffice to meet the changing American condition and the changing condition of American schools. Restructuring trials implemented by school system administrators that are aimed at achieving substantial improvement in science and mathematics education will explore examples of radical, but educationally justified, departures from traditional school practice, with the potential for greater benefits. Benefits will be measured in terms of improved student achievement or reduction in the rate of rising student cost or a mix of the two. Students will learn, who typically do not; students will learn more quickly, allowing for an enriched curriculum; courses will be offered that otherwise are not; and educational resources not needed by faster learners will be allocated to the slower. The nature and expense of these trials will require external support.

This program element aims to assist school system administrators undertake trials of changes in school practice and organization using the best of existing software products. Sophisticated new software products can be phased in as they becomes available. Three complementary approaches for improving science and mathematics education are considered here:

small class instruction, to provide access to selected science and mathematics courses to students now denied;

improving school productivity, to assist school system administrators in the (inevitable) circumstance of taxpayer resistance to increased education levies; and,

special science and mathematics schools, to provide advanced programs to interested and capable students, which can serve as examples of science and mathematics education for regular schools.

Intensive consultation with school system administrators and extensive educational, economic and technological design should precede the implementation of any of the restructuring ·ials described. School system administrators should be expected to want to tie the conduct of these science and mathematics activities to activities aimed at improving education in other curriculum areas.

Federal leadership in sponsoring ·ese restructuring trials should not mean the federal government will bear their full cost. State and local government and business interest is necessary for their successful financing and operation.

A. SMALL CLASS INSTRUCTION

Current data are that of some 25,000 secondary schools, 7,100 do not offer a physics course, 4,200 do not offer a chemistry course, and 1,900 do not offer a biology course. There is some debate to what extent this undesirable condition should be attributed to a shortfall of qualified teachers and to what extent to insufficient enrollment by students to justify a teacher on economic grounds. In either case, students are presently deprived of the opportunity of taking these courses. Ten students per school may be an insufficient number to justify the cost of a classroom teacher on economic grounds; repeated 7,100 times, this figure can represent 71,000 deprived students, as an example.

Whatever the present facts precisely, this condition is more likely to get worse than to improve. School consolidation, undertaken in order to enrich the offerings of secondary schools, has gone about as far as possible; travel time to school in many rural areas is already longer than desirable. Whatever the present shortfall of qualified science and mathematics teachers, it is likely to increase. Industry can be expected to be unyielding in its demand for precisely the talented individuals needed in the classroom, and will outbid the taxpayer for their services. It is timely to explore a possible solution to this problem that represents a radical departure from common school practice: *distance learning in school.*

Distance learning in school is a variation, conceptually and practically, on the open university model, where older, more mature students are expected to learn independently, largely from print materials, outside the social context of the classroom. Centers, which the student may visit occasionally, manned by a proctor, and containing a small library and any special equipment needed for course work, are distributed geographically. This model for higher education has been found to work effectively around the world, in the United Kingdom, Israel and Thailand, often for academically weak students, although with substantial drop-out rates.

In *distance learning in school*, the learning of the younger, less mature secondary-school student is supported by interactive software in addition to print material, and by a social context for learning that includes a small number of other students in a school classroom, a parent or older student to monitor activities, and a qualified teacher, who is a telephone call away. In assisting a student, the teacher can view the student's computer screen on his own.

A course offered in almost any style to the interested student seems a better individual and social choice than none at all, but not at any cost at all, including drop-out rate, especially. Questions about the utility of distance learning in school that can be answered empirically include the average student cost for this instructional model, (under different conditions;) the number of students that should constitute a 'normal' teaching load (which includes the grading of homework and tests) for the remote teacher; and most importantly, the kinds of student who are able to complete course work successfully under these conditions.

The equivalent of four solicitations by the overnment seems desirable for the conduct of this program: (1) course assembly, distribution and maintenance; (2) design study; (3) implementation of trials; and (4) evaluation.

Course assembly, distribution and maintenance

Proposals will be solicited for course assembly, distribution and maintenance. Only advanced cour es for more mature students should be considered for this program, like second-year physics, chemistry and biology, and pre-college and college calculus. More than one curriculum package may be assembled for each course, using existing interactive software and print materials. One dimension of variation distinguishing different packages for the same course might be 'class size', with very small groups of students of one to three needing more complete and supportive curriculum packages.

The course assembly cost will include the costs of identifying existing materials, preparing any 'bridging' material necessary, preparing a self-instructional guide for the student, and preparing a guide for the remote teacher. Emphasis should be on interactive software.

Proposers will be required to structure one or more external reviews during the term of the award in which school system administrators will be strongly represented to assure practical and acceptable course packages.

Adequate capacity exists in the form of private sector firms and non-profit agencies to carry out the assembly, distribution and maintenance of these curriculum packages.

Design study

Proposals will be solicited for a design study. The design will consider classroom space and configuration, location of computer equipment, telephone arrangements, and so on, and emphasize per student cost calculations for 'classes' of varying (small) size. School system administrators will be accorded an important role in the proposal review process to assure practical designs. The completed design will serve as an addendum to the implementation solicitation.

Implementation of *distance learning* trials

Proposals for implementation trials will be solicited from school system administrators. Addenda to the solicitation will include the 'winning' proposals from the *course assembly, distribution and maintenance* solicitation and the completed design study. Project duration will preferably be for periods of four to six years and in no case for less than three. Successful proposers will be required to participate in an overall evaluation.

Evaluation

Proposals will be solicited for evaluation of this program, including the student cost for this instructional model; the number of students that should constitute a 'normal' teaching load for the remote teacher; the relative effectiveness of different course packages; the kinds of student who are able to complete course work successfully and factors influencing completion; etc. Early evaluation data can serve as a basis for comparison as sophisticated new software products become available that can be substituted for the best existing products that are initially included in the course packages for this program.

Cost distribution and budget

The distribution of costs for this program can vary. The principle can be adopted that the federal government should bear relatively fixed program costs while participating schools and school districts bear costs that vary with student number. By this principle, the government would bear the course preparation costs and the course maintenance costs for a fixed period of at least six years; the design study cost; and the evaluation cost. Participating schools would bear the costs for preparing suitable classroom space, for equipment acquisition, telephone charges, course distribution, and a pro rata share of the remote teacher. Application of this principle allows for a relatively large number of school trials at a cost to the government that increases relatively slowly with the number of participating schools.

The government can increase its share of the cost by partial support of equipment acquisition, for example.

B. IMPROVING SCHOOL PRODUCTIVITY

The opportunity for improving education that is based on small classes and an excellent teacher is becoming vanishingly small. The taxpayer is unlikely to sustain the recent history of growth in the public education budget necessary to support the combined cost of small classes and excellent teachers, in the face of continued competition for academically capable individuals from the economy.

The partial substitution of capital for labor has been a solution to the problem of rising costs and declining productivity in every other sector of the economy. It seems timely and prudent to explore this avenue for improvement in education. The cost of computer hardware will continue to decline for the foreseeable future; the cost of teacher labor to rise.

Educational debate today favors *understanding* over *basic skills* as the goal of improved education, in the absence of an operational description of the royal road to either. Without exaggerating the present pedagogical capabilities of interactive software, which depends upon many factors, the computer has demonstrated potential for implementing drill-and-practice, said to lead to rote learning of the *basic skills*; and problem solving, said to lead to *higher order thinking skills*. In trials of some examples of sophisticated new prototype software, students have demonstrated success in learning course content where they have otherwise typically failed. The empirical evidence is clear that students, on average, can advance more quickly in the curriculum using individualized instruction. The potential of interactive technology for improving educational productivity has not seen adequate public trial.

A wide range of variation in productivity trials can be imagined in which capital resources are partially substituted for labor resources in the schools. A willingness by teachers and teacher unions to explore the issue of specialization would further broaden the range of design options.

Important questions that can be answered empirically include the range of student costs that can be achieved by variation in traditional classroom instruction and reorganization of the school day; the differential rate at which ifferent students advance in the curriculum under an expanded regime of individualized computer-based learning; the *savings* in resources that can be reallocated to assist low achievers; and so on.

An expanded regime of individualized computer-based learning does not exclude the use of other instructional methodologies during the school day. The central question of these productivity trials is precisely the mix of lecture, traditional classroom instruction, small group learning, individual tutoring, and individualized computer-based learning that should replace the exclusive lock-step practice of traditional classroom instruction that is in widespread use today.

Generally, the management and conduct of this program can parallel that of *distance learning in school*, with some important differences! This program involves the large-enrollment core courses in science and mathematics education, not the small-enrollment advanced courses. Teachers are generally available for classroom instruction in these courses. Textbooks for these courses are typically available from school publishers, who will have strong interest in the conduct of this program.

Course assembly, distribution and maintenance

Proposals will be solicited for course assembly, distribution and maintenance. Several curriculum packages should be assembled for each course, using existing interactive software and print materials.

The course assembly cost will include the costs of identifying existing materials, preparing any 'bridging' material necessary, and preparing a guide for the teacher. The availability of a teacher with subject-matter expertise should reduce the requirement for a self-instructional guide for the student and for new 'bridging' material. The course package should emphasize interactive software for individualized learning that allows the student to advance in the curriculum at his own rate.

Proposers will be required to structure one or more external reviews during the term of the award in which school system administrators will be strongly represented to assure a variety of practical and acceptable course packages.

Adequate capacity exists in the form of private sector firms and non-profit agencies to carry out the assembly, distribution and maintenance of these curriculum packages. School publishers should be expected to compete strongly for the opportunity.

Design study

Proposals will be solicited for a design study. The study should consider the organization of instructional space for a school that aims at replacing the lock-step practice of traditional classroom instruction with a mix of lecture, classroom recitation, small group learning, individual tutoring, and individualized computer-based learning. It should emphasize per student cost calculations for various mixes of these instructional methodologies.

School system administrators will be accorded an important role in the proposal review process to assure practical designs. The completed design study will serve as an addendum to the implementation solicitation.

Implementation of productivity trials

Proposals for implementation trials will be solicited from school system administrators. Addenda to the solicitation should include the 'winning' proposals from the *course assembly, distribution and maintenance* solicitation and the completed design study. Project duration will be for periods of four to six years. Successful proposers will be required to agree to participate in an overall evaluation.

Evaluation

Proposals should be solicited for evaluation of this program, with emphasis on student achievement and average student cost at participating schools. Inter-school comparisons of the effect of variations in the elected instructional mix should be particularly revealing. As they become available, the effect of sophisticated new software products on student achievement should be observed.

Cost distribution and budget

A principle for distributing costs for this program will have to be found that takes into account its potential for affecting the entire school program beyond science and mathematics education, and the possible need for school building modification.

C. SPECIAL SCIENCE AND MATHEMATICS SCHOOLS

A complementary federal approach to help assure the quality and quantity of U.S. scientific manpower is assisting interested State and local education authorities to establish special secondary schools or academies for science and mathematics education. A substantial local planning effort would be required for each school contemplated, whose organization, operation and educational program would doubtless influence those of regular secondary schools in the region. Some especially interesting planning issues include the content of the educational program; the instructional methodology and organization of the school day; the length of the school day and duration of the school year; the mix of labor and capital; the nature of the teaching staff; and the average student cost.

Concerning the content of the educational program, these special schools represent an opportunity to explore and redefine the science and mathematics education requirements for the *knowledge worker* of the 21st century. A critical educational decision that sharply affects student cost is choice of the instructional mix of large lecture, traditional classroom instruction, small group learning, individual tutoring, and individualized computer-based learning -- the mix of labor and capital. Important questions that can only be decided empirically are that length of the school day and the duration of the school year required for this strenuous academic program; and the sorts of teachers and teacher training needed for large lectures, and individual tutoring and counseling.

Strong interest by the public and by the business community are necessary to assure the successful financing and operation of these schools. A measure of resistance to the concept can initially be expected from some school system administrators, concerned about the overall educational effect of skimming good learners from regular schools. A small number of successful trials to refine the concept and its practice should alleviate unnecessary concern and generate broad national support.

To initiate this program, the government should solicit planning proposals from State and local education authorities for fixed awards, in amount and duration. Implementation awards for a variety of trial schools should be for a period of at least five years and can cover instructional costs in excess of the average for the region.

III. APPLIED COGNITIVE SCIENCE; TEACHER TRAINING

A program that aims in the long term to explore and develop a science and technology option for American education will be concerned with applied research in cognitive science and artificial intelligence, and with teacher training. Not a central focus of this grant activity, these topics are only discussed briefly here, unaccompanied by any specific proposals for action.

A. Applied Cognitive Science

The successful development of a science and technology option for education depends partially upon new knowledge from research in cognitive science and artificial intelligence. Much has already been written about the educational potential of this research, which will not be repeated here. Areas of research with high potential for educational payoff, institutional arrangements for conduct of the research, and suitable levels of investment are subjects even now under review by private foundations and agencies of the federal government.

Without doubt, the successful conduct of activities proposed above will make great demands on the relatively small academic community concerned with applications of cognitive science to education and training. The special knowledge and expertise of this community are required for the development of sophisticated new interactive software; and for school-site research on the cognitive, affective and social effects of a more individualized program of education on students. This prospect should raise a measure of concern about the capacity of the academic cognitive science community to meet present and future demands for basic, applied and developmental research.

Sensitized to the possible shortfall in capacity, federal program managers can use the proposed activities as an opportunity for expanding the affected community by interpolating support for graduate research assistants and graduate fellowships whenever possible and appropriate.

B. Teacher Training

What should constitute a suitable program for the pre-service preparation of classroom teachers has long been debated, with little conceptual or practical resolution. The introduction in schools of an educational model that assigns a larger instructional role to science-based interactive technology for individualized learning should affect this debate, and possibly advance its resolution. The increasing use of science-based artifacts in health has had the affect of deciding the nature and content of medical training.

In principle, it seems the importance of training in techniques of classroom management should give way to an emphasis on the knowledge and techniques necessary to facilitate individual student learning, for which traditional classroom instruction is only a surrogate. As a corollary, the importance attached to training teacher candidates in techniques for *lecturing* the classroom student on facts in the textbook and for preparing students to solve problems *at the end of the chapter* should decline sharply. Conversely, the importance attached to developing in the teacher candidate a deep knowledge of the subject matter, and the knowledge and technique required for individual student tutoring and counseling should sharply increase. With suitable development, the changed knowledge and practice that are only suggested here could in time become the basis of a new professional credential.

Candidates in training for this credential would presumably be given the benefit of the same individualized instruction, which emphasizes the use of interactive technology, that they are later expected to implement in school. Training programs necessary for the success of the restructuring proposals described in earlier sections above will have to be improvised.

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CONCLUDING REMARKS

We are concerned here with instructional strategy and tactics; with developing a science and technology option for education; and with the expanded use of interactive technology for individualized learning. Alternatively, many observe that 'in American education, politics is everything,' by which is presumably meant that educational financing and programs are strongly influenced by what everyone wants; that in education 'everyone is an expert'; and, not surprisingly, that what everyone wants and thinks best can vary considerably.

This picture contrasts sharply with that for agriculture and medicine, where a deep and abiding understanding of the meaning of hunger and pain appears to inhibit the politics of individual preferences concerning how best to deal with them. Instead, there is widespread agreement that hunger and pain should be reduced to a minimum, and that the strategy of choice is the application of science and technology, which have so far had little to say to education.

Now, many experts think the objective situation is changed; and that enough scientific knowledge and enough technology at the right price exist to begin the systematic exploration of their educational potential. Initially, the most visible consequence of the extensive use of interactive technology in school will be a change in traditional classroom practice and school organization. Those who prefer traditional classroom practice will resist. But the strategic aim of developing a science and technology option is to minimize ignorance over the long run at a price society is prepared to pay. This is good thing for America, and for the less wealthy part of the world as well, where a large fraction of the planet's children remain uneducated and undereducated.

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APPENDIX 1

Information Technolc_y Directions for NSF Science Education

Report of a Meeting Held at New York University
on 15 January 1987

Information Technology Directions for NSF Science Education

Report of a Meeting Held at New York University
on 15 January 1987

Arthur Melmed, Chairman
Alan Lesgold, Rapporteur

Background

Under a grant from the National Science Foundation (NSF), a meeting of experts was convened at New York University to discuss ways of improving the productivity of mathematics and science education in the United States, using educational technology. The meeting began with a presentation by Dr. Andrew Molnar of the Science and Engineering Education Directorate at NSF. Dr. Molnar outlined some of the reasoning behind the proposed major expansion in the NSF budget. He then went on to discuss the specific shortcomings in mathematics and science education that NSF confronts.

The United States has a major shortage of scientific and technical manpower at all levels, from personnel who can be efficiently trained for technical occupations to engineers to doctoral-level scientists. Because scientific theory and method build upon foundation mathematics and basic principles, lack of adequate science and math schooling at the precollege level is a substantial barrier to later entry into technical and scientific positions. Accordingly, if the United States is to overcome its present status as a net importer of high technology, it must produce more scientists and make more of its work force trainable for technical positions — it must increase its science and mathematics education productivity.

Educational productivity can sometimes be improved through better motivation and leadership. However, more is likely to be needed to improve science and mathematics education in the nation's schools. The current state of our schools is that there is a lack of adequate teacher personnel in exactly the areas where productivity must rise. Fewer than half of the teachers of precollege mathematics and science are certified in all the subjects they teach. Of the 14,000 to 15,000 high schools in the U.S., 7,100 have no physics courses, 4,200 have no chemistry courses, and 1,900 have no biology. In addition, many courses lack fundamental rigor because of inadequate teacher capability. In general, our teachers are motivated and well led — there just are not enough and they sometimes lack the skills they need. Given a substantial shortage of scientifically literate labor force, it would seem senseless to attempt to solve this problem via economic incentives alone. A scientist attracted to teaching is simply one fewer scientist available to drive technological production, and industry already shares the scientific literacy shortage with education.

Summary of Discussion

In the circumstances outlined above, the experts listed in Appendix 1 met at New York University on January 15th, 1987 to discuss ways in which educational technology can be brought to bear on the problems of mathematics and science education and how potential solutions to these problems can best be demonstrated in a convincing way. The participants represented a variety of viewpoints and pursued a variety of agendae. An outline of the comments throughout the day is attached as Appendix 2. There were certain clear themes that recurred throughout the course of the meeting, and it is these themes that are reported in this report.

Participants, responding to (a) recent technological and scientific advances, (b) the problems of science education in the United States, and (c) the constitutional, political, and bureaucratic character of schooling within the United States, agreed that the critical next step in the application of educational technology to improving the productivity of mathematics and science education was the development and extended trial of a number of complete technology-assisted science and mathematics courses for use in -- and possibly outside of -- school. Some form of federal support was deemed to be necessary for this purpose. Further, it was felt that these courses should be prototyped and tested in ways that heavily involve school systems, school-related industry and researcher/developer teams in efforts to demonstrate productive ways in which the use of technology can restructure the educational process. The need for support of major, integrated, course-sized efforts based upon competing approaches to the use of information technologies was clear to all. Smaller efforts cannot produce substantial change in systems as stable as our schools, and substantial improvement is needed. Further, schools are requesting and clearly need broad examples of how they can develop substantially more effective structures for fostering mathematics and science learning.

Summary of Consensus Views

- The participants favor the establishment of a number of course-sized, technology-driven development efforts. Each of these efforts should apply new technology, artificial intelligence techniques, and/or cognitive science principles to the teaching of a whole course. Because of the economics of the market for school goods and services, it is extremely unlikely that any entrepreneurial source will provide major funding for these ventures — there are much more profitable opportunities elsewhere, and the risks are too high. In the absence of private investment, federal support should be provided for these projects.

  The efforts should concentrate on "bridging" subjects that are needed to progress in studying science, such as algebra, calculus, physics, chemistry, and perhaps foreign languages. In each case, the first year of such subjects should be the focus (to maximize the number of students affected). These are subjects for which the curricular goals are reasonably well defined, so the outcomes of technological efforts can be more readily assessed. Ideally, there should be multiple, competing course development efforts, so we can learn which approaches are most promising and how robust the new educational technologies are.

- The goal of each course should be mastery, in a rich, broad sense. That is, students should not only be learning scientific and mathematical principles and methods; they should be able to use their knowledge in everyday life. The courses should both replace and go beyond existing standard courses.

- The cycle of development and trial for each course needs to last at least four to five years, preferably six to seven, and they need protection from premature demands for final accountability. A uniform characteristic of productive innovations in education, as in industry, is that initial prototype efforts are generally no better than what preceded them; a few years of tuning are required. A n v automobile gets several years of tuning and refinement before it is released — new curricula need this, too.

- The evaluation of the final products should be sensitive not only to current standards for measuring achievement in science and mathematics courses but also to the two preceding points concerning higher than usual criteria for these efforts and the need for several years of refinement before summative evaluation begins. While the appropriate criterion for evaluating the outcomes of mathematics and science courses is mastery, as opposed to partial learning, it is important that mastery criteria (and the uses made of them) not superficial or destructive.

- The courses should be developed and tested in realistic environments, real school systems with a wide range of student backgrounds and abilities and normal financial and other resource constraints.

- The development projects should vary in the design philosophies they employ. A basis for a cognitive science and technology of education now exists, and some of the supported efforts should be driven by that work. On the other hand, advances in video delivery technology, such as the interactive compact disc, offer new possibilities for motivating students who do not respond to more abstracted media. The superiority of one approach over another (or the advantages of mixing them) can best be established empirically.

- Just as current printed materials include lesson plans, consumable materials, texts, etc., which are integrated into a coherent package, so the courses developed in the proposed efforts should be integrated wholes. Just as present commercial curricula require minimal materials-specific teacher training for their use, so the new products should either be usable with minimal training or should include training as part of the target product.

- The course development projects should make technology a lever for new educational visions. They should inspire in teachers and school leaders new ideas for structuring the learning process.

- More generally, the projects should help school leaders, teachers, and the American public understand the ways in which education can improve and the role that new science and technology can play in that improvement. They should convince, demonstrate and lead as well as inspire.

- A significant barrier to private initiatives in educational technology today is the lack of standards for computer equipment and the insufficiency of most equipment already owned by schools. The projects supported in this effort should use standardized hardware, operating systems and software. While premature standards stifle effective development, the existing lack of standardization also makes improvement impossible. A compromise is to have most efforts use standards set in other markets, such as the newly emerging interactive compact disk market, the small business computer market, and the low-end artificial intelligence market.

Details of the Discussions

Support should be provided for a number of course-sized development efforts. This was the major theme that emerged in the discussions. A few years ago, there were a few venture capitalists involved in projects to develop educational software. However, they were discouraged by several problems. First, the market for specific programs designed to teach one component of the curriculum is quite small. Schools have stable, deeply-ingrained instructional practices. When a new piece of software appears, teachers immediately ask where it goes, and what it replaces, in the curriculum. Truly innovative software requires some rethinking of curriculum, which is hard to do in general but is particularly hard to do for separate, unconnected fragments. The costs and risks of full-scale curriculum development based upon computer technology were, from the beginning, to high to attract venture capital. The exceptions are efforts to provide systems to help children practice skills acquired from existing best-selling print curricula.

Software is generally purchased at low levels of the school system, so each sale requires a sales effort that is large relative to the size of the sale. A publisher's sales crew can invest the same amount of time selling a piece of software to one teacher as it spends convincing a decision maker to purchase materials for an entire district. Because the decisions are local and because local discretionary budgets (for individual principals or teachers) are extremely small, there are pressures to make pirate copies of educational software, further reducing the return on development and sales investment. Two other factors relate to the hardware in schools. First, it is underpowered, making it harder to produce software that it can run well. Second, it is non tandard, which means that reaching the school market requires the production of three or four different versions of a program, to match the different operating systems used. And, the spectrum of school computers changes continually.

In contrast, existing print projects represent long-term investments, so that, in general, most curriculum product development is primarily a tuning of existing designs. The print curriculum world also provides a particularly strong money maker, the disposable workbook. Relatively unspecialized talent can be recruited to develop workbooks, which are keyed to existing texts. Once designed, these workbooks are a continuing source of sales. So, developing a text series lays the foundation for sales of disposable materials. So far, publishers have not found the computer-technology equivalent of the disposable workbook. Relative to books, technology is more expensive and less likely to yield a high return.

Once the front-end development costs have been borne, the situation changes to some extent. Publishers might even develop homework materials that build upon the content in the courseware. Or, they might market home-computer software keyed to the school materials. At the very least, the high development cost problem is solved. Certain industries, for example the computer manufacturers, might welcome courseware to their catalogs if they thought it could help sell hardware. In general, there are good reasons for publishing companies and computer manufacturers to cooperate in courseware development projects once they are relieved of the high start-up costs.

Their help will be needed. The competing source of courseware development expertise is, to a large extent, the universities. It was noted that universities are the best repository of bright, creative, inexpensive talent. However, university-based projects often lack real-world development experience, over-specialize, fail to make realistic decisions about the scope of projects, use of standard hardware, etc., and may lack general project management capability. University personnel also are often insensitive to issues of intellectual property rights, thereby decreasing the rewards available to offset development risks. Th[illegible] are areas where industry involvement can add strength.

In summary, despite the lack of profit motivation for major educational technology ventures, the participants shared a belief that substantial, technology-enhanced course development projects were the best way to attack the science education productivity problem. A number of specific issues relating to that possibility are discussed below.

The goal of each supported effort should be the mastery of ecologically valid performances. Two participants spoke strongly in favor of mastery approaches for the proposed curriculum projects. There was general support for setting the goal of mastery of, rather than moderate competence in, the course curriculum. Further, there was specific support for goals of externally referenced mastery. That is, students taking the courses to be designed should end up able not only to demonstrate textbook knowledge of the materials but also to apply their new skills in relevant real-world situations. It was agreed that the projects should set high goals and show that they have been met.

On the other hand, there was strong objection to any mastery system driven by micromanagement or curricular fragmentation. It was noted that there are several inappropriate practices that are referred to as mastery approaches. These include systems in which small curricular goals are attacked one at a time, in restricted contexts, with students not permitted to move on to other material until they pass the current mastery test. Such approaches are not consistent with the goal of enhancing students' ability to assimilate and operate upon bodies of knowledge. Further, they can have the effect of perpetuating disadvantages due to social or economic status. Mastery relative to external criteria should be a broad curricular goal; fragmentary mastery of small snippets of knowledge should not be an internal course barrier.

The supported projects need to last at least four to five years, preferably six to seven, and they need protection from premature demands for outcome accountability. It takes a school system years to adapt to new approaches. Further, many aspects of a curriculum need to be tuned in light of experience with real children in real schools. It appears that curriculum projects undertaken so far have had the property that short term effects are no better, but not particularly worse, than existing methods. In contrast, after several years of tuning, the new approach can have a substantial advantage over present practice.

Politically, it is difficult to have an expensive project under way for several years without experiencing a call for evaluative data. Consequently, participants saw the need to protect the proposed projects from premature accountability of certain forms. It is appropriate to ask for external examination of the rate at which materials are being designed and produced and of the process whereby the curriculum is being tuned and evaluated. The performance of students in the first years of the project should not, however, be considered. Also, the approach to accountability in terms of materials productivity should not interfere with the inevitable need to revise prototype materials in light of formative evaluation data.

Some of the efforts that are supported should be driven by major advances made in recent years in artificial intelligence and other cognitive sciences. The general view of participants was that cognitive science and artificial intelligence research had great potential for improving education and for driving the development of new, technology enhanced approaches to education. It was felt that continued support for research and development work applying cognitive science and artificial intelligence to education was important. Some participants held the view too that the motivating power of quality video was a critical part of the new technology's potential for education. Course developers are advised to seize these opportunities where appropriate.

The supported courses should be developed and tested in realistic environments. It was broadly agreed that the courses should be developed, or at least tested, in realistic school environments. It is a truism that all educational innovation seems strikingly successful in the hot-house environment of its initial development, where a class sees not only its teacher but also a cadre of curriculum specialists who make everything turn out right. The other side of this truism, though, is that most educational innovations show marginal results when they move from the development environment to real schools. Real schools are short staffed, have a wide mixture of children from both supportive and nonsupportive environments, have staff entrenched in particular ways of teaching, and often lack in-house troubleshooters. The courses that are developed must, from the outset, address the environments and people for whom they will have to be effective.

The software industry model is to have three levels of implementation, an alpha level in which testing is entirely in-house, a beta layer in which specific users keep good records of their test usage in order to inform the tuning process, and then a gamma level, which is for general public consumption. Time likely will not permit the full use of this three-stage strategy. The beta testing level will have to occur earlier than for industrial products, and it will have to involve more use of realistic school environments in the earliest stages.

The competing course development efforts were seen as an experiment. The critical decisions and experiences of the developers should be recorded so that others can learn from them. Sometimes, the formal decisions of organisations do not reflect the important aspects of a group effort. For this reason, projects might choose to include an anthropologist or other specialist to observe and study their efforts.

The supported projects should produce integrated courses. As noted above, schools are very stable entities that resist change. A free-standing piece of software meant to teach some specific concept that might or might not be in the curriculum will not readily penetrate a system organized around an integrated curriculum and supported by schedules, texts, workbooks, teacher manuals, and years of prior experience. For that reason, it seems likely that significant change may require the displacement of one stable system with another, i.e., the introduction of a complete course. Further, the ecological validity of the new educational products, in terms of their ability to teach knowledge that transfers and that is relevant to the outside world, rests on teaching a coherent mass of knowledge and not just one fragment.

American education rests on the belief that schooling is fundamentally a local matter. On the other hand, technology is generally exploited in part by some form of centralization. Indeed, the fact that only a small number of competing texts are even available for a given subject is partly the result of the inevitable move from cottage industry to large-scale technically sophisticated production. Nonetheless, a natural reluctance to further decrease the range of choices open to local school systems prompted the participants to favor locating the proposed projects in *standard subject areas* such as the bottleneck courses for scientific and technical careers, such as algebra, calculus, physics, chemistry, and perhaps introductions to foreign languages.

Some of the forms of technology-enhanced instruction that might be exploited in the various course experiments include use of video technologies such as interactive compact disk to provide overviews, reference data bases, and ties to real world applications; coached practice environments on computers, simulation environments that can not only demonstrate phenomena but also explain them (e.g., efforts driven by current work on qualitative physics); and exploratory microworlds, generalizations and extensions of the traditional science laboratories. Some of these applications will require powerful computers, but these are becoming affordable.

Schools now own many computers that have 8-bit processors and 64,000 characters of memory. Machines with ten times as much memory are now well under $1,000, and chips with 640 times as much are about to be introduced — soon, two chips will provide 1,000,000 characters of memory. The key to rationalizing school hardware problems is to develop whole courses' worth of software that will make a particular kind of machine worth buying. That, in turn, will create a de facto standard, just as it has in industry. Also, as computers become sufficiently powerful, it is increasingly feasible to create the same operating environment on many different versions of hardware. Operating systems such as Unix, OS/9, and MS-DOS already exist in multiple machine architectures.

The supported projects should make technology a lever for new educational visions. Participants spent considerable time on the theme that the proposed projects should use technology to open up new educational visions. A number of issues were considered.

One concern was curriculum. In spite of the belief we have in local supremacy in schooling, the country does, in fact, have highly stable national curricula. Publishers develop tests that measure what is common to a course across many different school systems. School systems see high scores on such tests as a measure of success and select materials that cover what is tested. Publishers, realizing this, specifically design text materials to correspond to a mixture of current demands and current test content. An example of this was the establishment of Pascal as the dominant computer language for high school programming courses. An advanced placement test was demanded by parents and children who noticed that the introductory programming courses in colleges tended to cover material they already had learned in high school. The test maker did some research and found that Pascal, though not universal, was the most common language in introductory college programming courses; they would have surveyed high schools, but not enough taught programming at the time, and there was wide variation in course content and in the language used. The test that was developed assumed knowledge of Pascal. Soon thereafter, the available texts and the local course contents were dominated by Pascal.

The supported projects should avoid the creation of whole new curricula and address the current demands. However, if the materials produced are truly more productive, it should be possible to extend them beyond current practice to include additional curricular goals. This extension process should accommodate a variety of visions of how education can proceed in the future. Commercial efforts, like WICAT and ESTC will attempt to provide improved performance tied strongly to existing testing practices. The efforts proposed in the NYU meeting should go further toward the goals outlined above. They should be more than a means of boosting scores on the existing tests — though they should be judged minimally by whether they do raise such scores, too.

The projects should convince, demonstrate and lead as well as inspire. School systems, in spite of the inertial forces described above, actively seek opportunities to change. However, they are pushed and pulled in all directions. Glib statements of vague ideas abound, but clear directions to follow are absent. Participants saw the proposed projects, in their varying methods and design philosophies, as a set of possible directions along which different schools can move, each in its own way. Therefore, the projects must take account of, involve, and set possible directions for all the constituents of education: teachers, school leaders, students, and parents.

Marginal, incremental change seems unlikely to have significant or lasting effect; major restructuring is needed. School people believe this as much as the meeting participants do. What technology can do is not merely to improve the productivity of our current practices. More important, it can enable a fresh look at subject matters and thereby help in restructuring curriculum. Given integrated word processing and spreadsheet systems, does it make sense for writing to be done only in English classes while science labs deal only in tables to be filled in? Given electronic networks, are geography courses, foreign language courses, and composition courses totally separate undertakings? Students in expensive, private schools make exchange visits to other countries as part of their foreign language training; could public school students make exchanges via electronic networks? Scientists spend much time doing computer simulations; should science students do that a part of the time instead of memorizing definitions to which they cannot relate?

A final issue that arose in this regard was the constituency to be addressed. Inadequate science education has a long history in this country. It was felt that at least some of the projects suggested might also be of use to adults who wish to acquire now what they missed during their formative education. Can the same software used in schools also be available in libraries, in computer stores, in school laboratories at night? Will an appropriate interest group want to provide, for parents, a Spanish-language version of what their children use during the day in English? Such possibilities may attract private investment at later stages in the proposed projects and might be a partial basis for deciding which consortia should be selected to develop courses under the program proposed.

NOTE: Individuals appearing in Appendix I not able to be present at the workshop are Edwin Cohen, David Florio and James Finkelstein.

Appendix 1

NSF-SPONSORED WORKSHOP
15 January 1986
NEW YORK UNIVERSITY
Loeb Student Center
566 LaGuardia Place [corner of LaGuardia & Wash. Sq. S.]
Top-of-the-Park, 5th floor
Starting time: 9:15AM

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Appendix 2

Report of NSF Science Education Program Planning Meeting

Overview

Burnham: What are our shared visions?

Molnar

Context: Preparation for rapid expansion of NSF budget

Stimulus is negative balance of even high-tech trade

Educational problems

Shortage of potential scientific/technical manpower

Quality problems

Less than half of math/science h s. teachers certified in subject(s) they are teaching

Quantity problems

Of 14,000 to 15,000 high schools in U S.

7100 have no physics

4200 have no chemistry

1900 have no biology

Why technology

Past approach of one-shot teacher institutes not effective

Meta-analyses show TV, videodisc, and CBI are at least as good as, and faster than, standard approaches

CURRENT AND NEAR-TERM R&D ON APPLICATIONS OF COGNITIVE SCIENCE AND TECHNOLOGY TO EDUCATION AND TRAINING

Cognitive task analysis

Models of procedures

Subtraction in detail

Auto troubleshooting in some detail

Real-world diagnoses at lesser levels of detail

Representational (mental modeling) capability

Qualitative physics

Analogy and other partly empirical work

Problems in understanding ties between conceptual and procedural knowledge

Anderson's theory insufficient

The computer as research assistant

Artificial intelligence methods

Device models

Diagnosis

Language processing

Intelligent construction of exercises to meet curricular specifications

Basis for individualization

Research on skill and its acquisition

Constructivist theory

Backing for guided discovery, structured laboratory approaches

Need for concreteness

Backing for reciprocal teaching approaches

Role of causal, functional explanations

Procedure learning theories

New understanding of the role of practice

Performance orientation: Coached practice useful

Situation orientation: Increasingly complex microworlds

The limitations on processing capacity

Utility of intelligent tools for students

Schwartz: Current technology scene

Some technological facts

Generally, hardware issues not a bottleneck to development of educational tools, except perhaps for most advanced applications

Technology is broadening from computer to other technologies

PC in a few years will be 15MHz processor and 4Mbit memory chips (16 chips would give 8MB)
Much of the new technology is from outside the U.S.
Videodiscs, CD-ROM, and CD-I
Cheap hard disks
WORM technology
Real-time production on cheap machines of 2-D cartoon images possible virtually immediately
Hollywood-level 3-D still expensive
Specialized graphics and other chips dramatically cut costs
Broader issues
A major industry is needed to produce educational materials Technology is not the main bottleneck. Need to "beat books" This will not be cheap. Will have TV levels of cost. (AML. $1-4k per minute is what TV people tell me)
Note that both public education and commercial movies cost about $5/1.5hr to deliver.
Need for standardization of interfaces and higher-level languages
Maybe common lisp is the right standard
But, it avoids interface and run-time issues

Discussion after Schwartz

Soloway: Are our goals too complex for standardization
Anderson: Standardization comes from large markets, not government
Bowman: Stressed importance of CD-I standard
Anderson: Described CD-I
Maybe the standard, maybe only an instance of the technology
Phillips/Sony developed. Licensed to Sony, Hitachi, Matsushita, etc.
Current version: 68070, 1MB memory, memory may increase
Will drive up production values threshold and turn educational market into a big company market
High production costs, low delivery costs
Soloway: Standard too superficial, too low
Bork: All this really aimed at the home market
Mecklenberger: All this is home entertainment, not schools. It's using technology to beat the system
Melmed: Sudden rapid crash in the costs of technology, especially on the graphics side.
Haver: Will CD-I be upstaged in 5-7 years?
Weingarten: CD-I ties together the various media that have been developed.
Stressed importance of integration
Gattis: What do we mean by standards?
At one extreme: media standards
At other extreme: definitional standards
Schwartz: The need is for a higher-level language standard
Anderson: What does it mean to say that a standard could be upstaged?
Schwartz: CD-I will succeed, and we have to deal with that!
Charp: Hardware isn't the driving issue
Selby: Can industrial/military training drive things?
Bunderson: Will it sweep through the schools
It lacks testing and data collection
Pricing of disks a problem
Management of the volume of disks a problem
Soloway: Need more people and more computer power. Maybe we're closing off to quickly in standardizing
Bork: Things like the Sleeman algebra tutor now on MS-DOS machines
Bruce: A fourth category: Integration with existing classroom structures or evolving new integrated forms
Teacher-centered efforts
Siegel There's more than cognitive science involved. Suppose you were doing a basal reading series.
5-7 yr project.
$5-7 million
Need "highly integrated" teams
Most current stuff not mainline curriculum but rather supplementary materials
Selby: We need some exemplary successes.
Molnar: How much does it take to convince?
Bork: What about "Writing to Read" and similar efforts?
Bruce: Different groups will need different evidence to be convinced.
Mecklenberger Real question. Are there any good ones? There's lots of good stuff there already that people are starting to use
Schwartz: Really convincing good materials are needed to drive the field.

Fisher Even current educational knowledge can be enough to drive some good technological advances.

Pea: Who are the audiences to be convinced? What evidence is needed?

Anderson: Ecological validity in schooling depends on curriculum, not on microscopic fragments of curriculum.

Need for training materials producers Designers needed who understand cognitive science and media. No one is really that good at doing this stuff, yet.

Bork on Academic software development

We have emergency needs and technology is not the barrier

Problems of software development in academic environments

The research syndrome: Everything has to appear to be research Development, though, needs to go beyond theory

Too much concern with hardware. It's not the bottleneck!

Lack of real-world experience in the development groups.

Narrow specialization.

Lack of experience in curriculum development

Lack of management capability

Advantages to software development in academic environments

Bright faculty, and especially bright students

Some curriculum development already going on in universities, e.g., Open University and others modeled on it.

Bork's proposal

The large-scale experiment: 20 full-scale courses.

$200,000,000 over five years

Should be developed by lots of different groups with different viewpoints

Should be careful documentation of production and usage.

Need international cooperation, perhaps involve World Bank.

Perhaps need mixture of private companies and universities

Discussion after Bork

Charp: Agrees with Bork's problems. But can't impose large-scale development on existing educational system

Bork: Must be done incrementally; schools clamoring to participate.

Melmed: Enrichment or instruction?

Bork: It will be different than conventional instruction, but it should teach the whole course.

Gattis: Universities unrealistic in terms of hard[illegible] e choices, intellectual property rights, etc

Soloway. Universities won't play without an alternate structure; maybe separate nonprofit corporation

Universities produce mainly preprototypes.

Pea: What is THE curriculum; educators want to rethink curriculum!

Agrees with Pea.

Anderson: Schools do more than "teach the curriculum." Reform movements based only on intellectual principles fail.

Siegel: Centers mean university-industry-schools partnerships.

Bunderson: When ETS came in to evaluate TICCIT, even the summative data weren't enough. Also, from his experience in formative evaluation, several semesters of tuning were required before TICCIT was better than a good teacher. Need years of formative evaluation in these programs - at least four years. Note that teachers take at least three years to learn to use a new text

Bruce: Problem of fitting demonstrations into the mold of a course or a curriculum. We may need some whole new courses or a major and radical redesign of the curriculum

Another key evaluation question: How do technology effects vary with ages and subjects?

Haver: Private sector trends

Financial overview

Educational publishing is perhaps a $2 billion/yr market

Hardware people: perhaps another $2 billion/yr

Independent software producers

in 1980, 300 companies for home/school

in 1986, perhaps 50, and they're dying

All venture capital has withdrawn from independent software developers, even the winners didn't meet return goals of venture capitalists

Most publishers cutting back on software development, but all watching it carefully

Educational publishing companies spend $200,000,000 on all product development combined, no more than $10,000,000 on software development.

Who sets the curriculum

It's a highly stable process

Publishers publish what people buy

Testers set the standards against which texts are evaluated -- they must teach what is measured.

Teachers establish sales patterns by text selection -- they generally don't want to change very much -- it's hard work.

Could do excellent video for physics, for example, but it might not get used much at all if not correlated with currently used texts.

No way to profitably develop and sell educational software today.

Software sales of perhaps 2,000 schools is about all that can be achieved, at most, today

Discussion after Haver

Mecklenberger: WICAT and ESTC are two big efforts to break the textbook cycle It will be interesting to see if they do any better.

Gotts Big problem is the compatibility problem. Need to make 3-4 different versions of every product. Much more profit in CME and administrative computing, because it is economically productive and usually for MS-DOS machines.

AML Note how industry and DARPA solve this -- prospectively, not retrospectively!

Any hope of automating software conversion?

Bunderson: Wicat marketing scheme very different -- more on TO'AM model. 20 min/da in computer resource center

They sell to central administration

WICAT still not very profitable

Molnar: Two major problems:

Market too weak

NSF spent 10 years building curriculum

Other thoughts

No "farm bank" for developers

At what level (city, school, state) should software be purchased to create a reasonable market

Performance never plays a role in software selection, given 90% + of budget in teacher's salaries

Problem: How do you get more sales (100 times the current dollar volume) for the software

Anderson. Market share costs money (initial investment)

Fisher. Infers that the textbook industry is the wrong place for the software problem to be solved

Bowman: What is the size of the school market for independents -- $20-30 million/yr. Add general purpose software, like WP. Maybe publishers sell $20-25 million/yr more.

Consumable workbooks is where the money is, and software actually destroys some of this.

Bork: Japan first studied everyone's mistakes in educational software development. Just now getting started.

We should think about the training market and the home market and the military market, too.

AML (thoughts during mtg): Why is training market easier than school market?

Immediate payback.

No piracy?

Larger-scale decisions to purchase?

Haver: We don't value the outcomes enough to pay for them.

Bowman: Need to go to something like "deregulated schooling" (must mean vouchers)

Charp. Need to change school structure if anything is to happen

Bork: Technology changes school structure. Also, we are losing teachers and have to do something about that

Fisher: In order to make significant improvements, we need to redo K-12.

Bruce: Change is hard to achieve in the public school system. Where can a superintendent look to see a variety of successful models for change?

Weingarten: Is our discussion leading to a no-win argument?

Technology is subversive and doesn't produce immediate local change, for the most part.

Need to evaluate possibilities in terms of issues congressmen, superintendents, etc.. can understand.

Melmed: Currently, we follow the strategy of marginal enrichment. This has not been a success.

Through some extraordinary confluence, schools built an inventory of 1.5-2 million microcomputers

Schools now at asymptote, except maybe for teacher shortage. Back to marginal enrichment strategy

Sharp changes in curriculum likely to be difficult or impossible.

Main lever for change is examples of restructuring that schools can look to for guidance

Charp Schools will do a little restructuring What has been lacking is a means for them to be sure that the directions they were taking were ok.

Selby: Schools do restructuring in some places

Computers brought expectations for change without any guidance in how to change.

Lack of curriculum materials.

Need consensus on "what works."

What is the effect of technological aids? They give us fresh ways to look at phenomena and hence help in redefining the curriculum.

Bunderson: There are enough pressures for catastrophic change Clearly need to have impact on the GOALS of curriculum, perhaps via measurement.

Test performance goals are a way to allow local curriculum but still change what is taught.

Schools need a new financial structure.

We need tests referenced to on-the-job performance

Industry could use computerized training labs at night, adding economic base.

Also need tc support group instruction with technology.

Bruce: Restructuring entire school system is a long-range goal, not a 5-7 year goal. For shorter range. combination of technology research and models (examples) of restructuring

Bork· California now setting up model technology schools What is lacking is imagination on what should go on in these exemplary places.

The '88 election may be a particularly sensiti e time for infusing interest into the problems of education

Because of national textbook publishing and population mobility, we implicitly do have a national curriculum.

Schwartz· Skepticism about structural and institutional change as a primary goal

Being subversive means burying the restructuring goal

Need really good examples of excellent software.

Siegel: PLATO allowed more bad software than anything else, but by the 80's, good stuff was happening

Bowman: Need to have vision, and to market it. But technology is a painful vision for most people.

Technology is the tool, not the outcome. What really is being discussed is MASTERY LEARNING.

AML. Mastery of what. Mastery must be referenced to external criteria and transfer.

Aim at rapid growth areas of the country, where new school buildings are being erected.

Molnar: Can't do it piecemeal

Many different patterns lead to success

Aim at big social problems, e g, rural education, gifted education, Hispanics.

Curriculum restructuring more important than mastery.

Look for targets of opportunity that might be big (but not whole school systems) that might be politically supported.

Haver: Demonstrate mastery learning

Need to get very specific: Focus on a course or two as currently defined in the curriculum. Set pre-reqs and enforce them. Set high goals and show that they have been met.

Lesgold. What does mastery refer to: outcome goals? Transfer goals?

Mecklenberger· Can we use our existing accomplishments to excite people? Texas is taking the Haver route for physics.

We can only sell in terms of what is currently being done.

Mastery is a political issue in terms of political goals.

Bork: Need to demonstrate several best approaches.

A single course is not a big enough goal. Need perhaps to do 20 courses.

Mastery is a wonderful democratic vision

Pea. Need different models tied to different visions of education

One vision: epistemic participation.

Others lifelong learning interests, transfer to real-world problem solving. Invention rather than reception of knowledge.

Anderson: Tie back to national needs Mastery learning is like Japanese education Do we want merely to be just like the Japanese?

Instead. Enhance ability of learners to assimilate and operate upon bodies of knowledge.

Soloway: English as a Second Language might be a good target.

It would be amazing if children could be totally integrated into Anglo society's opportunities.

The only barrier to doing ESL is speech recognition, which is [in his view] getting solved

Selby: Doing striking education of a minority group would be a good tool.

Goal: Learning for understanding.

Bunderson: ETS experience with mastery learning.

Mastery is not the same as competence. NAEP, for example, is a competence measurement system.

Reference task: Calibrated competence measures.

Mastery is that which cannot be standardized -- it is unique progress moving beyond competence.

It could be graded using some ETS holistic scoring schemes.

Bork: Mastery just means learning all there is [on someone's list] to learn.

Schwartz Basically agrees with Haver: Concentrate on a few selected areas, perhaps barrier subjects like algebra, calculus, physics.

Melmed: What can we do now that we couldn't do 100 years ago.

Anderson· Mathematics/science retrofitting of adults who left school without adequate basic math/science education

Charp· Restructuring argument again: Saturate a school with what we know how to do.

Siegel: Manhattan project approach: work to avoid early accountability -- mini-Manhattan projects.

Bork. Not enough material available to run a model school.

Involve school in development, too

The hot house problem. how do you get things to work in real, impoverished settings

Pea: Aim at replicating what good teachers do

Bowman: ESTC is something that really works (currently K-6 math and reading).

Molnar In the past, the model had been the research - development - dissemination-implementation model But, we have 16,000 different school districts

What do we know: time on task matters.

The national science problem.

Bruce: Teacher problem: comprehensive program in a subject that builds in teacher training from the outset.

Fisher: Need more of a teacher voice

Teachers deserve more credit.

Importance of measurement.

AML note: What forms of computer usage should be included in exemplary developments

Advance organizer, concreteness producer, etc. Best done with CD-I or the like.

Practice of skills.

Exploration of educational reactive microworlds.

Explanation of phenomena.

Selby: Who will do the software development.

Empower teachers to design software.

Haver: Give three entities one course, such as algebra. Give them 3 years and $750,000 to go out and produce good stuff.

Burnham: Everyone recognizes the crisis.

One approach: An information utility approach.

Need large-scale implementation to force integration.

Charp: Pushing for toll-free data base and information resources.

Soloway: What's next?

Anderson Production values! Matching the quality of media outside school is more than free market forces can sustain.

Mobilize basics of cognitive psychology (e.g., John Anderson applied text) in appropriate media.

Mecklenberger. If there's going to be a campaign, school boards want to help.

Heard no mention of government reports and Carnegie report. Those call for demos to satisfy political needs.

Testing can provide new frames of reference. Can external referencing create parent/teacher/student commercialism?

Software development incentives.

Industry-school collaboration. E.g., schools using company laser disks to teach auto mechanics.

Bork: Need visions of what we want in future education.

Partial to George Leonard's vision. Need $10,000,000 for proposed experiment of that kind Should have 20 experiments.

Next steps

Today: What is possible

Next (from educational administrators) What is needed.

APPENDIX 2

Information Techn ogy Directions for NSF Science Education

Report of a Meeting Held at New York University
on May 12, 1987

INFORMATION TECHNOLOGY DIRECTIONS for NSF SCIENCE EDUCATION

Report of 2nd Meeting of Experts Held at New York University on May 12, 1987

by Arthur Melmed

INTRODUCTION

A group of 20 experts met at New York University on Jan. 15, 1987 to review the state-of-the-art of educational technology, and to assess the opportunity for its application to the sharp improvement of American education. A report of this meeting, including participants, is included here as Appendix A. In summary, the Report concludes, the *main chance* lies in the restructuring of education, using technology, that requires increased application and practice by the student. A smaller group of eight experts met at New York University on May 12, 1987 to consider some politically and socially workable educational restructuring models that the present state of the technology can support. This paper is a summary report of the discussion of that meeting. A list of participants can be found in Appendix B. In early fall 1987, the findings of these two meetings of experts will be presented to a conference of educational leaders and practitioners at New York University for their reaction.

BACKGROUND

There is widespread concern that the nation's secondary schools are not up to the task of preparing candidates for the national pool of scientific and technical manpower necessary to meet the present challenge to the nation's economic and military security. The required *hard* subjects like mathematics, science and foreign language instruction are not offered in the absence of teachers, or are often inadequately taught by uncertified and unqualified teachers. Student performance in these subjects is poor, measured by national tests and international comparisons. Marginal changes that school administrators can make on their own will not improve this situation sufficiently.

The growing shortage of certified teachers of *hard* subjects is the natural outcome of an economic competition between the taxpayer and industry for precisely the talented individuals needed for successful classroom instruction. Industry should be expected to continue to be unyielding in its demand.

Traditional classroom instruction, with its emphasis on the presentation of new material by the teacher, does not provide sufficient time for application and practice by the student to learn what is now required for entry into higher education, industry and the armed forces. The time society allocates for elementary-secondary education for its youth, more than 12,000 hours, is inefficiently utilized. Whatever the earlier advantages of traditional classroom instruction as the chosen social instrument for mass education, it's exclusive use no longer serves the present American population.

Since the march of civilization gave legitimacy to the goal of mass education in Western society some two centuries ago, science and engineering have brought dramatic change to every sector of the economy and society, with possibly the sole exception of *schooling* based on classroom instruction. Thanks to science and technology, the planet produces a surplus of food for its vastly increased population, proving Malthus wrong; and life expectancy in the developed countries of Western society now exceeds 70 years. Communication and transportation, entertainment and home entertainment, and the conduct of business and industry have all been revolutionized. Mankind stands, albeit somewhat uncertainly, on the threshhold of extended space voyage. Indeed, an alien space visitor, engaged in a reconnaissance of the U.S., might be expected to wonder at the contrast between the electronic operation of Boston General Hospital, Wall Street and NASA Houston on the one hand, and a school with its chalk dust, dull scissors and broken film projector on the other. *Whatever had the school done to deserve such neglect?*

As in the case of o ining American industry, school restructuring seems necessary and timely. School restructuring is necessary to overcome the condition of inadequate teacher supply, and to improve student achievement by providing more time for student application and practice than traditional classroom instruction allows. The Report of the meeting of January 15 (Appendix A) reveals clearly that a sufficient scientific and technological basis exists to undertake the selective restructuring of educational practice that can sharply improve educational attainment through increased student application. New knowledge from scientific research in human cognition and new developments in computer and communication technologies and in consumer electronics provide the requirements for substantial educational improvement. Interactive computer-based technology provides the best means, at a socially acceptable cost, to present new subject matter, to motivate the student to practice, and to test the student's knowledge. What is needed now are some demonstrations to reveal the promise of this approach. Educational restructuring demonstrations using technology will typically be expensive, because of the high front-end development cost of computer-based curriculums. This should not be confused with the ordinary annualized operating cost per student in which front-end costs are amortized over large numbers of students, which needn't rise at all or rise only slightly, and, in circumstances that can be imagined, could even decline.

SOME EDUCATIONAL RESTRUCTURING DEMONSTRATIONS

Four broad suggestions for educatio. restructuring demonstrations, using technology, which were discussed at the experts' meeting on May 12 are set forth here. (~~A paper prepared in advance of the meeting to stimulate discussion can be found in Appendix G.~~) For the purpose of easy identification these suggestions came casually to be called, during the meeting, *small course enrollment, great (curriculum) package, magnet schools,* and *distance teacher (re)training.* These suggestions are not and should not be viewed as project designs, but as opportunities for making sharp improvement in American education in problem areas widely recognized by educational practitioners. They represent national strategies for educational improvement that lie beyond the independent reach of the individual school or school district.

A. Small Course Enrollment

Small course enrollments in advanced courses in mathematics and science education, which do not justify the cost of a teacher in straitened economic circumstances, are a current problem in both urban and rural school settings. Often, a certified teacher is simply unavailable.

A stand-alone computer-based course with integrated video, diagnostics and a textbook would provide many students across the country the opportunity, although not the guarantee, of successfully completing a course that is otherwise unavailable to them. The option exists for offering courses like this (without instruction, but) with supervision during regular school hours; or without supervision outside of school hours, in school, at home or elsewhere in the community, wherev suitable equipment is available. Issues of test and credentialling would have to be resolved by State and local education authorities.

B. Great (Curriculum) Package

The circumstances surrounding first courses in mathematics and science education as opposed to advanced courses are different. Schools generally offer these courses (although not all,) even in the absence of a fully qualified and knowledgeable teacher, to larger enrollments. School publishers compete to market a textbook for these courses, but in the circumstance of weak teaching and inadequate classroom time for student application and practice, weaker students don't learn enough.

A computer-based course with limited integrated video and a textbook would allow schools to offer first-year courses using fewer uncertified teachers. Larger classes could be assigned to qualified teachers, whose role would devolve from traditional classroom teaching to supervision of student learning, including diagnosis and remediation of individual student problems, when necessary. Student performance would be improved by the increased application and practice made possible by the computer, by the improved organization and presentation of new material that is possible with interactive technology, and by the qualified teacher's diagnostic and presentation skills, when necessary.

A federal subsidy for which private sector firms could compete -- with several winners -- would enable school publishers to risk producing and marketing a *great package*, which included educational software along with a textbook. In return for the subsidy, each private sector firm would have to agree to market the product vigorously in competition with the others, pay royalties into a fund that supported teacher training, and work cooperatively with an academic team to ensure the pedagogical quality of the material, especially the educational software. The software should bring to bear our best knowledge about learning from research in cognitive science and our best knowledge about the presentation of new material from the nation's television experience.

The subsidy should be *sized* so that the cost of the *great package* to the school (without equipment) would closely match the present price from the publisher for the textbook alone.

Students could apply themselves to learning the course material during *official* class time and wherever suitable equipment were available in school, the community or at home. In this circumstance, school administrators could restructure class size and class time so to match the existing number of fully qualified and knowledgeable teachers available, and to avoid the use, insofar as possible, of unqualified teachers.

C. Magnet Schools

Magnet schools may offer the single most important opportunity for exploring a critical change in the curriculum of American education. School curriculums are now organized along traditional disciplinary lines. Interactive technology makes possible increased student application and practice in an environment of real world problems, which are much less strictly compartmentalized. Magnet and other special schools established to offer an enriched program of mathematics, science and technology education provide the opportunity for exploring the restructuring of traditional course content in addition to the restructuring of classroom instruction.

D. Distance Teacher (Re)Training

Regular and continual teacher (re)training is critical to the success of any strategy for educational improvement. As in other professions where research continually develops and refines the knowledge and practice of the profession, the teacher's knowledge must continually be upgraded. However, for the teacher's newly gained knowledge to produce new educational practice, the evidence is that the culture of the school must also be affected, that is, a substantial fraction of the school's teachers must simultaneously *get the message*. This can most economically and conveniently be done at the school site.

Modern communication technology now provides the means to do this at low cost. Four-meter satellite antennas capable of receiving two TV channels with simultaneous two-way voice and computer file transfer can be installed at a school site for a cost between $10,000 and $15,000. Teachers at many school sites can be aggregated into a *distance class* instructed by experts at the State university or from elsewhere. Transmission cost is independent of distance. Instruction can be on a regular basis for credit, or occasional on special topics, or consultative.

The facilities and techniques that make this instruction effective are already developed and in use in the engineering and business professions.

SUMMARY and CONCLUSIONS

A group of 20 experts met at New York University on Jan. 15, 1987 to review the state-of-the-art of educational technology, and to assess the opportunity for its application aimed at the sharp improvement of American education. The group found that the *main chance* lies in the restructuring of education, using technology, that requires increased application by the student. Restructuring using technology requires suitable educational software. A smaller group of eight experts met at New York University on May 12, 1987 to consider some specific, politically and socially workable educational restructuring models that the present state of the technology can support. The group identified three models of educational software development that could advance the strategy of educational restructuring. The computer-based courses necessary to make possible local choice on these and other opportunities for school restructuring are not presently available. It seems certain that, given the present incentive and risk, private sector firms will not undertake their development and marketing. The availability of such courses in the planning horizon therefore requires public, probably federal, investment. This raises in the minds of some the unwelcome specter of a *national curriculum* that has in past been dissipated by use of *arms-length arrangements* that separate the federal funding source from the developer. Nevertheless, questions concerning the organization and management of the necessary development capacity and distribution mechanisms for federally-supported computer-based courses do have to be considered and resolved. A new economical model for regular and continual teacher (re)training necessary to support educational restructuring is also described. In early fall 1987, these propositions will be presented to a conference of educational leaders and practitioners at New York University for their reaction.

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APPENDIX A not included.

Participants, School Demonstration Selection Meeting (Appendix B)

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APPENDIX 3

Information Technology Directions for NSF Science Education

Summary Report of a Meeting Held in Washington, D.C.
on August 12, 1987

INFORMATION TECHNOLOGY DIRECTIONS for NSF SCIENCE EDUCATION

Summary Report of 3rd Meeting of Experts Held in Washington, D.C. on August 12, 1987

by Arthur Melmed

The characteristics of the hardware available for shool use in the planning horizon are generally known. A meeting was held with selected publishers' representatives on August 12, 1987 to try to gain some sense of what can be expected generally in the way of educational software products. Major findings of the meeting are summarized briefly here.

> School publishers are not agents of educational change or school improvement. Rather, they meet the demands of the market as they understand them, and in the matter of educational software believe they are doing so adequately, with products designed primarily for compensatory and remedial education and educational enrichment.
>
> School publishers do not seem to engage in the typical behavior of technology firms, which *get out front* early in order to shape the market and seize market share. School publishers seem to see no profitable business opportunity in developing and marketing substantial bodies of computer curriculum, approaching a full course.
>
> School publishers do not necessarily have technological capacity in-house, but will contract for computer programming and video production, when necessary.
>
> The quality and quantity of educational software presently provided by school publishers will not change much in future, unless there is a change in the incentive system they face.

A list of participants is attached.

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APPENDIX 4

Information Technology Directions for NSF Science Education

Summary Report of a Meeting Held at NYU Club
on September 29, 1987

Information Technology Directions for NSF Science Education

Report of a Meeting with School Administrators
Educational Administrators
Held at the New York University Club
on September 29, 1987

Alan Lesgold, Rapporteur

On September 29th, 1987, a group of 29 people with interests in computer uses for mathematics and science education met in New York City to hear several presentations on the opportunities for significant new uses of technology to improve mathematics and science education. The meeting was pa of an NSF-funded effort by Arthur Melmed to study the feasibili of alternative approaches to the exploitation of computer and information technologies for mathematics and science education and to identify ways in which NSF could, with broad support from the education community, make a contribution to the successful development and dissemination of improved educational technology in these areas.

The group who met represented a wide range of viewpoints including school technology pioneers, chief city and state school officers, educational publishers, cognitive scientists producing educational technology prototypes for research and for school use, and several other educational experts. A complete list of participants appears at the end of this report. They first listened to several introductory presentations. Andrew Molnar of the National Science Foundation discussed some of the critical national manpower needs in mathematics and science and the relatively poor outcomes of the U.S. education system compared to those of our economic competitors. This was followed by a brief presentation by Sylvia Charp, who described the long-term efforts in the Philadelphia schools to exploit computer technology for education. She suggested the need for a major restructuring of American education to accommodate the full range of new demands on it and to better use the human and machine resources becoming available to it. Then, two cognitive scientists, Alan Lesgold and John Anderson, described some of the more advanced possibilities for educational technology that have recently appeared. Thomas Haver then discussed some of the issues in software development from the viewpoint of educational publishers, most particularly the need for complete and coherent packages of materials for the school market. Lionel Baldwin followed with a brief description of the National Technological University, a distance learning facility making substantial use of satellite technology. The briefing portion of the meeting ended with a presentation by Arthur Melmed describing the outcomes of the first three workshop meetings that preceded the present one.

This report details the remainder of the day, the reactions and advice from school leaders that followed the morning briefings. It is, of necessity, an interpretation in which the points that arose in discussion have been rearranged and occasionally elaborated to provide a coherent account. The rapporteur believes he has been faithful to the discussion and that the school leaders present would find the points below quite agreeable and representative of what they said.

Summary

The discussion can be summarized as follows:

- School leaders, like other leaders in our country, agree that we need to greatly increase the productivity of our school system in order to educate all of our children sufficiently so that they can participate in our high-technology society and meet the challenges of our world economy.

- There are many current barriers to the full exploitation of computer and information technology, although it shows great promise of being a major source of new educational productivity. Current educational computing products are not very serviceable, teachers are inadequately trained to use what good software there is, and the constituencies that school leaders must respond to are not yet convinced that computer power for the schools is worth the investment, especially when so much has already been spent on inadequate systems.

- In spite of these barriers, the schools really do want to change. Many are making creative uses of the available technology and are otherwise reorganizing themselves to provide better education. Even when fully adequate tools were not available, schools have made a major investment in computer hardware and software. Simultaneously, via magnet schools and other experiments, they have been experimenting with alternative approaches to school and classroom organization and function.

- Demonstration efforts, in which the computer and publishing industries join the schools, the educational research and development communities, and the federal government in developing complete courses that use powerful computer resources, were seen as a good way to teach the schools' constituencies what is possible, to stimulate an adequate supply of talented and trained people to develop and apply educational technology, and to develop models for teacher training and for improved approaches to teaching. It was felt that these efforts should concentrate on providing models for restructuring of the educational system to improve math and science education, using technology as appropriate.

These points are discussed in more detail below.

Meeting of Educational Administrators
New York, September 29, 1987

Increased Educational Productivity is Needed

There were two fundamental needs discussed in the meeting. The leaders of urban school systems, in particular, pointed out that the continuing lack of sufficient funds for urban education, combined with socioeconomically rooted problems, made it increasingly difficult for the less wealthy half (or more) of our population to get an adequate education, especially in mathematics and science. Given the evolution of our job market, this tends to mean that this large group of children is very likely to enjoy a much lower standard of living than the upper tier of our children. The gap between the educated haves and the undereducated have-nots in our society appears to be widening, and urban school leaders think that shrinking this gap should be the first priority.

From the viewpoint of economic competitiveness, the situation has a slightly different, but not necessarily incompatible, appearance. In order to keep our high standard of living, we need to produce resources that others want to buy. Many believe that our special capability as a nation is the production of high technology products and services. However, our balance of payments for high technology has, in recent times ranged from negative to zero. If we are to develop the economic strength we should have in this area, we need to produce high-quality scientists, technologists,[1] and technical workers.

It was pointed out that most children who become scientists have aspirations in this direction by 4th grade. Accordingly, special importance was placed on developing the science and math curriculum for the elementary and middle school. This would be, however, a major exercise in curriculum development and refinement, something particularly ambitious. At the high school level, great good could be done by increasing the availability of competently taught math and science courses to children who have mastered the offerings normally available in the United States (some of our competitor countries are far ahead of us in this). Both the hard task, of restructuring math and science education in the lower grades, and the more manageable task, of developing computer-enhanced courses for the upper grades (and upper ability levels) were seen as important to undertake.

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[1]We use technology in its original sense, to mean the artful application of knowledge. The artful application of scientific and engineering principles requires perhaps more training than the development of those principles. It is quite different from the rote instruction following of the old-fashioned factory economy. Even today's factory workers need new skills, though, in order to be able to engage in the small-group problem solving that is common to such approaches as quality circles.

Meeting of Educational Administrators
New York, September 29, 1987

Barriers to Using Computer Technology to Enhance Educational Productivity

There are many barriers to school improvement via the computer technology route. The software available today is mostly inadequate, and there is nowhere near enough of the good stuff. Even the best of currently available software just begins to make use of techniques and ideas that are now to be seen in the laboratories of cognitive scientists and the most innovative software developers. Further, the schools have just completed a major investment in computer equipment that is absolutely inadequate for the kind of easy-to-use, supportive, intelligent software that is beginning to appear in other sectors of our society. Yet, this inadequate hardware represented an unprecedented level of non-salary investment for our schools, which, in recent years, have spent only 0.7% of their budgets on non-salary costs.

It should be noted that the inability of the schools to run well-designed, user-friendly software on their machines has a number of side effects. First, it almost guarantees that teacher training will be a big problem. In most technology-using parts of our society, the standard solutions to the training problem are to make the software easy to use and obvious in what it is doing. Without adequate hardware, good design approaches becomes much more difficult, and fewer talented designers are willing to bear the extra pain of being constrained to only the solutions that inadequate computers can execute. The reaction of teachers that educational software is complex, hard to use, and of dubious educational value, is at least true in general, even if a few counter-examples of powerful, simple approaches can be found among the hundreds of worthless programs. Poor quality software has convinced a generation of teachers that using the computer in the classroom is difficult and perhaps counterproductive. (There are of course many substantive teacher training problems beyond those relating to educational technology.)

The participants in the meeting felt that the need for better pre-service and in-service training of teachers and principals was something that had to be addressed in any demonstration project of the sort discussed below. Once or twice, it even was suggested that the whole demonstration effort should be aimed at teaching teachers rather than students. It is certainly possible to build software that conveys powerful new ideas about subject matter to teachers even as it helps students to learn.

<u>The Problem of Constituency</u>. A particularly massive barrier to major restructuring of the educational system, we were told, is the lack of conviction in the constituencies of school leaders that technology-enhanced approaches will make a big difference. The educational system was defined as serving <u>defined</u> needs with <u>existing</u> approaches. It is not very able to serve <u>emerging</u> needs or to <u>exploit</u> <u>emerging</u> opportunities, because of the <u>many</u> ways in which it feeds <u>back upon</u> itself. Publishers make what teachers on adoption committees want to buy. Teachers want to buy what they already know how to use.

Financial boondoggles over the years have led to very complex restrictions on the purchase of school supplies, and these restrictions apply to computer purchases as well. Long time lines for the procurement process assure that schools will be buying obsolescent equipment at relatively high prices, being unable to be opportunistic. When parents and school board members see that schools pay too much to get too little, they impose further restrictions, compounding the problem. Teachers do not receive adequate training in technology or input into how it is used, so they fear it. Their fears lead them to oppose major technological changes, thus insuring perpetuation of the current level of user-unfriendly software.

It was repeatedly pointed out in the meeting that because of the many complex inter-relationships that keep the educational system stable and resistant to change, any major restructuring effort needs to arise out of a bona fide collaboration of all of education's constituencies -- parents, students, teachers, and school leaders -- with researchers and developers. Educational restructuring is ipso facto a major rewriting of the social contract. In a democracy, that requires wide participation.

A particular problem in this regard is that the constituents of the school world do not know what is possible. Many ideas familiar to the scientist or computer engineer are not yet in the experience of the average parent. Because of its low capitalization, the school is an unlikely spot to find the kinds of advanced software that people working in large businesses might already have experienced. More people have experienced, and they better remember, computer fiascos than real enhancements of life by the computer. Highly visible demonstrations of what is possible in modern education are needed in order to convince the participants in schooling that technology can really help make a difference.

Schools Really Want to Change

While change is difficult, school leaders showed a real willingness to change, and they backed up their words with many examples of changes already underway. Schools across the country are experimenting with new approaches to teaching and learning. Team teaching is becoming more common, permitting more use of small-group instruction and other arrangements in which the student can become an active shaper of his/her own learning, an apprentice of the teacher rather than a patient. Many schools are making the tools of learning more accessible, by staying open late, letting children take computers home, etc. Schools and companies are teaming to provide opportunities for learning that otherwise would not exist.

However, these activities are on too small a scale, and they have not engaged basic subject matters sufficiently. Too few teachers know quite what to teach, how it is learned, and how to facilitate that learning. The best ideas and the best equipment are characteristically available only to a few of the wealthiest students and even fewer of the others. For every magnet classroom saturated with computers, there are hundreds of others with minimal resources. Even more important, though, is the piecemeal nature of the efforts made to date. While many are exemplary, they do not show the way toward broad adoption. Often, even the school system's investment in a magnet school is more than it can afford as a standard policy for all its schools. The model efforts that can now be seen do not answer the critical questions: How can we extend the good idea to the whole course? How can we make it affordable? How can we train teachers and principals for it? How can we adapt it to our needs? A textbook is infinitely adaptable; one simply selects the pages one wants to use. The only problem is whether the content of those pages are mastered by the student. The best new techniques, occasionally demonstrated in limited and incomplete form, will need to show similar adaptability before teachers, school leaders, students, and parents will accept and use them.

The Needed Comprehensive Demonstration Efforts

Earlier meetings held by this project have made it clear that substantial improvements in education are possible through restructuring the schooling process, using advanced computer technology. The outcome of thi meeting was to make it clear that such restructuring will not occur without first having demonstration programs that can show the public, including teachers, voters, and school board members, what is possible. It was also clear that several special requirements should be placed on these demonstrations. In order to assure their replicability, they should be full implementations of a standard unit of instruction, a course. They should be developed by a multi-disciplinary team that includes not only R&D experts but also actively participating teachers and school leaders. The school must feel that it owns the program, and this means that its interests must be represented in the original design.

To insure that demonstrations result in usable educational products, and especially to insure that the demonstrated approaches are financially feasible for both buyer and seller, the demonstration efforts should involve a partnership of instructional designer/developers and school people with the institutions that produce and sell products to the schools, publishers and/or computer companies. While the federal government will probably have to bear the costs of stimulating a market for a new and much more productive educational technology, the technology that is federally financed should be such that it can feasibly be taken over and sold, at affordable prices, to schools by companies for which selling it makes good business sense.

The issue of "exportability" of the demonstration effort to other schools that see its value is especially critical. As noted above, this means that print materials, computer materials, teacher training resources, lesson guides, and any out-of-school resource possibilities must be designed as an integrated package, but one from which the schools can sensibly select those topics that they find most important to teach. The demonstrations should also be such that they illustrate, as options, new approaches to staffing and budgeting of our schools. Finally, they should embody the very best approaches to teaching, including emphasis on active participation in the learning process by the student.

Invited Meeting:

- Information Technology Directions for NSF Science Education: National Advisory Meeting on Large Scale Demonstrations of School Restructuring Using Educational Technology

Date : Tuesday, September 29, 1987
Place : New York University, New York

Purpose: Review and critique of new directions for improving science education by school restructuring using educational technology

Participants: approximately 32
eleven educational administrators; ten sci. and tech. experts; four publisher representatives; seven public policy experts

PROBLEMS and OPPORTUNITY

There is widespread concern that the nation's secondary schools are not up to the task of preparing candidates for the national pool of scientific and technical manpower necessary to meet the present challenge to the nation's economic and military security. The required hard subjects like mathematics, science and foreign language instruction are not offered in the absence of teachers, or are often inadequately taught by teachers who do not know enough. Student performance in these subjects is poor, measured by national tests and international comparisons. Marginal changes that school administrators can make on their own will not much improve this situation.

As in the case of non-competitive American industry where the tactics of marginal change have had to yield to the strategy of radical restructuring, school restructuring also seems necessary. School restructuring can overcome the condition of inadequate teacher supply, and can improve student achievement by providing more time for student application and practice than is allowed by traditional classroom instruction. Interactive computer-based technology appears to provide the best means, at a politically acceptable cost, to present new subject matter in an improved way, and to motivate the student to greater application and practice contingent on test and diagnosis of the student's knowledge. What is required and what is not presently available to make possible local choice on school restructuring using technology is a supply of suitable computer-based courses.

Reference: Report of a Meeting at New York University, 15 Jan. 1987 (copy enclosed)

Session 1: 9:00am - 10:30am
Chair : Robert Burnham
Speakers : Andrew Molnar [national manpower needs; school problems]
Alan Lesgold [educational technology can make a difference]

OPPORTUNITIES for SCHOOL RESTRUCTURING USING TECHNOLOGY

Examples of opportunities for school restructuring using technology that can improve student achievement are: (1) advanced mathematics and science education courses in urban and rural schools where small enrollments do not justify a teacher or when a certified teacher is unavailable; (2) first-year mathematics and science education courses where too few qualified if certified teachers are available; and (3) special (magnet) schools that offer an enriched program of mathematics, science and technology education.

Small enrollment advanced courses. A stand-alone computer-based course with integrated video, diagnostics and a textbook would provide many students across the country the opportunity, although not the guarantee, of successfully completing a course that is otherwise unavailable to them. The option exists for offering courses like this (without instruction, but) with supervision during regular school hours; or without supervision outside of school hours, in school, at home or elsewhere in the community, wherever suitable equipment is available. Issues of test and credentialling would have to be resolved by State and local education authorities.

First-year mathematics and science education courses. A computer-based course with limited integrated video and a textbook would allow schools to offer first-year courses using fewer unqualified if certified teachers. Larger classes could be assigned to qualified teachers, whose role would devolve from traditional classroom teaching to supervision of student learning, including diagnosis and remediation of individual student problems, when necessary. Student performance would be improved by the increased application and practice made possible by the computer, by the improved organization and presentation of new material that is possible with interactive technology, and by the qualified teacher's diagnostic and presentation skills, when necessary.

Special (magnet) schools. School curriculums are now organized along traditional disciplinary lines, with limited objectives. Interactive technology makes possible increased student application and practice in an environment of real world problems, which are much less compartmentalized. Magnet and other special schools established to offer an enriched program of mathematics, science and technology education provide the opportunity for exploring the enrichment and restructuring of traditional course content in addition to the restructuring of classroom instruction.

The computer-based courses required to make possible local choice on these and other opportunities for school restructuring are not presently available. Given present incentives and risks, private sector firms are unlikely to undertake their development and marketing. The availability of such courses in the planning horizon seems to require public, probably federal, investment. This raises issues like a *national curriculum*, the organization and management of development and production capacity, and mechanisms for product distribution.

Regular and continual teacher (re)training is critical to the success of any strategy for educational improvement, including school restructuring using technology. As in other professions where new knowledge from research continually develops and refines the knowledge and practice of the profession, the teacher's knowledge should continually be upgraded. However, for the teacher's newly gained knowledge to effect new educational practice, the evidence is that the culture of the school must be affected, that is, a substantial fraction of the school's teachers must simultaneously *get the message*. This can most economically and conveniently be done at the school site.

Modern communication technology now provides the means to do this at low cost. Four-meter satellite antennas capable of receiving two TV channels with simultaneous two-way voice and computer file transfer can be installed at a school site for a cost between $10,000 and $15,000. Teachers at many school sites can be aggregated into a *distance class* instructed by experts at the State university or from elsewhere. Transmission cost is independent of distance. Instruction can be on a regular basis for credit, or occasional on special topics, or consultative.

The facilities and techniques that make this instruction effective are already developed and in use in the engineering and business professions.

Reference: Report of 2nd Meeting on 12 May 1987 (copy enclosed)
Report of 3rd Meeting on 12 Aug. 1987 (copy enclosed)

Session 2: 10:30am - Noon; 1:15pm - 2:00pm
Chair : Sylvia Charp
Speakers : John Anderson [enriched mathematics program]
Thomas Haver [computer-based course development]
Lionel Baldwin [distance teacher (re)training]

LUNCH : Noon - 1:15pm

STRATEGIC REVIEW and CRITIQUE

Session 3: 2:00pm - 4:45pm

Chair : Linton Deck
Speaker : Arthur Melmed [introductory remarks]

Open discussion.

CLOSING

Session 4: 4:45pm - 5:00pm

Chair : Arthur Melmed

NOTE: Dr. John A. Murphy, shown in list of participants, was unable to be present.

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