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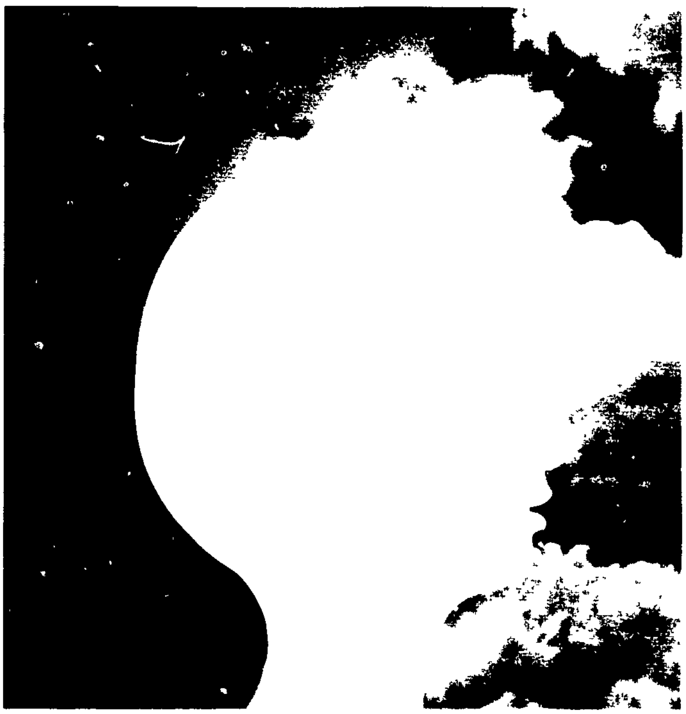
ABSTRACT

This report summarizes the proceedings of a conference on the impact of computer technology on education. The 90 conference participants participated in small group meetings, panel discussions, and synthesis meetings, which focused on the following issues: (1) the implications of technology for changes in student learning, the curriculum, the role of the teacher, and the organization of the schools; (2) the relationship between technology in education and proposals for the reform of teacher education and the teaching profession; (3) the potential of technology for expanding theories of teaching and learning, especially via practice-sensitive, interdisciplinary research; (4) the barriers and problems inhibiting the incorporation of technology in teacher education generally and the corresponding need for incentives and resources to encourage and implement change; and (5) the benefits of coordinating the interests and expertise of universities, industry, and schools in order to infuse technology into education. The report of the conference proceedings elaborates on the issues and recommendations in an introduction and in individual sections addressing "Technology and the School of the Future," "Meeting the Challenge," and "Recommendations for Action." Figures and photographs are included in the text. Three appendixes consist of the keynote address (by John Sculley), the welcoming address (by Bernard R. Gifford), and a 32-item annotated software bibliography. (74 references) (EW)

Teaching
in the
Information Age

EDUCATION AND THE CHALLENGE OF TECHNOLOGY



SUMMER 1986

Apple Computer
and
University of California
at Berkeley
Conference on
Technology and
Teacher Education

Teaching in the Information Age

Education and the Challenge of Technology

Proceedings of a Conference on Technology and Teacher Education
August 5-8, 1986
Monterey, California

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The author wishes to thank the participants for their thoughtful contributions to the conference and for their generous help in producing the report. Thanks go to all participants for letters summarizing the implications of the conference and for detailed comments on the draft report. Special thanks go to Kathryn Sloane for coordinating all phases of the conference and to Freda Husik, Nancy Songer, and Loretta Warn for invaluable assistance in using technology to record conference discussions and in demonstrating and summarizing educational software. Vivian Auslander's excellent technical editing is greatly appreciated.

The author would especially like to thank Dean Bernard Gifford for leadership during the conference and for help in shaping the conference report.

We hope that the productive partnership we have formed with Apple Computer, Inc. will inspire more such cooperative ventures concerned about improving American education in the Information Age.

Executive Summary

From August 5 to August 8, 1986, the Graduate School of Education at the University of California, Berkeley, with support from Apple Computer Inc., conducted a Conference on Technology and Teacher Education. In attendance were 90 participants from throughout the nation, including deans of schools of education, directors of teacher education, researchers, industry experts, and policy officials.

The themes of the conference were set forth in opening addresses by Apple Chairman and Chief Executive Officer John Sculley and Dean Bernard R. Gifford of the Graduate School of Education, University of California, Berkeley. Sculley spoke of the enormous potential of computers to alter and expand concepts of teaching and learning. If the promise of technology for improving schools is realized, he said, then our nation's youth will be well-prepared for the challenges of the complex, dynamic, and global society of the 21st century.

The infusion of technology into education, Gifford observed, depends upon systematic planning, well-conceived research, and concerted implementation efforts. To transmute the promise of current and anticipated advances in technology into significant improvements in the instructional process, he stated, expert knowledge of the culture of schools and the school change process as well as a deep understanding of the cognitive consequences of computer-based instruction are required.

To explore the potential of technology in teacher education in particular and in education in general and to define and create conditions for progress toward the application of computers in education, the conference participants met in small group meetings, panel discussions, and synthesis sessions. The issues of focus included: (a) the implications of technology for changes in student learning, the curriculum, the role of the teacher, and the organization of schools, (b) the relationship between technology in education and proposals for the reform of teacher education and the teaching profession; (c) the potential of technology for expanding theories of teaching and learning, especially via practice-sensitive, interdisciplinary research; (d) the existence of barriers and problems inhibiting the incorporation of technology in teacher education and education generally and the corresponding need for incentives and resources to encourage and implement change; and (e) the benefits of coordinating the interests and expertise of universities, industry, and schools in order to infuse technology into education.

Four interrelated recommendations were made by the conference participants:

- Establish partnerships among universities, industry, and schools to define and achieve objectives for the incorporation of technology in teacher education and education in general. These partnerships should create opportunities for communication, collaboration, and a sharing of human, technological, and financial resources.
- Create Centers for Collaboration in Technology and Education to foster: (a) interdisciplinary research and development; (b) partnerships with elementary and secondary schools to link research and professional practice; (c) experimental models of teacher education; (d) partnerships with industry to develop, test, and evaluate technologically-based curriculum materials; and (e) consortia for developing, reviewing, licensing, and disseminating educational software.

• Establish experimental classrooms and schools where multidisciplinary teams can explore the interaction of teaching, learning, and technology in real educational settings.
• Provide opportunities for all those concerned about technology in education to come together to study the relationship among education, technology, and society.

The report of the conference proceedings elaborates on the issues and recommendations in an introduction and sections addressing Technology and the School of the Future, Meeting the Challenge; and Recommendations for Action. The report underscores the enormous tasks ahead for those dedicated to educating citizens for the Information Age; however it also reflects a remarkable phenomenon that took place at the Conference on Technology and Teacher Education.

For three days in August, 90 individuals with diverse interests and areas of expertise met together for the first time as a group, voiced strikingly congruent views about the potential value of technology to education, and proposed pathways they believed would be effective in linking technology and education. Surely, if it is possible in so brief a time to agree upon a perspective and a set of directions, it is equally possible to work collaboratively and productively toward the realization of the promise of technology as a tool for significant improvements in the educational process.

Introduction

Computers and electronic communications have ushered in an age of burgeoning information and accelerating change. Coping with the Information Age requires skills that our schools have always applauded but must now teach, either for the first time or better than ever before.

Our high school graduates must not only understand and use computer technology, they must also be able to gather, synthesize, and analyze information on an unprecedented new scale, to make informed personal decisions about scientific, economic, social, and political issues that are increasingly complex, and to adapt creatively for the rest of their lives to a changing world. These developments put the teaching profession to one of the hardest tests it has ever faced.

A growing number of educators and researchers believe that high technology, which has brought us to this juncture, also holds the key to the instructional innovations we need in order to move successfully into the future. Others are skeptical, wondering whether computers will become just one more "quick fix" in a long string of intended reforms that have withered. All agree that we must involve a broad range of experts to respond to the challenge of technology in education.

To explore the potential of technology for improving teacher education in particular and education generally and to examine the policies, practices, and research needed to realize the potential of technology in education, the Graduate School of Education at the University of California, Berkeley, with support from Apple Computer Inc., invited deans of schools of education, directors of teacher education, researchers, industry experts, and state officials to a conference.

Apple Chairman and Chief Executive Officer John Sculley provided insight and inspiration for participants at the opening of the conference, predicting that, sooner or later, Americans will decide that education is "important enough to become a national priority."

Sculley described the changes wrought by technological progress, his vision of the role computers can play in the world of the future, and his hopes for education on the threshold of the 21st century.

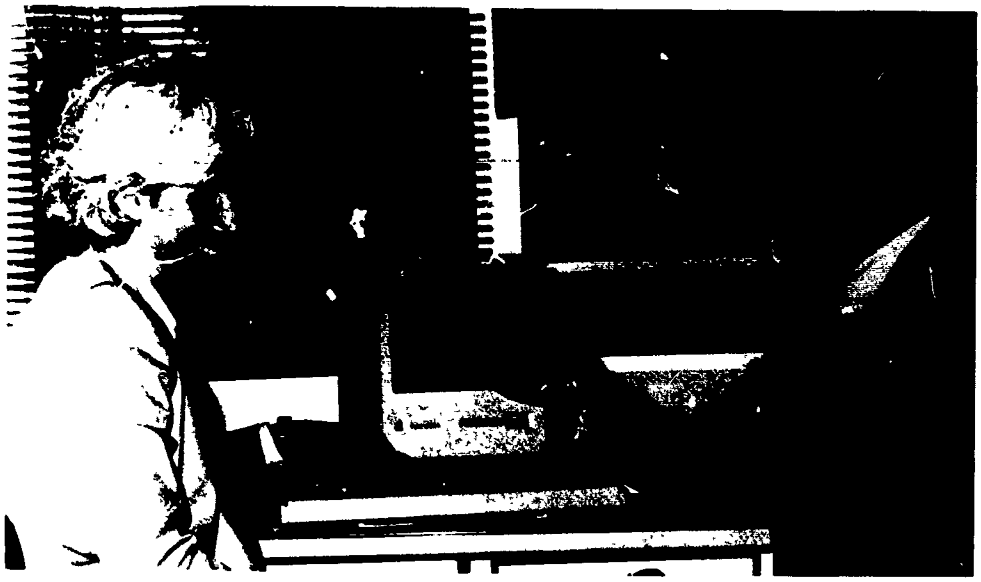
"What makes our job at Apple exciting, and what makes your job as educators equally exciting is that all of us really do have the possibility of touching the lives of millions of people who will spend most of their lives in the next century. If we do it right, we really will change the world," Sculley stated. The complete text of Sculley's keynote address appears in Appendix 2.

John Sculley and SueAnn Ambron discussing keynote address.

Welcoming the conference guests, Dean Bernard R. Gifford of the Graduate School of Education, University of California, Berkeley, reflected that, as recently as three years ago, anyone reading about technology in the press would have thought that the "computer revolution" would be "self-implementing."

"We now know that we won't be able to sit back and let the revolution happen all by itself," Gifford noted. "We will need systematic discussion and the leadership of educators and corporations engaged in technology," he said. "We will have to change the way our schools are organized, our curriculum evaluated, and our teachers trained." The complete text of Gifford's welcoming speech appears in Appendix 1.

Marcia Linn and Bernard Gifford discussing software.



Following the opening session, conference participants discussed the problems and progress associated with the challenge of technology in education. In small group sessions, participants with a variety of professional interests met together to contribute information from their own perspectives. In synthesis sessions, the results of the deliberations of the small groups were shared and discussed. In panel discussions, leaders in technology and education described their latest ideas. Software developers demonstrated and discussed commercial products as well as educational tools under development. Outlines of the sessions were prepared by technographers using computers in each meeting room, so that printed summaries of the discussions could be made available to all conference participants immediately after each session.

Robert Tinker, Nancy Songer, and Loretta Warn using technography to summarize a small group session.

Jill Larkin demonstrating software to Fred Reif, Marcia Linn, and Andrea diSessa.

The small groups discussed: (a)Technology in Teacher Education: What Are the Problems? (b) Preparing Teachers for Schools of the Future: What Are the Solutions? (c) Changing Teacher Education: Recommendations for Action. The panel presentations addressed: (a) The School of the Future: Technology's Role; (b) Software and Curricula for the School of the Future; and (c) The Current and Potential Use of Technology in Teacher Education. Subsequently, deans of schools of education, directors of teacher education, and educational researchers and developers each met separately to discuss the special problems they face and to propose paths for future discussion and action. Moderators of these sessions summarized each group's deliberations and recommendations at the final synthesis session.

The following report sections describe the concerns and issues raised in the small group and panel discussions and the recommendations made at the synthesis sessions.

Technology and the School of the Future: Progress and Problems

Technological advances challenge the educational enterprise. As we shape technology to our needs, so does technology change what we do. As Professor James Greeno of the University of California, Berkeley, remarked, "As we increase our resources for learning, the nature of learning will change." Ultimately, technological advances will influence all aspects of education—not only the nature of student learning but also the curriculum, teaching, teacher education, the organization of schools, and research on learning and teaching.

The school of the future must respond to widespread demand for improvement of our educational system. Myriad forces press for this change. Our nation faces an unprecedented shortage of teachers. Our teaching force is held in low esteem and suffers from noncompetitive salaries at the very moment that the best and the brightest minds are needed in the classroom. Citizens across the country are recognizing that technological advances provide new and important opportunities for education. Yet little of a systematic nature has been done to integrate technology into the classroom or to envision how computers can best serve the educational enterprise.

Never have demands on citizens changed more rapidly. Individuals can now expect to change jobs two, three, or even more times during their lifetime. Within a job, individuals can expect to change their roles as a result of technological innovation. In the last five years, the word processor, the spreadsheet, automated billing and recording mechanisms, automatic controls for machinery, robots to construct automobiles, and other technological innovations have vastly changed the nature of a wide range of occupations.

To accommodate to the realities of rapid change, the school of the future must help build a society in which citizens can constantly absorb and adapt to new information. Education must prepare students to be lifelong learners. Teachers must also be prepared to be lifelong learners, ready to adapt to changes in the educational system and to make innovations that lead to change in their activities.

As the demands on citizens change, so will the demands on the educational enterprise. Our system of education, including our teacher preparation programs, must therefore be flexible enough to adjust to new challenges. Our teacher education programs face a dual challenge: they must constantly adjust programs to incorporate recent advances in learning and instruction, and they must continuously refine techniques for preparing lifelong learners.

Never before have citizens had a better opportunity to participate in shaping their own destiny. As Roy Pea, a professor from New York University, told the conference, "A picture is emerging of who the learner ought to be: someone with a sense of agency, a belief in one's own ability to make a difference; a view of oneself as a learner and a thinker for life, as a distinctive voice in a pluralistic community, and, most important, as a voice in defining future societies."

To create informed citizens, our society must train students to reflect on the nature and quality of their own reasoning and to adjust their thinking accordingly. Technology is one important tool teachers can utilize to help students become aware of this process. In so doing, it is the responsibility of our educational system to uphold the goals of democracy by insuring such opportunities for all students. Educators are concerned that computer technology can potentially drive yet one more wedge between the privileged and others in our society. Instead, education should be redefined and revitalized in such a way as to increase equity while promoting excellence for all.

Synergy
It is essential that all constituencies concerned with improving education participate in bringing about change. Schools of education must prepare teachers to participate and must also insure that the institutions hiring them are willing and able to utilize their new skills. Curriculum developers must improve the curriculum to provide time and opportunity for reflection, and must also insure that the classrooms and institutions that offer this curriculum are altered to deliver it effectively. Educators must identify the benefits of technology and nurture its use, where appropriate, aware that the uses must be shaped to meet the needs of learners in the 21st century. Unless we address all of these issues synergistically, our efforts may be for naught. As Professor Karen Sheingold from Bank Street College of Education noted, "No important cultural change will occur unless those involved 'own' it. What we need to think about is a mutual crafting of a vision of what teaching can be all about, a mutual crafting of cultural change. The ownership of change has to be shared ownership."

Modifying the educational enterprise requires synergistic interaction of individuals involved in all aspects of education: teachers, learners, researchers, administrators, and others. Conference participants cooperated to address the problems faced by education and succeeded in reaching agreements on key issues. As we continue this process we need the direct involvement of classroom teachers, parents, and others.

Computers in Schools

Technological advances provide new and important opportunities for education. Schools have responded by purchasing over 1.2 million computers in the last 5 years. Over 86% of all American schools use computers for instruction. Public school computer use doubled between 1984 and 1986 (see Figure 1). Over 97% of secondary schools use computers (see Figure 2). Most of today's youngsters have already gained some computer experience. Many students use computers regularly (see Figure 3). As more and more students come to classes with computer experience, the possibilities for school uses of computers expand.

Figure 1
Increase in number of computers in public schools, 1984-1986.

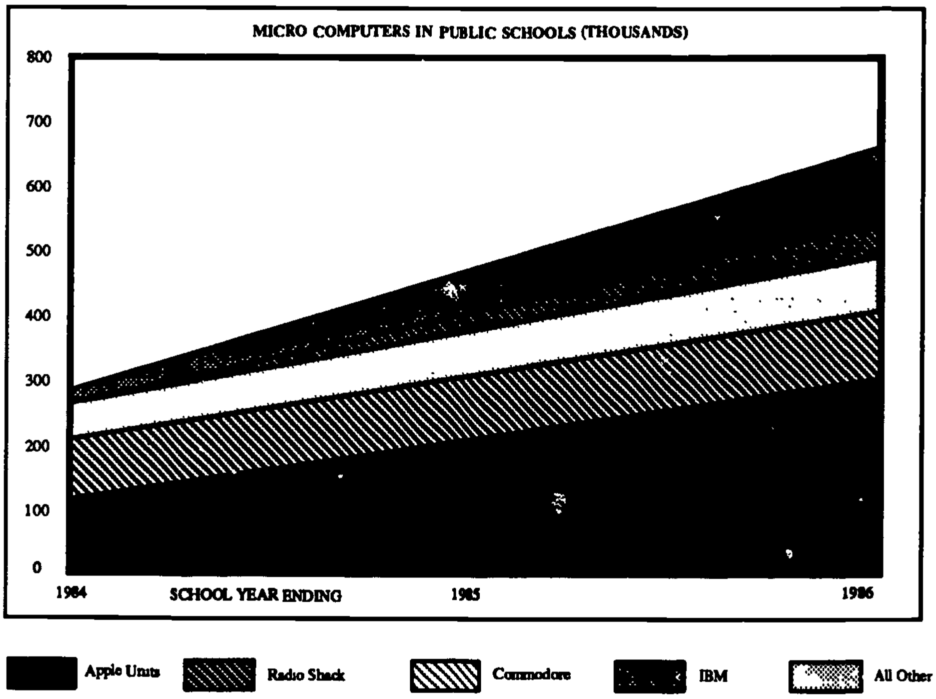


Figure 2
Percentage of small, medium, and large schools using computers: Five year trends.

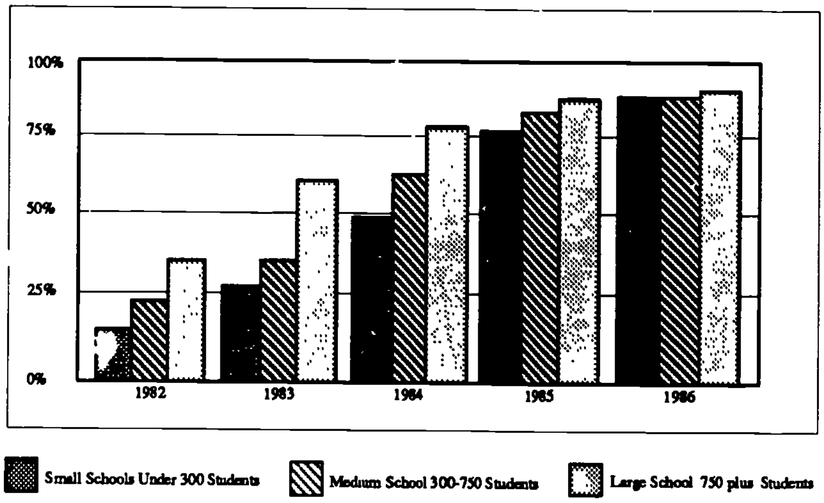
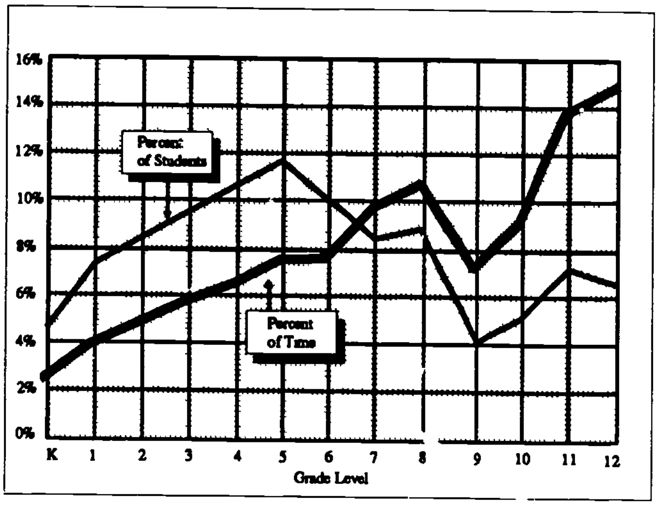


Figure 3
Percentage of students who use computers and percentage of time computers are used by grade level.

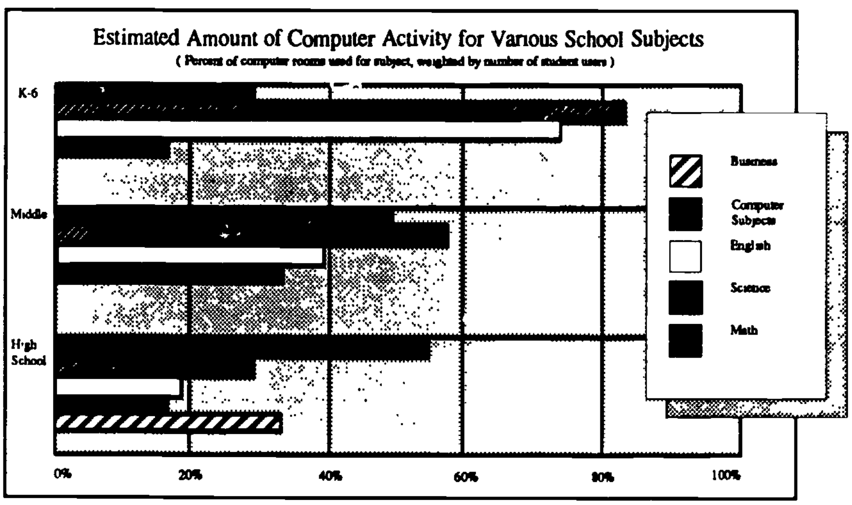


As the number of computers in schools increases, so does the use of computers for problem solving rather than for drill and practice. As might be anticipated, older children use computers more for problem solving than do younger children (see Figures 4 and 5). In 1985, half the computer use in elementary schools was for drill and practice while 16% of the high school use was for drill. In contrast, 59% of high school computer use was for programming or other problem solving, compared to 29% of elementary school use.

Figure 4
Instructional computer time allocated to drill and practice, word processing, and problem solving.

Grade Span of School	Drill & Practice	Problem Solving		Word Processing	Other
		Discovering	Programming		
K-6 Elementary	56%	17%	12%	9%	6%
Middle/Jr. High	30%	15%	32%	15%	9%
High School	16%	10%	49%	20%	5%
U.S. Total	**32%**	**14%**	**33%**	**15%**	**6%**

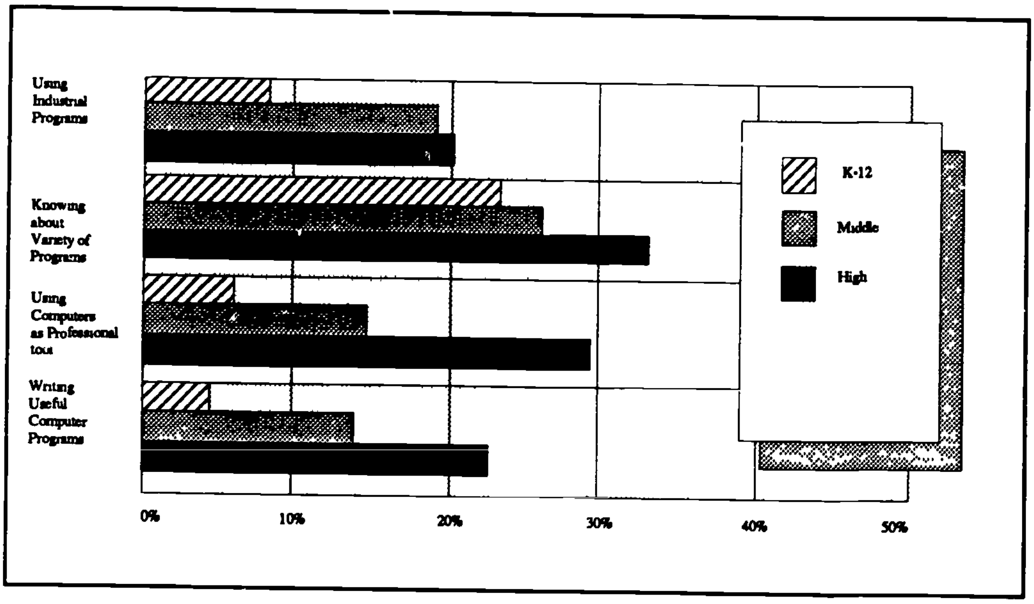
Figure 5
Allocation of computer use by school subject.



Computing power gets less expensive each year. Experts estimate that computer costs drop by 50% every two years. Computer companies concerned about education have offered upgrade programs and substantial discounts to schools to allow them to maintain computing power, given this rapid advance.

Few programs exist for training teachers to use computers, yet over 25% of American teachers use computers "regularly" with their students. Many have learned their skills on their own. Fewer high school teachers than elementary school teachers use computers, but 25% of them are viewed as "experts" compared to 10% of computer using elementary school teachers (see Figure 6). Primarily, teachers have expertise in using computers as a professional tool and using computers for instructional programs. Of those who use computers, about 20% of high school teachers and 3% of elementary teachers write useful computer programs.

Figure 6
Percent of computer-using teachers rated expert at various computer activities.



In summary, most schools have computers and some teachers who know how to use them. Nevertheless, few schools have the resources and organization necessary for successful integration of this new technology. Already overburdened teachers cannot keep abreast of new developments in technology. Schools lack resources to select and purchase software and to train teachers to use new products. A comprehensive plan for use of computers in education must be developed and implemented to ensure that our nation's children are prepared for the Information Age.

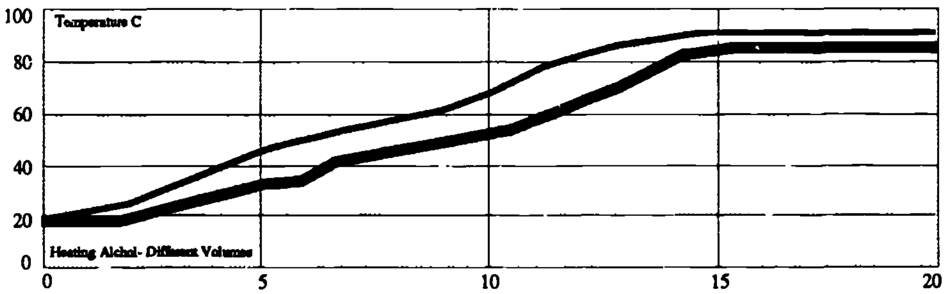
Innovative Teachers

The impact of technology on education is apparent in the classrooms of innovative teachers. Imaginative teachers illustrate the potential of technology by taking isolated computer tools and integrating them into the curriculum, by identifying unanticipated uses for existing computer applications and elaborating on them, by matching student difficulties to available tools, and by many other self-initiated instructional practices.

Typically, innovative teachers have support from administrators and parents, but often they succeed in spite of state and local regulations that impede their work, limited resources, awkward logistic arrangements, and other difficulties.

Microcomputer-Based Laboratories

Box 1: Results of an experiment comparing the rate of heating for different volumes of alcohol.



Microcomputer-based Laboratories (MBL), constitute a new group of 'probe software' which directly link laboratory parameters to computer-based data collection. In MBL, temperature, motion, sound, or light-sensitive probes are connected to a microcomputer through the game paddle port. Data measuring changes in such parameters as pendulum oscillations or light intensity are collected and instantaneously displayed on the computer monitor.

Students have control over several parameters associated with the representation of their data. Choices as to representation style (such as a graph of changing parameter vs. time, or a pictoral representation such as a thermometer) length of experimentation, and the quantitative ranges over which data is represented are easily altered. Students may collect data from up to 4 probes if desired. After collection, additional data manipulation is achieved through detailed analysis of a specific point on a graph, and/or the superimposition of one graph on another.

MBL as a laboratory tool allows greater student focus on immediate data analysis and data manipulation than is possible in traditional laboratories. As the computer-probe combination collects and records all data, the students have more time to observe results and implications may have direct representation of dynamic relationships. Through instantaneous visual feedback, students can test and re-test hypotheses as the experiments progress, rather than performing all data analysis long after the experiment is completed.

"Heat and Temperature," "Illusion Experiments," "Sound" and "Motion" MBL software kits were developed by Technical Education Research Centers and are commercially available through HRM software.

For example, Douglas Kirkpatrick, at Foothill Middle School in Walnut Creek, California, has created a semester-long physical science course using Microcomputer-Based Laboratories developed by Robert Tinker of Technical Education Research Centers (see Box). Apple Computer, Inc. donated a classroom set of computers. The school provided a science laboratory. Parents provided security and repair funds, and collaboration with the National Science Foundation provided research and development funds.

Kirkpatrick has refined the curriculum over four semesters in collaboration with researchers at the University of California, Berkeley. During the first semester he offered the course, he resolved logistic problems. The most recent version of the curriculum incorporates activities to help students integrate one energy concept with another and experiments that illustrate how classroom science experiments help explain everyday scientific problems. Thus, Kirkpatrick encourages students to study how surface area influences the rate of heating or cooling and to use these insights to explain, for example, why soup cools faster in the spoon or why it is quicker to heat one serving of lasagna than the whole pan. Each semester, Kirkpatrick reflects on the effectiveness of the project and redesigns and refines the curriculum accordingly.

Kirkpatrick's Computer as Lab Partner project covers only a small portion of the topics middle school science courses are required to address under state and district curriculum guidelines. Since he has found that deep coverage of a few topics prepares his students well for statewide achievement tests, he can justify omitting topics from the course curriculum. Indeed, Kirkpatrick's students attain a depth and sophistication of understanding that standardized achievement tests do not measure.

We have a great resource in programs developed by innovative teachers. We need to encourage partnerships involving industry, universities, and schools to foster such programs. We need to find ways to amplify these programs and to eliminate the obstacles in the paths of the teachers who develop them.

Innovative Technological Tools

Technological tools amplify and modify the learning environment when used by innovative teachers. They provide a level of interaction never before thought possible. From the beginning, programming environments provided feedback to learners on the function of their programs. Now, innovative new software provides opportunities for a wide variety of feedback on a vast range of intellectual problems and allows teachers to increase emphasis on problem solving and thinking skills needed for lifelong learning.

Participants discussed the impact of technological advances currently used in schools as well as those under development. The products demonstrated at the conference are listed in the annotated software bibliography, Appendix III.

Already, computers have changed the nature of education, assisting with many of the mechanical aspects of learning and freeing students to use complex problem-solving skills, such as planning and analysis. Where students once had to memorize myriad facts and figures, now electronic data bases put such information at our finger tips, challenging instructors and students alike to master how to retrieve information and use it effectively. Professor Judah Schwartz of Harvard University and the Massachusetts Institute of Technology asserted, "We must seize the intellectual high ground with technology and emphasize problem solving in education."

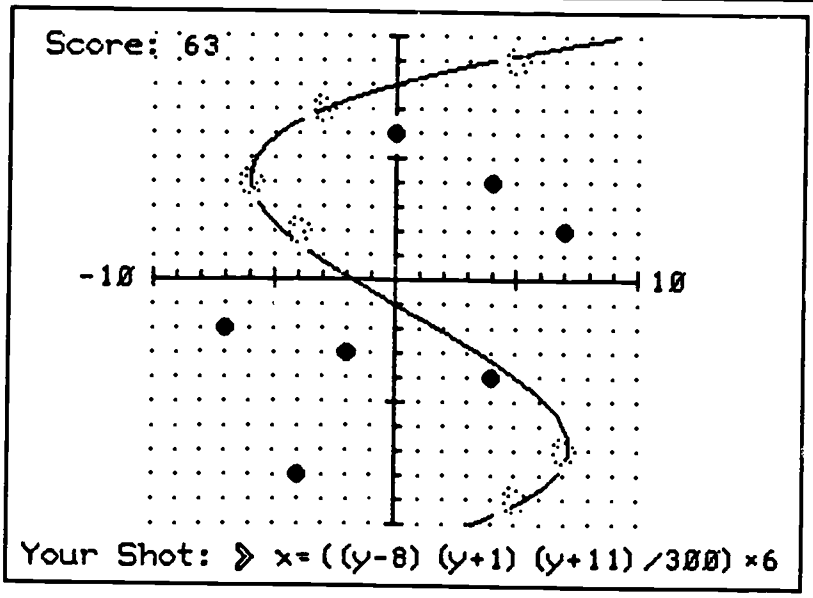
Computer algebra programs such as muMATH can perform complex algebraic manipulations too often taught by rote memorization of algorithms. They free students to concentrate on more important conceptual issues, such as problem formation, problem solving, and evaluation of problem solutions. Thus, available software makes it possible to focus on key concepts in mathematics and physical science rather than on the mechanical skills which once had to be learned before the concepts could be explored.

These programs challenge educators to reexamine the curriculum for topics which have become superfluous or which need to be taught differently.

Computers can represent relationships and concepts in several different ways and allow learners to move from one to another. Thus, students can move from geometric expressions to graphic constructions. Using Graphing Equations and Green Globs, they can transform algebraic expressions into graphs. Such changes help students integrate their ideas and improve their conceptual understanding (see Box).

Graphing Equations and Green Globs

Box 2: A graph hitting six green globs.



Students in high school algebra or analytic geometry classes can use either the novice or expert "Green Globs" educational game to relate algebraic equations to their graphs.

In the novice game the computer displays coordinate axes with thirteen green globs (small spheres) scattered randomly on a grid. Students enter equations for graphs they think will pass through the globs. The goal of the game is to hit as many green globs as possible with one shot (i.e., the graph of a single equation). The scoring algorithm encourages students to think of the most efficient graphs to make the hits. Equations for lines, parabolas, circles, ellipses, and hyperbolas are all acceptable, and students may also use square root, absolute value, logarithmic, and exponential functions.

In the expert version, the coordinate grid contains the thirteen green globs plus five "shot absorbers," which stop any shots that touch them. The goal here is to hit as many green globs as possible without bumping into and losing graphs to the absorbers. Students may enter trigonometric functions, as well as all of the equations that can be used in the novice game.

A "hall of fame" contains the top ten scores of all students who participate in the game. Students can view these games to see what equations the top players used, thus picking up strategies that may be useful for future games.

Whether played individually or in small groups, Green Globs is a useful learning tool for students of widely varying backgrounds and abilities. Students have the opportunity to link graphs to equations and to explore the effect of each component of one equation on the resulting graph.

The software is by Sharon Dugdale and David Kibbey and is available from Sunburst Communications.

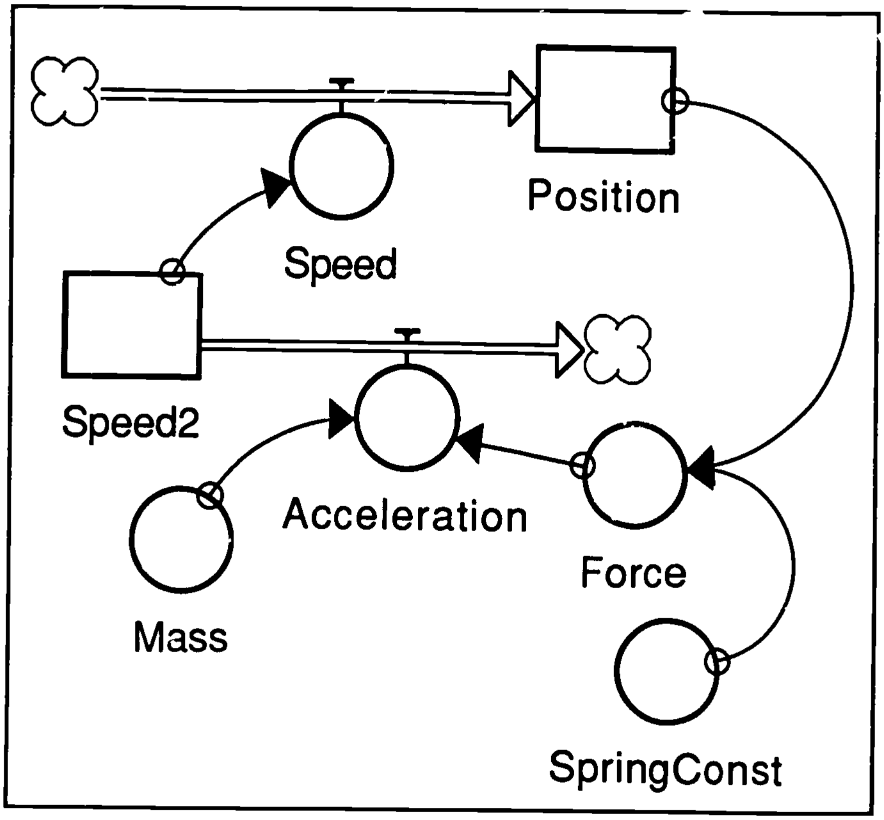
Students develop revision and refinement skills through computer word processing. Using software products such as Guide, students can link verbal descriptions to graphic displays and animation. Using structure-oriented editors, students can form alternative representations of texts. Students can learn to construct and interpret such representations, increasing their potential for communication and also for thinking.

Color design environments such as Paintworks encourage students to develop an understanding of color and perspective by trying their own ideas. Other tools allow students to compose and transform music, to simulate stage productions, and to design houses.

Computers can expand and improve the curriculum by simulating real world problems. They can model the economy, or forest growth, or automatic control of robots. Using modeling environments such as STELLA, curriculum developers can set up models for students to investigate (see box). As Robert Tinker, President of Technical Education Research Centers, remarked, "The computational power of the computer will force a reconceptualization of what is possible at the pre-college level. One example is modeling environments which teach students how to create mathematical models of complex, real-world physical, biological, and social systems. These problems often involve solving coupled, nonlinear differential equations. While the students do not know the formalism of calculus nor the algebra of derivatives and integrals, they learn the underlying concepts of change and accumulation, which are at the heart of calculus."

STELLA

Box 3: STELLA diagram. Shows a model of a mass-spring system that oscillates.



STELLA refers to Structural Thinking, Experimental Learning Laboratory with Animation, a powerful modeling and simulation tool with widely diverse applications.

Through the creation and manipulation of systems dynamics models, STELLA users have the power to model and simulate unlimited versions of complex systems as they change over time.

Using the modeling tools provided (data=boxes, flow regulators=fat arrows+circles, limit switch=thin arrows), a user builds a model such as the pictured mass spring system that oscillates. Through the entering of input values for all data boxes, the model can be run and results displayed. Various data combinations can be tested on the same model. The model is easily altered prior to a re-run.

STELLA is an ideal learning tool for all those who are interested in understanding the central concepts of calculus without the rigor of the mathematics. It has been used as a learning exercise for high school math students, as well as an application in economics, chemistry, management, physics, biology and the social sciences.

STELLA was developed by Barry Richmond of High-Performance Systems, Inc.

Computer simulations and design environments help students explore various solutions to problems. Computers can illustrate the implications of students' problem solutions without judging them right or wrong.

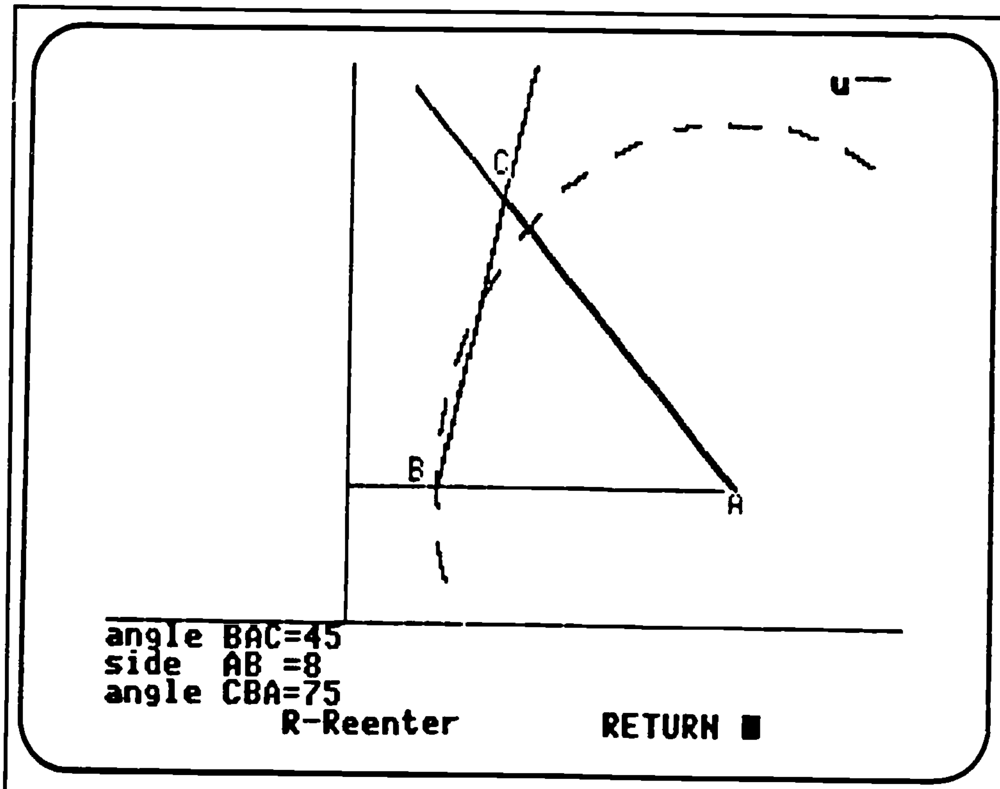
Interpreting the feedback provided by computer design environments changes teachers. Students need skill in evaluating feedback, reformulating solutions, and comparing designs. Some design environments provide hints or strategies to help students generate revisions to their ideas. To help learners take responsibility for finding problem solutions, teachers serve as guides, consultants, and co-explorers rather than as sources of answers.

The Geometric Supposer, developed by Professor Judah Schwartz and his colleagues of the Massachusetts Institute of Technology and Harvard, allows students to conjecture about geometric relationships, to construct those relationships, to examine them in a graphic environment, and to reach conclusions supported by technologically-generated evidence (see box). Such software allows more tutoring and coaching to occur, because other forms of feedback are provided by the learning environment.

Professor Schwartz reports observing a student testing an idea about geometry, discovering that she had ignored an important feature, changing her idea, and testing it again. Eventually she remarked, "This must be what real mathematics is like!"

Geometric Supposer

Box 4: The construction of a triangle by side-angle-side.



Geometric Suppc er is educational software that transforms the microcomputer into a new and effective tool for exploring geometry. This tool can be used to construct geometric figures and to derive information about their properties.

Geometric Supposer generates geometric figures that are described by the user either in terms of general restrictions or specific measurements. It can also perform tasks such as measurements, rescalings, or additional constructions.

The effect of this tool is different from the standard compass, protractor, and ruler approach because of the speed and accuracy of Geometric Supposer's constructions and measurements. This speed and accuracy provides an environment for effective experimentation. Thus, Geometric Supposer is intended to be used in conjunction with instruction--ideally instruction that raises open-ended questions and that encourages the exploration of those and other questions.

The Triangles, Quadrilaterals, and Points and Lines Geometric Supposer is available through Sunburst Communications.

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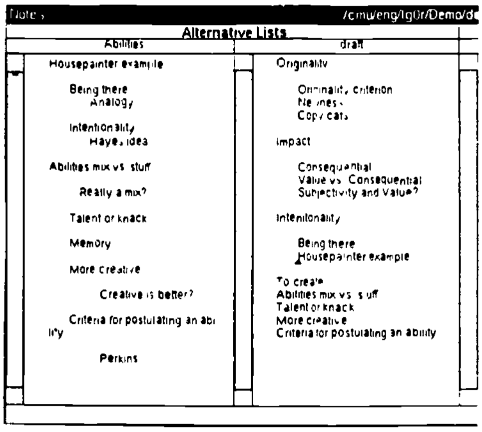
Technological tools often provide opportunities for students to observe the processes that they and others use to solve problems or generate arguments. Without such tools, process information is often hidden. When students can observe the reasoning processes that they and others use, they are encouraged to reflect on their own strategies for solving problems and to compare their strategies to those of experts.

For example, the Notes program developed by Professor Christine Neuwirth and her colleagues at Carnegie-Mellon University uses computers to help students extract information from a text and construct a logical argument. Students also observe how others do the same. This environment encourages students to reflect on the reasoning process and to improve their problem solving strategies (see box).

Notes

Box 5: Using Notes to generate two organizations of the same notes.



The Notes program is specifically designed to alleviate the difficulties and inconveniences that writers experience when they try to acquire and organize information from different sources. The program is currently in use in four sections of writing courses at Carnegie-Mellon University.

Notes allows writers to take notes from either on-line, electronic sources, or from off-line, printed ones. For each note, the program automatically keeps track of the note's source. All notes are listed in a Main List that the program creates. From the Main List, writers may view notes they have already taken.

If a writer is taking notes from an on-line source, the Notes program links the section in the source from which the note is taken to the note itself and places an icon after the section in the source to which the note refers. Writers can access the note by activating the icon in the original source as well as from the program's Main List. In addition, since the program links the note to the on-line source, writers can refer to the original source of their notes quickly and easily from any note.

Writers can create categories of notes. The program also allows writers to create, in addition to its Mail List, any number of "alternative lists." With alternative lists, writers can create alternative arrangements of notes, including hierarchical ones. Both these facilities help writers to organize their notes in preparation for a writing task.

Writers can search in their directory of notes for general or specific information. For example, they may search for notes taken from a specific source, from a specific author, or in a particular class. Writers may also search for the name of a note or for a particular word or string in the notes. In addition, they may search on the time the notes were created or last modified.

Notes is implemented on the Andrew system by Christine Neuwirth and David Kaufer. It was developed at the Information Technology Center, as a joint computing venture between Carnegie-Mellon and IBM.

For further information contact: Center for Educational Computing in English, Baker Hall 160, Carnegie-Mellon University, Pittsburgh, PA 15213.

Computer tutors are being developed which can diagnose and model human performance and thereby provide explicit feedback to learners on well-defined problems. At present, such tutors follow student behavior closely and intervene as soon as a problem arises. They supply memory support for learners by providing accurate information as soon as a difficulty is encountered.

The LISP Intelligent Tutoring System, created by Professor John Anderson and his colleagues at Carnegie-Mellon University, teaches students how to program in LISP (see box). The computer tutor assesses the student's level of understanding, detects misconceptions, and seeks to remediate them by engaging in an on-screen dialogue with the student. John Anderson has also developed tutors for algebra and geometry.

Computer tutors now available can take over introductory instruction on well-defined problems. They may free teachers to focus on more advanced topics or help alleviate widespread teacher shortages in mathematics and science. We need large-scale trials of these innovations in realistic settings to understand their potential.

Tutors also allow educators to test and refine models of instruction. For example, computer tutors can immediately supply details such as a geometry axiom or the syntax for a programming language. As a result, learners do not need to keep their information in memory and can, instead, place all their attention on solving problems. To investigate ideal levels of memory support, educators can vary the information supplied by the tutor. Similarly, investigators could compare different ways to present problems and assess how students respond to varied problem representations. As a result, computer tutors are important tools for studying how students learn.

Lisp Tutor

Box 6: Example of the LISP tutor correcting a student's program for computing the factorial of a number.

You will have to use fact at some point but right now you want to multiply.

CODE FOR fact

```
(defun fact (n)
       (cond ((zerop n) 1)
             (t (fact   )))
```

GOALS

code for the recursive case
*** Write code for the action in the recursive case ***

The LISP Intelligent Tutoring System (LISP-ITS) is based on research on problem solving, learning, and intelligent tutoring performed at Carnegie-Mellon University. The design of the LISP-ITS combines cognitive science theory and artificial intelligence (AI) technology to provide individualized instruction for LISP programming, carefully monitoring the student's progress and providing feedback and guidance when necessary.

The knowledge built into LISP-ITS enables it to actually solve the LISP problems it presents to its students. The LISP-ITS will try to figure out each student's individual answer and follow the student through any reasonably correct path through the problem, providing helpful feedback when necessary.

Instruction can be effective when provided while students are solving problems. The LISP-ITS provides all of its feedback while the student is trying to write programs. As soon as the student makes an error, the tutor can diagnose it and respond with a helpful hint.

The LISP-ITS initiates a planning mode if the student begins to flounder while writing a problem. The tutor helps the student plan out the algorithm to solve the problem. After this plan has been constructed, the tutor returns the student to the coding mode, so that the plan can be transformed into a working program.

The LISP-ITS quickly catches annoying syntactic mistakes, and enables the students to easily correct them without losing track of the more important conceptual components of the problem. A structured editor checks syntax and balances parentheses, enabling students to concentrate on how to implement the algorithm for the program.

Available from Advanced Computer Tutoring, Inc., 701 Amberson Avenue, Pittsburgh, PA 15232.

Contrary to the stereotype of the lone student staring at the computer screen, educators are finding that computers are encouraging group effort and joint problem solving. By providing information to groups of learners in an easily accessible manner, technological tools encourage them to debate the meaning of the information provided and to reflect upon its accuracy and relevance. For example, the Microcomputer-Based Laboratories used by Douglas Kirkpartick can foster group problem solving. The labs make it possible for groups of students to examine jointly collected data. Having a computer on each research "team" not only permits groups to observe dynamic relationships on the screen, it also encourages them to discuss the relationships between their observations and their experience. Students can jointly explain the results of their investigations.

Researchers studying learning and instruction are beginning to understand how groups with diverse expertise can cooperate to solve joint problems and how technology might help. John Seely Brown, Vice-President of Xerox Palo Alto Research Center, called on conference participants to address this problem, saying, "Real creative problem solving is a group effort. We need to learn how to streamline our ability to collaborate." Only by working together can we hope to achieve large-scale change.

As Dean Henrietta Schwartz of California State University, San Francisco told conference participants, "The chief function of schools in our society is to socialize children. To tie technology into that function, we should think of computers as facilitating the socialization enterprise." Tools that promote joint problem solving can contribute to this effort.

These are a few of the opportunities that technology offers education. They illustrate how the new technologies can easily represent information in several different ways. They show how skills that used to be necessary can be de-emphasized, while others take on a more prominent role. The potential of computer technology as an aid to education appears to be boundless. The challenge is to identify the most promising ways to tap this potential.

We have examples of powerful technological tools for education. We need more. Often, available applications of technology for instruction relate to only a few topics in the curriculum rather than covering a complete course. Computer tutors work for well-defined problems such as geometry proofs. Much work is needed before similar tutors for open-ended or verbal problems become available. Tools that teachers can adapt to their plans are becoming more common. We need to determine how best to use design environments. We need to provide support for teachers who want to use these programs. Thus, we have only just begun to develop technological tools that make a difference in education.

Integrating Technology into the Curriculum

As the amount of information available in given fields has expanded and new fields have emerged, schools have attempted to cover more and more information in the available courses. Middle school science courses often survey all of college science. This approach clearly cannot continue. We must reflect upon not only what should be added to the curriculum, but also what should be removed. Technological advances suggest some candidates. In mathematics, computers can do long division and reduce complex equations. Students could spend less time learning these skills and more time learning how to set up equations and to analyze relationships among different phenomena, thereby focusing on problem solving rather than on mechanics.

Voyage of the Mimi

Box 7: Learning Modules.

Learning Modules from "The Voyage of the Mimi"

Maps and Navigation, with Navigation Computer Activities	Whales and Their Environment, with The Bank Street Laboratory	Ecosystems, with Ecosystems Modeling Activities	Introduction to Computing, with Turtle Graphics Activities

"The Voyage of the Mimi," developed by the Bank Street College Project in Science and Mathematics, combines the media of television, print, and software in an integrated approach to science and mathematics. Through a series of informative and entertaining episodes depicting a sea voyage to study whales, students see science and mathematics in action. Mathematics and technology are used as tools in all of the tasks required in the expedition, e.g., in navigation as well as collecting and analyzing data. Science becomes a human activity, conducted by recognizable people who are applying mathematics, science, and technology in a wide range of daily activities. The print and software materials accompanying the television series encourage students to experiment further with the elements of the natural world they have viewed in the television segments.

"The Voyage of the Mimi" was designed as an integrated curriculum for children in the upper elementary grades. Initial funding for the project was obtained from the U. S. Department of Education, with additional funds provided through publication and distribution agreements with CBS, Inc. and Holt, Rinehart, and Winston. The video materials consist of thirteen 15-minute episodes of a dramatic/adventure story, each paired with a 15-minute documentary-format "expedition." Students use printed guides and interactive software to explore the concepts in depth. LOGO activities and Microcomputer-Based Laboratory (MBL) simulations allow students to investigate scientific and mathematical ideas.

The series is broadcast on PBS, in half-hour episodes for home viewing and quarter-hour episodes for school viewing. Videocassettes and softwar are available from Holt, Rinehart, and Winston.

Technological tools offer impetus for curriculum reform. Conference participants called for integrating technology across the curriculum. An example of such an effort is the Voyage of the Mimi developed at Bank Street College of Education (see box).

Computers can transform the goals of the curriculum. In language learning, word processors now make handwriting and redrafting less important than students' ideas. Instead of spending time recopying, students can think more about their ideas. Word processors also provide spelling checkers that identify misspelled words. Students using spelling tests generated from words they misspell may learn more efficiently. Word processors support revision and refinement and group writing projects. As a result, writing courses can emphasize communication to specified audiences. In history, computers can provide access to real-world data bases. By manipulating these data, for example, by graphing voting patterns over time, students can gain a deeper understanding of complex relationships.

In classrooms where technology is widespread, instead of memorizing information, students can devote attention to learning about causes and effects, about how to construct an argument, and about how to select appropriate evidence. By using the computer to expand their memory, students can address complex problems. As a result, students have the opportunity to gain deeper understanding of fewer topics rather than superficial knowledge of many topics.

Changing the curriculum will change the nature of learning and instruction. Skill in reasoning and problem solving involves a great deal of autonomy. The learner must generate the solution to the problem as well as test the solution to be sure it is accurate. Learners who understand the nature of problem solving, and who realize that problems often have many solutions, will be far more effective than those who believe problem solving involves following a discrete set of steps of a memorized algorithm. Thus, educational activities must transfer responsibility for a correct solution to the student and help students learn to work together to generate possibilities and test their implications.

Computer-based testing will also change notions of student assessment. For example, since computers can store large banks of test items, they can generate test questions based on a student's answers to previous items, thereby creating a test tailored to the individual student's level of achievement. Furthermore, computers allow test developers to create questions never before thought possible. For example, students could be asked to analyze a data base or design and improve a simulation of a complex system. Such tests assess how students go about gathering information and refining their ideas as well as whether they come to accurate conclusions.

Teaching in the Information Age

Teachers in the Information Age will have technological knowledge and skills. To incorporate technology into their teaching, such teachers will benefit from substantial support ranging from financial resources to programming assistance. Unencumbered by excessive rules and regulations applying to their performance and responsibilities, they will have decision-making authority to select and develop curriculum materials and to set instructional goals for their students. They will enjoy regular opportunities to reflect on their teaching and to consult with their school-based colleagues as well as with university researchers and industry experts. In short, teachers in the school of the future will have the same level of expertise, the same support, the same decision-making discretion, the same intellectual challenges, and the same financial rewards typically afforded other professionals in their work.

Conference participants agreed that this conceptualization of the teacher in the Information Age matches the vision of expert teachers developed by the Holmes Group in its report entitled, *Tomorrow's Teachers*, and by the Carnegie Task Force on Teaching as a Profession in its report entitled, *A Nation Prepared: Teachers for the 21st Century*. These groups outline an ambitious and thoughtful plan for the professionalization of teachers. Key to these plans is the conceptualization of diversified roles within the school and the need to accord teachers the rights given those in other professions. They recommend restructuring the teaching force to introduce a category of exceptionally skilled and knowledgeable teachers who would advise and guide novice teachers and assist experienced teachers who need targeted assistance.

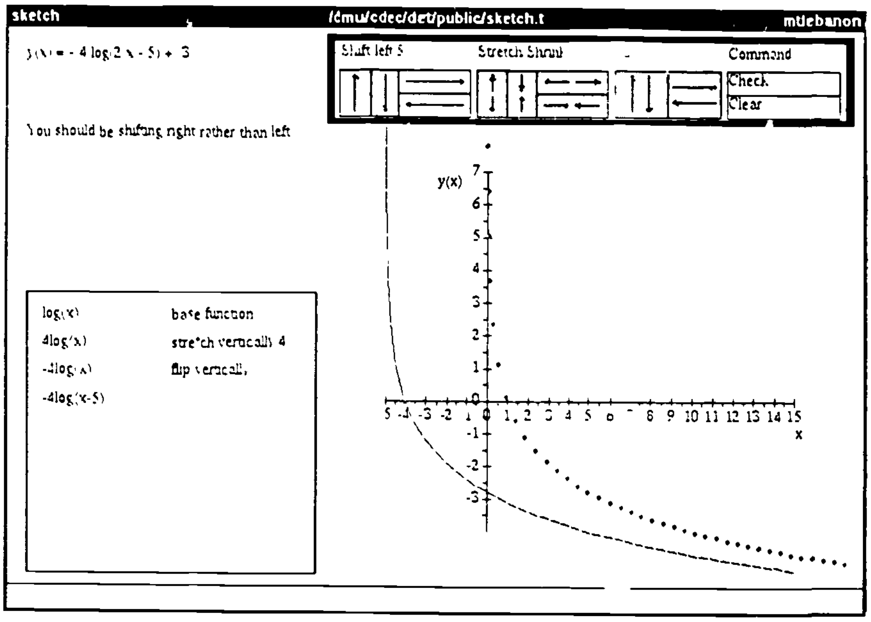
Rigorous, graduate-level teacher training is recommended, including one year of formal coursework drawing upon practice-sensitive research on teaching and learning and a one-year apprenticeship in one or more clinical settings. Advocated as well are teacher autonomy in classroom instruction and teacher leadership in school-level decisions, such as the selection and evaluation of peers.

Technological advances give added impetus to the teacher reforms advocated by the Carnegie Task Force. As Professor Decker Walker of Stanford University noted, "The demands made on a teacher's skill and knowledge by using computers are of the same order as those of keeping abreast of her subject or of trends in the teaching of it." Conference attendees stressed the need to recognize the extraordinary responsibilities of teaching, including the complexities added to the teaching process by technology, and the importance of supporting and rewarding teachers who demonstrate a high level of professional dedication and commitment

Professional teachers will be able to use tools like CMU Tutor which allow educators with limited technical knowledge to design instructional materials. Professor Jill Larkin of Carnegie-Mellon University illustrated the power of this environment by demonstrating a program called Sketch that helped algebra students relate graphs to equations (see box). Teachers can incorporate technological tools where they have the authority to select curriculum materials and select instructional goals for students.

CMU Tutor

Box 8: Screen displa, midway trough a student's solution to a problem.



Sketch was developed by researchers at CMU working closely with classroom tutors. It is written in CMU Tutor, an authoring system requiring minimal technological skills. Sketch helps students to develop skills of visualizing and quickly sketching curves, emphasizing transformations of shape and location, rather than the plotting of individual points. Sketch can guide the graphics of any expression that contains a single non-arithmetic function (which we call the base function), e.g., y(x) = 2sin(3x) or y(x) = 2x3-4. Within that class of expressions, Sketch provides instruction for any problem entered by a student or teacher.

Sketch features:

- A problem solving model and coaching strategies for problems posed by the program's users.

- A coach for helping students to apply the problem solving model that gives appropriate help at each step.

- Instructive examples expandable by the teacher to reinforce the current lesson or to review previous lessons.

- An interactive guide to using the program so no separate instructions or documentation are required for effective use.

Sketch was developed in CMU Tutor by David Trowbridge, Jill Larkin, Carol Scheftic.

For further information contact: Center for Educational Design, Carnegie-Mellon University, Pittsburgh, PA 15213.

In the school of the future, teachers will determine how space is used and how students' time is allocated. Current formulas for space allocation and student time are too restrictive. At times, teachers will want to address large groups of students, and at other times they will tutor individuals. Teachers will use laboratories for social science classes, for humanities classes, and for science classes. The current organization of schools mitigates against this possibility and therefore prevents creativity in redesigning the educational enterprise. For example, intensive concentration on new information probably should take place in very short spurts, whereas student reflection might require a two- or three-hour session with access to technological tools for feedback and trial and refinement of ideas. At present, schools attempting to integrate technologically based programs find themselves fighting against the 50-minute school period and even abandoning innovative programs because of this constraint. The school of the future will overcome these limitations to implement an educational program for the Information Age.

With technological advance, life in the future will increasingly demand more reasoning and problem solving skills, more collaboration, and less rote learning. As a result, teachers will reward students for their ability to analyze, synthesize, troubleshoot, learn new systems, locate information using technological tools, ask the right questions, solve problems jointly, and identify new approaches and applications.

Like Douglas Kirkpatrick with his Computer as Lab Partner curriculum, models for the teacher of the future can be found among the innovative and creative teachers in schools today. Conference attendees stressed the need to support and encourage those few who have achieved this role in spite of the difficulties and limited incentives. Changing the role of the teacher and the nature of teacher education will attract more innovative professional teachers, amplify the strengths of innovators through apprenticeship programs, and ensure that the talented teachers we have do not "burn out" and leave the field.

Educating Teachers

Technological advances give added impetus to recommendations for "professionalizing" teaching. Computer technologies make teaching more complex. The information explosion affects the knowledge and skills that students must learn. These factors must be considered in the redesign of teacher education programs.

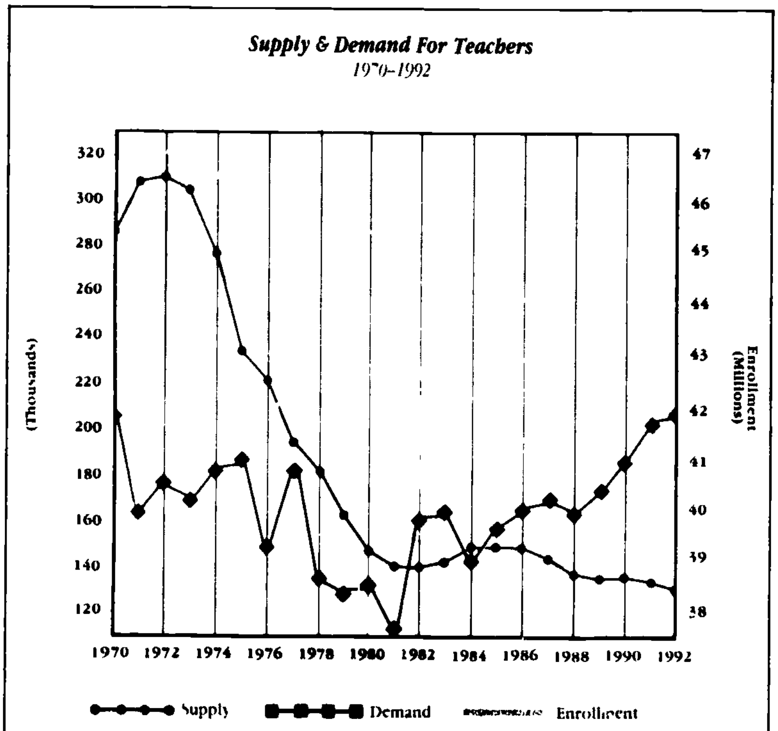
Teachers must have the opportunity to use the latest educational tools from the very start of their careers. They need course work on educational technology as they begin their preparation programs. They need to learn and assess research findings that reveal the cognitive outcomes of technology-assisted learning. They need opportunities to use and evaluate different technological tools in controlled and clinical settings. They must have opportunities to reflect upon their own pedagogical knowledge and teaching practice and to design and experiment with technology-assisted solutions to problems they encounter. They must be guided and advised by teachers, teacher educators, and researchers with expertise in educational technology.

Prospective teachers need a firm grounding in the subject they plan to teach. Rather than prematurely specializing, teachers in the school of the future will develop a deep and coherent understanding of the structure of their discipline, they will have a sense of the meaningful questions in the field, and the ability to recognize emerging issues. They will be able to restructure their own learning in light of new information.

Most important, these teachers will involve students in understanding new material. They must empower students to take responsibility for learning. Recent research shows that students can be taught to seek and incorporate information autonomously. Most students need incentives to reflect on their ideas, strategies for extracting central concepts, and techniques for evaluating new information. Traditional lectures and assignments place students in a passive role and imply that learning consists of absorbing new information. Few students change their ideas under these conditions. Instead, students who actively construct new perspectives become lifelong learners.

Our teacher education programs face an unprecedented series of challenges. They must counteract declining interest in teaching among our most talented college students. They must be responsive to the demand for more than one million new teachers in the next five years (see Figure 7). They must prepare individuals for expert teaching in schools where computers are commonplace. Examples of successful responses to these challenges exist, but are not widespread. We need to examine, highlight, and expand these teacher education program models if we are to prepare for education in the 21st century.

Figure 7
Trends in supply and demand for teachers. By conservative estimate, districts will need to hire over one million teachers by the 1990's.



Sources U S Department of Education, National Center for Education Statistics *Statistics of Public Elementary and Secondary School Systems*, various years, *Projections of Education Statistics to 1992-93*, 1985, and *The Condition of Education 1985* 1985

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The Learner in the Information Age

At the same time in our history that computers are becoming ubiquitous, researchers have been uncovering evidence about learning which points to using technology much more widely as a fruitful direction for improving instruction.

Those who study learning and instruction are beginning to understand how learners respond to new information and how technology can help students incorporate new ideas. Essentially, students incorporate new information into the models and knowledge structures that they already have. Their knowledge remains specific to the problems they know. To prepare students to cope with the rapid increase in information we need to teach them how to reflect on new information and restructure their understanding. Such reflection and restructuring is extremely well suited for taking great leaps forward in one's understanding, but is rarely encouraged in existing educational programs. Learners rely on their available knowledge when solving new problems. When given the opportunity and encouragement, learners organize and amplify information by reformulating previously held models based on new information.

Often people assume that innovations can do no more than facilitate previous approaches to the same problem. This tendency was apparent when computers first became available. Curriculum designers implemented familiar models for instruction. They used computers to replace books, producing drill and practice electronic workbooks. They used computers to replace lectures. Often illustrations taken directly from blackboards were reproduced by a computer. The full interactive potential of the computer was not tapped.

Researchers and developers are creating models for instruction that specify how technology can encourage learners confronted with new problems to go beyond previous approaches. Researchers aware of the learner's process of reflection and reconstruction have created simulations and design environments that are completely new educational tools with tremendous advantages for students. Design environments such as STELLA allow students to try ideas, observe their implications, and refine them. Environments that represent the same process in different forms, such as the Geometric Supposer, encourage reflection.

Teachers in the school of the future will understand this process of reflection and restructuring, and will articulate it in order to prepare students for life in a world now characterized by constant, rapid change. Curriculum developers will use technology to help students become life-long learners. In this effort, curriculum developers and teacher educators will also need opportunities for reflection and reconstruction. Only by realistic trial and refinement of innovation can we hope to create software for the school of the future and educate teachers who can use it.

Those guiding the school of the future will need robust, comprehensive theories of teaching and learning. Available theories often focus on a particular technological innovation, like artificial intelligence, or on specific research, like comparisons of experts and novices solving physics problems. These form starting points for broader, more multidisciplinary theories. As the synergy among those concerned with education grows, robust and dynamic theories will become possible. Constantly expanding theories will be needed to complement the constantly developing technology, the rapidly improving role of the teacher, and the responsive school of the ture.

Summary

We have just begun to tap the potential of technology for education. Examples of the power of computer-assisted teaching and learning are isolated. There has been little systematic incorporation of technology into elementary and secondary education. We lack comprehensive knowledge of how computer technologies are currently being used in the nation's classrooms and of the relationship between current patterns of computer use and specific learning outcomes. At the same time, new technologies are upon us, holding out the promise of innovation in education. Developments in computer technologies challenge us to examine future directions for student learning, the curriculum, the organization of schools, teaching, teacher education, and research on teaching and learning.

The impact of computer technology on education cannot be fully anticipated, especially because the field is ripe with invention and constant change. Therein lies a dilemma in educational planning, implementation, and resource allocation. Other innovations of similar magnitude, such as the steam engine, required a lengthy period of development, reconceptualization, and refinement before being fully exploited by society. Computer technology is undergoing the same evolutionary process, but the time frame is highly compressed. We cannot know what changes lie ahead for us, but neither can we afford to wait and see. As with any experiment, we must be open to a wide range of possibilities for the impact technology will have on the educational process.

Moreover, education is a complex and interdependent enterprise. Effective educational programs involve talented teachers, motivated students, specialists from the disciplines, curriculum developers, technological experts, supportive state legislators, the active interest of industry, and a vast assortment of other contributions. To meet the challenges of technology, we must insure the productive and collaborative interaction of everyone concerned.

Our educational enterprise no longer meets the needs of society. A myriad of reports document that students lack essential knowledge, that Americans compare poorly to students in Europe and Japan, and that many graduates of American schools are unprepared to cope with the Information Age.

Educating citizens in the Information Age requires widespread change in the educational system. Participants came to the conference to determine how technology could improve teacher education. However, changes in teacher education require changes in the organization of schools, the nature of the curriculum, the goals for learners, and other aspects of education. Since technology can play a role in all these areas, conference participants recognized the need to address them jointly. Participants applauded efforts of individuals and groups to respond to the challenge of technology in education and stressed that all concerned must work synergistically to achieve the needed changes.

Isolated groups and individuals recognize problems and respond independently. Innovative teachers seek to create effective programs. Researchers aim to advance our knowledge of how learners gain new understanding. Teacher educators seek to train resourceful teachers. Software developers aim to design exciting educational tools. Deans of schools of education seek to inspire professors to take advantage of technology. Schools seek to incorporate computers into the curriculum. The challenge now is for these and other groups to combine their expertise and experience to prepare citizens for the 21st century.

Meeting the Challenge

In 1982, *Time* magazine selected a computer as its "man" of the year. Five years have passed, yet the potential of this revolutionary technological tool has yet to be fully realized in our classrooms. Resources must be allocated in order to prepare students for the Information Age. Federal funding of educational research is far too limited, especially compared to funding for research on health and defense-related problems (Figure 8). The school of the future cannot be realized unless education becomes a national priority.

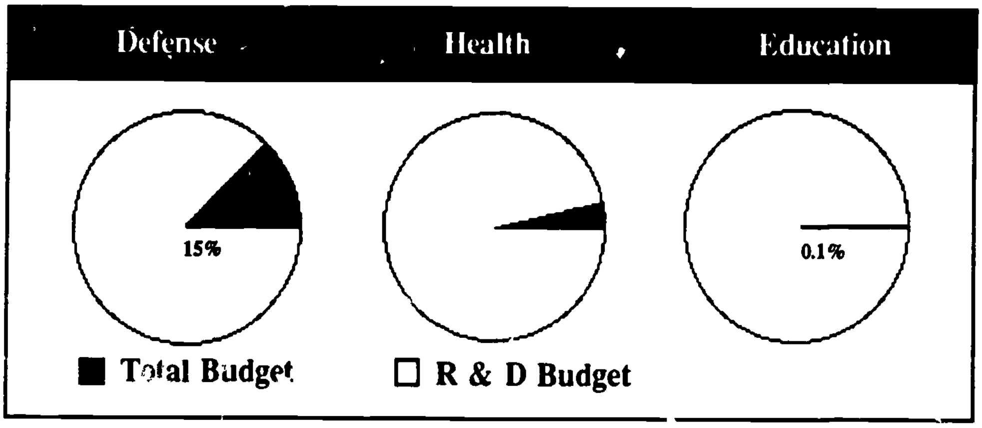

Figure 8
Percent of the federal budget for defense, health, and education allocated to research and development.

In order to meet the challenges of technology in education successfully, schools of education, teacher education programs, and the field of educational technology research and development must address objectives specific to their responsibilities and areas of expertise. At the same time, these groups must collaborate in pursuit of three broad objectives, described below.

Multidisciplinary Cooperation
First, because of the magnitude and complexity of the problems involved in exploiting technology for educational improvement schools of education, teacher education programs, and the field of educational technology research and development need to coalesce expertise from a vast range of diverse fields. We need to tap the wisdom of expert teachers. We need to understand the knowledge required in each discipline and the pedagogy needed to transmit that knowledge. We need to attract more talent to the field of educational technology. We need expertise and creativity in institutional planning and institutional change. We need imaginative federal, state, and local policies. We need the involvement of industry.

To create collaboration among all concerned with technology and education will require dedication, resources, and talent. We must find ways to work together. We need to communicate across disciplinary and professional boundaries. We saw the beginning of collaboration, and its benefits, at this conference. We must continue to support and nurture such efforts to meet the challenge of technology in education.

Large-Scale Investigations

Second, to increase synergistic problem solving, schools of education, teacher education programs, and the field of educational technology research and development must be able to experiment with new roles for teachers, new arrangements for teacher education, and new relationships between research and practice. We need large-scale experiments in order to assess the interaction between developments in each of these areas and developments in technology. We also need to seek new forms of evidence and new ways to incorporate such evidence into decision making so that large-scale experiments not only contribute to knowledge but also result in an improved educational enterprise.

Opportunities for Reflection

Third, schools of education, teacher education programs, and the field of educational technology research and development need to create institutional mechanisms for formulating our goals and objectives for technology in education through collective reflection, articulation, and negotiation. We need to explore what makes for an effective citizenry in an information society. This debate is already evident in the popular press. Questions such as, "Is programming worth learning?" and "Do computers dehumanize education?" appear regularly. For our part, we must seek to answer Alfred North Whitehead's broader question, "What knowledge is worth having?" Our new technological tools do not lead to a single or simple answer. Rather, they challenge us to envision and provide for a wide range of educational outcomes.

Schools of Education

To meet the challenges of technology in education, school of education deans and faculty need to contribute their expertise in teacher training, in educational policy analysis, and in practice-sensitive research. Their skills and insights are critical to collaborative planning and concerted action for the future of technology in education.

Opportunities

Of most importance, the approaches that schools of education take to the incorporation of technology in their own teacher education programs will ultimately, through their graduates, exercise a key influence on the extent to which technology contributes to education in our society as a whole. Schools of education need to seize the opportunity to provide leadership in introducing technological advances to the instructional enterprise. As this conference has demonstrated, deans of schools of education can work together profitably to define the opportunities, problems, and pathways they face for meeting the challenge of technology in teacher education. In the following major section of this report, these opportunities, problems, and pathways in teacher education receive special attention.

In addition to teacher education, schools of education need to seize the initiative to establish partnerships with industry to address research on technology questions in education. Traditionally, schools of engineering and business administration have worked in partnership with industry to further common research goals. Now that computer technology is on the brink of permeating the educational process, the role of schools of education as a bridge between technology researchers and educational practitioners, and between software producers and curriculum users, has become a vital one.

Furthermore, schools of education can provide leadership in higher education's use of technology. They can insure that academic policy-makers within universities consider the use of technological tools for teaching and learning. Schools of education can assist other university units to incorporate technology into their instructional programs. Schools of education can also participate in policy making regarding software licensing agreements and incentives for faculty and students to become more proficient at using technological tools.

Problems

Schools of education face many problems in responding to the challenge of technology in education. Only a few have the critical mass of faculty expertise required to begin developing leadership capacity in the new field of educational technology. At the conference, deans of the leading schools of education noted the difficulties of mounting new programs of study in educational technology with faculty whose technology expertise is uneven or limited. Some may not be aware of the latest advances, while others may focus on individual tools rather than on the field as a whole. In cases where faculty are prepared to conduct research on the effects of technology on teaching and learning, there may be no opportunities to conduct large-scale experiments in school settings.

Despite these difficulties, education deans recognize the danger of succumbing to the pressure of the status quo and failing to nurture technological innovation. They worry lest computers suffer the same fate as other classroom technologies now relegated to closets where they lie unused. They are concerned that the unwieldy nature of the educational enterprise, the often weak ties between research and practice, and the rapid pace of technological development will result in an educational system that fails to prepare students for productive and satisfying lives in the Information Age.

Promising Paths

Schools of education are identifying promising paths for meeting the challenge of technology in education. Schools of education are beginning to provide leadership within the higher education community in grappling with the complex issues of software licensure and copyright. Deans at the conference emphasized the importance of university-wide planning for licensing in order to negotiate favorable agreements and insure long-term relationships. Furthermore, they pointed out that larger consortia of universities might band together to provide incentives for software publishers to offer lower rates and create licensing agreements that serve the full consortia. Such consortia could also provide incentives for members to develop software. They might insure adequate return on effort and appropriate dissemination of new materials. In addition, such consortia might jointly secure funding for software development and dissemination from private and public foundations.

Schools of education are also beginning to explore research partnerships with industry. Schools of education can offer industry their expertise in research on teaching and learning, their understanding of educational change, and their ability to review and analyze educational applications of computer software and hardware. Industry can offer schools of education their expertise in technology research and development and provide access to state-of-the-art technological resources.

Teacher Education Programs

School of education faculty members involved in teacher education face a special challenge. Both the available technologies for education and the role of the teacher in schooling are undergoing rapid change. Coordinating and integrating these changes requires special skill, knowledge, and vision.

Opportunities

The Carnegie Task Force and the Holmes Groups have put forth visionary proposals for the reform of the teaching profession and the preparation of teachers. Teacher educators need to elaborate on these proposals after thoughtful consideration of the implications of technology for teaching and for innovative teacher education programs.

Ideally, certain highly competent teachers should be able to take professional responsibility for evaluating technology and incorporating technological tools into the practice of teaching. Such teachers would have the capacity to review and adjust the curriculum as new technologies emerge and to assess the relationship between technology-assisted instruction and student learning outcomes. However, this description of expert teachers who utilize instructional technologies competently and creatively does not readily translate into a teacher education program. Teacher educators need to devote time and thought to the design and implementation of experimental teacher education programs that attempt to infuse technology into the teaching process.

Problems

One dilemma facing teacher education programs stems from the rapid evolution of computer technologies. As Dean Carl Berger of the University of Michigan, Ann Arbor, told conference attendees, "The problem is how to prepare teachers for hardware that is not yet invented, for software that is not yet designed, and for curricula not yet imagined. It's hard to have a vision of what technology will be, but, as deans, we have to have a vision, and we have to realize that it will change."

A second problem concerns state regulation. Schools of education are overburdened with state regulations that minimize opportunities for the creative design of teacher education programs. Rather than directly assessing the knowledge and skills of credential applicants to insure their minimal competency as teachers, state licensing bodies often focus on the detailed regulation and evaluation of teacher education programs as an indirect means of insuring the quality of new entrants to the teaching force. These regulations and program guidelines are far from conducive to experimentation in teacher education, including the incorporation of technology in teacher education.

A third problem for teacher preparation programs in colleges and universities is the need to reform undergraduate education generally, and not just that portion in the school or college of education. Dean Alphonse Buccino of the University of Georgia commented that "A substantial portion of a teacher preparation program of a university is carried on outside the jurisdiction of the school or college of education. Often schools of education must cope with unintegrated programs in general education, excessively narrow subject area majors, and poor teaching role models in undergraduate education."

A fourth problem concerns apprenticeships for novice teachers. Teacher education programs must work in collaboration with schools and school districts to provide clinical training to beginning teachers. At present, few schools and school districts offer technologically advanced environments where teacher credential students can experiment with technological innovation. Few mentor teachers can provide advise and guidance to student teachers on the advantages and disadvantages of using technology to facilitate teaching and learning.

Promising Paths

Conference participants identified the work of the Holmes Group as a promising foundation for the design of teacher education programs that incorporate technology. As a first step toward the conceptualization of new teacher education programs, participants agreed that the use of technology must be widespread in teacher education courses. By providing a rich technological environment, schools of education can empower preservice teachers to use technology competently and confidently and to increase their understanding of the potential of technology for education.

A few of the schools of education represented at the conference provide a link to student teachers in the field through electronic networking. These schools of education are demonstrating the power of computer technology while at the same time reducing the isolation from other professionals that teachers frequently experience. In other institutions, professors in schools of education are providing teacher education students with access to research laboratories so that they can explore new technologies within a community of scholars.

Some conference participants pointed to the advantages of involving preservice teachers in the examination and evaluation of computer literacy courses and computer software packages. By challenging preservice teachers to analyze the strengths and weaknesses of innovations, teacher education programs help novice teachers to develop independent and confident approaches to assessing the benefits of technology and incorporating specific technological tools into their own professional practice.

Faculties of schools of education are beginning to train novice teachers in the use of technology in curriculum development. CMU Tutor allows educators with limited technological knowledge to design instructional materials. Professor Jill Larkin of Carnegie-Mellon University has involved teachers in using this environment to develop materials.

Conference participants involved in teacher education called for research and evaluation studies of technology in education to inform the preparation of teachers. Only by building on the knowledge and experiences of those who have examined the role of technology in education can teachers acquire the concepts that they need to assess new technologies and select those appropriate to their needs. By introducing results from research and evaluation in technology in the training of teachers, schools of education can help students incorporate research findings into teaching.

A promising path for effective teacher education is experience in a model educational setting, such as the professional development schools advocated by the Holmes Group. By training teachers in an experimental setting where the nature of the educational institution is also modifiable, professionals can jointly investigate different approaches for preparing teachers and determine mechanisms for creating the reflective and integrative teacher needed to cope with the rapidly changing technological environment and the enormous demands society makes on education. In such schools, teacher education programs could make arrangements for technologically rich classroom environments where student teachers can experiment with technology in instruction. Such environments could also serve as settings for experiments where student teachers work in collaboration with mentor teachers, teacher educators, and researchers to examine a particular technological innovation.

Educational Technology Research and Development

A new field of professionals concerned with research and development in technology and education has emerged. These individuals come from computer science, physics, engineering, educational psychology, biology, philosophy, and many other fields. They cross disciplinary boundaries, develop expertise in several areas, and work collaboratively on interdisciplinary research.

Opportunities

The work of these researchers has the potential to provide the theoretical basis for new approaches to learning and instruction in American education and for the development of innovative technological tools for fostering high-level reasoning and problem-solving skills. Indeed, as noted throughout this report, many exciting prototypes have already been developed, and researchers need to explore avenues for further development.

Based on recent research on the organization of knowledge, for example, we know that instruction must take into account both the knowledge structures students need to develop and the structures they have already acquired. We know that instructional models associated with a particular subject matter are not necessarily suited to other subject areas. And we know that we must consider creativity, imagination, and reflection in conjunction with specific subject matter, rather than relegating these topics to a separate domain. The development of technological tools for learning and teaching must build upon this body of research.

Problems

The emerging field of research in technology and education faces several obstacles.

First and foremost, financial resources are scarce. Most professionals familiar with the field believe that the results generated by those working in it are far more valuable than is reflected in the available funding. Without appropriate resources, promising graduate students and other talented individuals will not be attracted to the field. As a newcomer to academia and professional education, this fledgling field lacks visibility and has yet to be fully accepted.

No clear formative program or career path yet exists for this group, nor do they yet have an established professional infrastructure. Small enclaves of individuals specializing in technology in education exist across the country; however, their existence outside of the traditional academic departmental structure is precarious.

To succeed, this group must expand its base and interact responsively with leaders and innovators in related fields. Researchers in education and technology who attended the conference expressed the hope that it would be the first of many opportunities to share ideas and explore possibilities in a multidisciplinary and multiprofessional context.

The field also lacks sufficient technological resources. Often developers are frustrated in their efforts to create new technological tools because they lack needed equipment.

A second major problem faced by this emerging profession is associated with rapid technological advances. Developers must decide to what extent they should work with leading edge technologies that might never have direct application to classroom instruction.

This decision is far from straightforward. Much of the exciting work done by the Smalltalk group at Xerox in the 1970s never became visible to the world of practice, but it formed the basis for the Macintosh Computer that now has tremendous potential for education. In contrast, tools developed within the confines of widely available technology, such as The Geometric Supposer, have already had substantial influence on educational practice. Clearly a balance must be struck between concentration on leading-edge technologies and concentration on current-generation technology.

A third problem centers on the political economy of technological development and implementation. Issues of software licensing and dissemination of rights, royalties, and copyrights remain enormously problematic. Inspired by colleagues in engineering, developers should seek widespread use of their products. For example, the CMU Tutor authoring language is in the public domain. Large, complex development projects cannot build a tool and simply hand it over to the user; rather they must work closely with users for maintaining and refining the tool, training the recipients, and providing new versions as they emerge. Therefore, long-term collaboration agreements are also needed.

A fourth major problem is the resistance of schools and school districts to exploit technological developments. Researchers and developers engage in extensive trial and refinement of their products, examining how learners use their tools and how teachers incorporate them into educational programs. Yet, if schools and school districts are unresponsive to new technologies or unable to modify their programs or change the nature of their curricula to incorporate new technologies, the conditions required to implement technological breakthroughs simply will not arise.

Promising Paths

One promising approach for researchers and developers is first to design and develop, in advanced technological environments, prototypes of technologically delivered instruction for discrete curriculum topics, then to expand these prototypes to address larger segments of the curriculum, and, last, to examine how these expanded tools can be integrated with other types of instructional activities to meet an even wider range of student curriculum needs. With support from the National Science Foundation, the Fund for Improvement of Post-Secondary Education, the Office of Naval Research, and private industry, including Apple Computer Inc. and other computer manufacturers, researchers and developers have undertaken medium-scale projects using this approach. For example the Logo Project at the Massachusetts Institute of Technology developed a powerful learning tool that has subsequently been widely incorporated into curriculum materials and used by creative teachers in unanticipated ways. The Plato Project at the University of Illinois has continuously refined a model of computer presented instruction that has inspired products such as Graphing Equations and Green Globs as well as CMU Tutor. The Voyage of the Mimi curriculum, which provides a comprehensive set of learning materials to promote students' understanding of science, mathematics, and technology in the upper elementary grades incorporates developments such as Logo and Microcomputer Based Laboratories. Many of the tools demonstrated at the conference and described in this report were generated by similar research and development projects.

Another promising path is to conduct trials of technological innovations in model classrooms or other prototypic learning environments. Thus far, such experiments have been undertaken on a relatively small scale, often with funding from the Apple Foundation Wheels for the Mind program or from the Science Education Directorate of the National Science Foundation. The microcomputer-based laboratory project at Foothill Middle School is an example of such a project. Pursuing this path might lead to prototypic or model schools, which would provide opportunities for testing technological tools under varied conditions of teaching and learning. The California Educational Technology Model Schools Project, for example, provides funding and recognition for model curriculum projects involving technology and model uses of technology in schools.

A third promising path involves incorporating technological innovation into curriculum reform. One example, Kidnet, funded by the National Science Foundation, allows students from across the nation to gather information, combine it, and analyze national trends (see Box).

Kidnet

Box 9: Kidnet Units.

K I D N E T U N I T S

Earth Science	Physical Sciences	Life Sciences
• Forecasting the Weather • Saving the Soil • Timing the Seasons	• Acid Rain • Getting Energy from the Sun • Saving Energy • Cleaning Up the Air	• Growing Food • Building a Habitat • Observing Living Things

A nationwide, high-tech approach to elementary science education, The Kids Network Project, is just beginning through a partnership between the Technical Education Research Center (TERC) and the National Geographic Society (NGS), originated by Robert Tinker. This project, funded by a grant from the National Science Foundation with dollar-for-dollar matching by NGS, pioneers an entirely new educational use of technology.

Through the project, called 'Kidnet' for short, students in grades 4-6 participate in an exciting series of science experiments, share the results of these experiments with each other through a nationwide telecommunications network, and analyze patterns and trends in their data. In TERC's highly successful prototype unit on acid rain, students from nine states across the country collected rain samples, measured the pH, and enthusiastically shared their results via the telecommunications network.

The network experiments are unique in conveying important, realistic messages about science: that measurement is central, that science is cooperative, that everyone can participate, and that scientific inquiry and the results of that inquiry matter. It is conceivable that students will discover something new through the network experiments and likely that their measurements will be similar to those of professional scientists.

Each Kidnet unit meets several criteria. It must include an experiment that is interesting to students and address problems that matter to students. The major experiment must fit onto the network model, where need for substantial amounts of data requires the efforts of many student investigators. In addition, it looks for opportunities to address, in innovative ways, content areas typically part of the curriculum in grades 4-6, and to achieve good balance among the different sciences.

For further information contact Robert Tinker, Technical Education Research Center, 1696 Massachusetts Avenue, Cambridge, MA 02138.

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A fourth path is to create a network of regional and national centers for collaboration in technology and education. Conference participants envisioned centers with common goals and separate foci. At least one center should focus on theories of teaching and learning relevant to technology.

Conclusions

To meet the challenge of education in the Information Age we must work in concert. Infusing the educational enterprise with technology will require the collaborative interaction of individuals involved in all aspects of education—not only deans of schools of education, directors of teacher education programs, industry specialists, and educational technology researchers and developers, but also students, teachers, school administrators, government policymakers, and others. Only by working together can we realize our vision of the School of the Future.

Recommendations for Action

The explosion of computer technology in the last few decades has dramatically changed how we live and what we must know. Ours is a society of individuals who must be lifelong learners with the capacity to respond to technological advances that will permeate all aspects of our lives. The challenge for educators is to develop an educational enterprise that prepares citizens for a future in this Information Age.

At the Conference on Technology and Teacher Education, deans of schools of education, teacher education faculty, researchers and developers in technology and education, and state office explored the promise of technology for the improvement of education, and they suggested ways for each of the major participant groups to meet the challenge of systematically planning and incorporating technology into teaching and learning. Moreover, they discussed activities that should be undertaken jointly by all concerned. The conference participants made four, interrelated recommendations:

I. Establish partnerships among universities, industry, and schools to respond to the challenge of technology in education.

The reformulation of the educational enterprise in light of technological advances cannot be addressed by any one group working alone. Conference participants called for partnerships among universities, industry, and schools to:

- Capitalize on the talent and expertise of the small number of people now working in this field
- Address complex problems that affect all members of the partnership
- Amplify the impact of limited funds for education
- Share scarce technological resources
- Combine forces to influence state and national policy

Partnerships intensify the effects of creative ideas by encouraging more groups to experiment with them. They increase communication and create conditions for group problem solving. At this conference, some such alliances emerged. Software developers from industry and from universities discussed common problems. Industry groups that equip schools with the latest technological tools consulted universities that train teachers. All groups exchanged ideas about equitable access to technology and about attracting and educating teachers capable of preparing citizens for the 21 century.

Partnerships may vary from loose alliances to well-stipulated programs for collaboration. They can be established through informal discussions or formal initiatives. As a first step, we call upon university, industry, and school leaders to establish incentives for partnerships, to provide resources for these alliances, and to nurture fledgling efforts.

II. Create Centers for Collaboration on Technology and Education

Centers for Collaboration on Technology and Teacher Education are needed to coalesce the energies and expertise of those initiating this field and to attract and train those who are interested in participating. Centers are needed to respond to the simultaneous impact of (a) rapid increase in the power of technology, (b) an impending shortage of trained teachers, (c) increasingly powerful models of teaching and learning, (d) new alternatives to the traditional roles of teachers, and (e) increasing demands on citizens in the Information Age.

Reconstructing the educational enterprise to realize the promise of technology requires multidisciplinary collaboration, interdisciplinary research, sustained communication, and comprehensive, long-term investigation of innovative ideas. Conference participants called upon schools of education to foster Centers for Collaboration on Technology and Education that:

- Foster interdisciplinary research and development among experts drawn from a variety of disciplinary areas and professional interests, including teachers, subject matter specialists, cognitive scientists, technology experts, government leaders, and educational policy analysts
- Build partnerships with industry to address common concerns such as developing and refining technologically-based curriculum materials
- Establish partnerships with schools to narrow the gap between research and practice by involving teachers in developing and implementing innovative curriculum materials and teacher education programs
- Develop and continuously improve educational programs that meet the increasing demands on learners.

Conference participants also called for one or more centers to undertake the following responsibilities:

- Establish consortia with other institutions to negotiate software licenses and encourage development of new software
- Develop mechanisms for software review and the dissemination of the findings
- Develop visiting scholar programs
- Reformulate the curriculum for a specific subject areas such as mathematics, art, or Spanish
- Construct and test models of learning, teaching, or software design
- Construct and test models of electronic communication
- Develop models for evaluating whether students have acquired the thinking skills needed for lifelong learning

Substantial funding and the ability to collaborate are required to make Centers for Collaboration in Technology and Education a reality. As a first step, we must create a task force to identify mechanisms for effective collaboration, set priorities, and induce federal agencies, private foundations, state legislatures, and industry to provide support.

III. Create model classrooms and schools where multidisciplinary teams can explore teaching, learning, and technology in real educational settings.

To understand the effects of technological innovations in education we must study them in realistic environments. These experimental environments should reflect the diversity of our student populations and the variety of our school settings. By establishing opportunites to study teaching, learning, and technology in real educational settings, universities, industry, and schools will be able to:

- Investigate how best to capitalize on the talents of teachers and the strengths of technological innovations
- Examine student progress when technological tools replace books and lectures while teachers focus on tutoring individuals and small groups
- Explore how technological tools that relieve teachers of tedious tasks can be combined with curriculum materials that encourage students to solve problems
- Study the potential of electronic networks linking industry, university, and elementary and secondary school professionals.

As a first step toward increasing the number of model classrooms and schools, we encourage universities, industry, and schools to find ways to intensify use of available school resources. For example, arrangements should be made for the establishment of before- or after-school laboratories where students could engage in sustained problem solving unhampered by the time constraints of the daily class schedule.

IV. Create opportunities for educational leaders, policymakers, and others concerned about education to reflect on education, technology, and society.

While being hurtled into the Information Age, we need to reflect on our choices, examine unanticipated consequences of rapid advances, and hear the viewpoints of all concerned about education. Such issues as visualizing the educated citizen of the 21st century, insuring equitable access to technology for all students, and designing electronically stored curriculum materials that teachers can modify all require thoughtful, sustained analysis.

Conference participants recommend the establishment of institutional arrangements that encourage professional educators, researchers, and policymakers to work together to provide leadership in shaping and refining visions for technology and education. These opportunities for reflection should allow for the expression of diverse points of views and for the study of both long-term and short-term problems. The opportunities should take a variety of forms, ranging from brief conferences to national institutes modelled after the Institute for Advanced Studies at Princeton or the Center for Advanced Study in the Behavioral Sciences at Stanford. As a first step toward implementing this recommendation, conference participants should organize regional seminars where university, industry, and school leaders are invited to discuss technology and the school of the future.

Conclusions

Reflecting on the challenge that computer technology presents for education, Dean Bernard Gifford observed, "There is widespread agreement that the computer is a one-in-several-centuries innovation. There is a climate of promise and optimism about the potential value of computers to education. But, if we are to realize the potential of computers for the improvement of education, we cannot rely on predictions of its inevitable impact on society as a strategy for implementation in the schools. Rather, we must thoughtfully conceive and carefully conduct inquiries outlining how we will get from where we are today to where we want to be tomorrow."

The recommendations made by the participants at the Conference on Technology and Teacher Education are submitted in the hope and intent that they will serve as an important first step toward this end.

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Appendix I

Perspectives on Technology and Teacher Education

Address by John Sculley,
president and chief executive officer, Apple Computer, Inc.

I was born in New York in 1939, which also happened to be a year when a World's Fair was being held. At that time, someone put together a document that tried to predict what the world might be like during the next 50 years. It talked about the potential of television, which was then still a curiosity, and space travel, which was then only a fantasy. But it never once mentioned the computer or the laser. I think that story points out how difficult it is to predict the future.

I am not a scientist, I am a businessman. When I look at this unpredictable world, I start by looking at the current economy. And when you look at the economy, you cannot help but notice the large number of mergers in recent years. Not only is the structure of business changing, but we are also seeing a period of rethinking by companies about their goals.

Shortly after I joined Apple, the chairman of Citicorp came out to visit. I thought he came to talk about banking. He had, however, come to talk about technology. He had a vision that Citicorp would be a great information services company, and banking would be just one of the services.

I remember when Roger Smith, chairman of General Motors, came to visit our automated Macintosh factory. I thought he had come to learn better ways to manufacture automobiles. His real interest, I discovered, was in transforming General Motors from an automobile company into a large, powerful technology corporation.

For over a hundred years, Sears and Roebuck has been known as a great retailer of products and services. Yet today, its main interests are financial services and information-intensive products.

Other things are also changing radically. For example, I remember reading Walter Wriston's book, *Risk and Other Four-Letter Words*. In it, he said that in 1948, when he started out as a young banker, letters of credit went though the mail. Today, bank transactions are conducted in microseconds. This compression of time has also dramatically compressed distances. It has made us rethink the relationships between countries, industries, and companies within industries. We truly are living in a dynamic, global economy, in which information is the primary resource.

Now what does all of this mean to education? I think it means that the people who are going to be educated in the schools of this country will be living in a very different world from the one in which we grew up. As I look at the educational system, I see a system that has its roots firmly planted in the industrial economy. It's no accident that much of the curriculum of schools in the past has focused on teaching students how to memorize facts. At the time that curriculum was developed, the majority of people could look forward to working in factories for their entire careers.

But the young people who are graduating from the schools today are, in all likelihood, going to be changing their jobs—and maybe their careers—four or five times during their lifetimes. Their learning will not end at the boundaries of the institution, but will be an ongoing process. *We have to prepare them with skills that will enable them to learn after leaving school.*

We are living in a world in which technology plays an increasing role in conveying information. Therefore, technology can have significant impact on the role of the teacher. The teacher will no longer have to be the person who drills students on facts. Rather, the teacher can help students develop their critical analysis and conceptual skills. And these skills are probably going to be increasingly important in an age of explosive information growth.

I find it astounding to think that the sheer amount of information in the world is doubling every three or four years. If you project that growth to the end of this century, it means that a lot of us are going to be either overwhelmed with information and unable to cope, or we are going to learn to transform the massive amounts of information into usable knowledge. This second possibility is one of the exciting things that I would like to see happen through technology.

I believe we are going to see tremendous leaps in technology that will more than fullfill even the wildest dreams that you as educators may have about what you want to be able to do in schools—both in the way you want students to learn and the way you want teachers to teach.

I'd like to give you some examples of educational projects in which Apple has been involved. There are two schools in Connecticut that have been using Apple computers to help students develop their conceptual skills. In one of the schools, students are given the information that was available to the inventors and engineers who pioneered the steam engine. Using those facts, the students then simulate on a computer their own concepts of a steam engine.

In the other Connecticut school, the students have put together data bases of local information, things such as climatic conditions at different points in time, and what happens to agricultural crops or to the growth of industries and companies. This project lets the students study the place in which they have grown up, allowing them to relate to their studies in a personal way.

We are also supporting a project in Los Angeles in one of the open schools. Although this is a school not for gifted children but for average kids, over 85 percent of the students are going on to college. The reason: They have a very gifted principal, who is interested in programs that develop their conceptual skills.

Dr. Alan Kay, one of the early pioneers and visionaries of the personal computer, is leading a project in this school. Alan and a team from MIT are trying to produce the kinds of tools that will be available to educators and students in the mid-1990s and beyond. Their work involves the development of a very complex computer simulation—a simulation of the creation of living animals.

Alan and his group are using experimental artificial-intelligence software to build some level of intelligence into the creatures that the children will build through simulation. Those of you who are cognitive scientists, or who know something about artificial intelligence, know what a monumental leap this represents. It entails imbuing the computer with enough intelligence to enable it to access information that may be relevant to its user. The computer will know what the user is interested in and be able to do very sophisticated content analysis.

The point of these examples is that there is a tremendous amount of experimentation going on—experimentation not only in technology, but in learning.

I think that there are two important paths that are being pursued in computer technology—both of which are going to be very relevant in the world these young people are going to live in, but for different reasons.

In 1964, Tom Watson Jr. made a very bold decision. He stopped all development work at IBM on products that were already on the market. He believed that computers were going to be so significant that the companies must go forward, unbiased by the past. That led to the introduction of the IBM 360, which brought institutions to a full realization of the power of the computer as a data-processing machine. The manipulation of data in useful ways—for payroll, for accounting purposes, for information collection—suddenly took on a tremendous productive value. That is essentially the paradigm that we have been living with over the last 22 years.

But another conception of the computer also emerged during the 1960s. This idea focused on celebrating the individual's relationship with the technology, as opposed to the glorification of the institution's. And the people who held this idea viewed the computer as a wonderful machine that could expand individual intellectual capacity. A machine that could make it possible to communicate better, to learn better, to work better; in short, to do things that were not possible before the computer became available. This is the vision of computing that Apple is most interested in pursuing.

We don't think that this idea will invalidate the giant computers that are processing data. But we *do* think that it will further humanize computing, opening up the possibilities of the computer as a truly interactive machine—a machine that people can use in an intuitive way as a tool to learn more productively. I think that this is going to offer some tremendously exciting possibilities for everyone in education.

One of the things I discovered when I joined the computer industry was that this is a very metaphorical business. One of the metaphors that I like to use is to compare the personal computer industry to the automobile industry.

The automobile industry began around the turn of the century with machine enthusiasts. These were the people who could crank the engine, who were strong enough to shift the gears, who knew how to fix the car when it broke down. Somehow, over the past 80 years, this industry has developed from a machine-enthusiast industry to a personalized mass transportation industry. This would not have happened without some radical changes. The technology of the car itself had to become transparent—for example, the automatic transmission had to be developed—before we had a large population of people who could drive a car. We also needed the infrastructure of highway systems and service stations, and the petroleum industry. All of these things had to be in place before we had personalized mass transportation.

The personal computer industry, which is now coming up on its 10th year, also began with machine enthusiasts. And yet the real opportunity is to turn this machine-enthusiast's tool into a personalized information-handling tool for the masses. Perhaps along the way, we will discover that we may have been somewhat myopic today. Just as the early automobile developers thought they were in the automobile industry instead of the transportation industry, I think that we who develop computers may discover that we're not really in the computer industry, but in the knowledge systems industry—creating personalized information-handling products. But for that potential to be realized, we have to remove the intimidation of technology. We have to make computer technology as transparent as automobile technology was made.

Luckily, all of the trends are working in our favor. The cost of technology is coming down rapidly. Miniaturization of hardware is allowing us to put more and more on a single logic board. We can realistically dream of building computers the size of a Macintosh or an Apple II that will be far more powerful than today's giant mainframes.

But we don't have to wait for the future in order to begin to experience some of the possibilities of this different vision of computing. For example, we know that there is tremendous development work going on to integrate curriculum with software. Unfortunately, taking textbooks and just making software an addendum to them is an approach that some publishers have tried in the past. But I think there are serious efforts under way to look at software as something that is integral to the curriculum.

As that develops, I think we'll also see more networking of computers. The teacher can have a controlling workstation and be able to interact individually with students at their own workstations. Students can be connected to teachers, teachers to other classrooms, classrooms to school administration, school administrations to central districts, and so forth.

Optical-disc storage devices will also be important. We're all familiar with the impact that the compact disc has had on stereo sound. This technology didn't exist in the commercial market a few years ago, but is now the primary way that high-quality sound is conveyed. That same technology—which is called CD-ROM technology, or CDI technology, or optical-disc technology—uses the laser to store massive amounts of information on a small disc. This means that we can store not only textual information but also pictures. We can look forward to desktop libraries of information that can actually reside in a classroom.

I speak to you tonight neither as a businessman nor as a technologist. I speak to you as someone who is excited about the world that we live in and the world that we are entering.

I am not only excited, but also concerned about the awesome challenges that education has in front of it. It often seems to me that it will take a crisis of immense magnitude before enough priority is placed on education—either by the federal government or in the [illegible] conscience. I sometimes wonder whether we'll have to wait until we get some incredible combination of events—like the Soviets landing on Mars on the same day that all of our teachers decide to retire—before we finally decide to really deal with the condition of U.S. education. I have little doubt, however, that we will eventually decide that education is important enough to make it a national priority. This simply *has* to happen.

About 18 months ago, President Mitterand invited me to lunch, and we talked about the role of computers in education. He was interested in a concept that would take 40,000 schools in France and turn them into computer learning centers. The students would use them in the daytime, and the parents would use them in the evening. France's aim would be to develop the most computer-literate population in the world.

Clearly, Japan has understood better than any other country the importance of a global economy that is dependent on both domestic and foreign markets. And Japan has placed a high priority on improving its education system. Not that its education is particularly innovative—but there is a lot of it.

Just to give you an idea of the impact of the lack of priority placed on sciences and mathematics by this country's educational system versus the strong emphasis placed on these areas by Japan's—50 percent of the members of the Japanese Diet hold technical degrees, and only 2 of the 535 representatives of our congress have technical degrees. Of course, it's not necessary that all of our politicians be technologists, but if we really are becoming an "information economy" *somebody* involved in government had better have an informed perspective on technology.

The challenge that all of you face is to educate teachers, to play a role in shaping the curriculum and in choosing the textbooks that are used in schools, to introduce new tools for teachers to use, and to embrace new concepts of learning that will change the way that students prepare for the world that they will enter when they graduate from school. If we do not do it, who will?

Last fall, I was in Bulgaria to speak at a conference called Varna II, a symposium of business leaders from Europe, the United States, and the Eastern Bloc countries. It was about six weeks before Gorbachev and Reagan were due to meet for their summit in Geneva, and there were a number of Soviets at this conference. In my presentation, I said that we had no way of knowing what the outcome of the summit would be, but wouldn't it be wonderful if technology were not the thing that divides us, but the thing that allows us to bridge our differences? Wouldn't it be wonderful if we could pick something that was as nonthreatening as education, and pick a technology as new and innovative as the personal computer, and let that be the way that our two societies worked together?

I didn't think anything would come of that conference, but in fact, the Soviets showed interest. Of course, I can't promise that the Soviets will suddenly start embracing Apple computers—or IBM computers or anyone else's computers—but I think there is a genuine awareness around the world of the importance of technology to our future. I believe that somewhere on the face of the earth, whether in France, Japan, the Soviet Union, or China (where, by the way, there are some 983,000 schools with over 20 million pupils, and nowhere near enough teachers to even think about educating their future populations), there is going to be someone who is going to figure out how to use technology in a way that will challenge young people to learn. And this discovery may turn out to be a far more significant factor in determining what the world is like in the 21st century than anything we hear politicians talk about today.

What makes our job at Apple exciting—and what makes your job as educators equally exciting—is that all of us really *do* have the possibility of touching the lives of millions of people who will spend most of their lives in the next century. And if we do our jobs right, we really *will* change the world.

Appendix II

The Long Revolution: Computers in Education

Bernard R. Gifford, Dean,
Graduate School of Education,
University of California, Berkeley

If this conference had been held three or four years ago, it would have been characterized by not a little hoopla—and quite possibly, a fair amount of nonsense about the near-term impact computers were destined to have on longstanding methods and traditions in American education. Three years ago, many of us would have come here expecting to be told about the classroom of the future, a place where students would sit at computer workstations instead of desks.

In all likelihood, we would have been told a great deal about these powerful, intelligent, and interactive workstations—especially their ability to gear their instructional advice to the individual needs of each and every student.

In addition to this talk of the future, we might also have been treated to a simulation of the classroom of the future: a classroom staffed by teachers well-versed in the intricacies of instructional technology, led by educators committed to effective use of computers in every aspect of the instructional enterprise.

Even those among us with little formal knowledge about computers would have been prepared for the conference and its futuristic visions of education by the popular media. As you may recall, three years ago, the nation's newspapers and magazines were full of stories about the coming technological revolution in education. Many of these stories informed us that the only barrier between the present and the promising new world of computer-based education was our inability to free ourselves from our mind-forged manacles, our comfortable and familiar ways of looking at teaching, learning, and education. Some of us, quite possibly the majority, would have found this exhortation convincing.

Times have changed. We know now, better than ever, that talking about the potential of the computer to bring about a revolutionary change in the manner in which the nation's educational enterprise is run is not the same as bringing about the revolution. We know now, better than ever, that we must move away from prediction and in the direction of more planning.

Predictions may tell us where we might be at some point in the future, but they will not tell us how we are to get where we want to go. It's one thing to speak in glowing terms about how computers can help students manage information, formulate questions, test hypotheses, solve problems, make judgments, and express themselves logically. It's another task to translate these predictions into practice.

One condition is essential to any realization of the predictions about the impact of microcomputers in education. Educational policymakers, including those in the business of manufacturing computers for classroom use, should understand the following: the microcomputer has great promise as an aid to effective knowledge transmittal and acquisition, and with intelligent use, can foster significant improvements in the education process.

However, this promise and potential will not be easily incorporated into the social organization of schools. Unless we realize this fact of organizational life, the microcomputer is doomed to remain an educational curiosity, a source of eternal hope and promise, permanently locked outside of the instructional mainstream. Unless direct and purposeful action is taken to alter the ability of schools to incorporate the microcomputer into everyday instruction, this will surely be the destiny of the microcomputer for the foreseeable future.

At least two elements are required to transmute the promise of current and anticipated advances in microcomputer technology into significant improvements in the instructional process. First and foremost, microcomputer manufacturers, as well as software developers, need to deepen their understanding of the nontechnical, intellectual aspects of the uses of computers in instruction. This can best be done by investing resources in research in the area of cognitive science. This interdisciplinary field draws from a number of areas, including psychology, computer science, philosophy, anthropology, linguistics, and pedagogy. Knowledge in these disparate fields is being blended, integrated, and interrelated to produce new insights into the internal cognitive world of complex human behavior involved in thinking, problem-solving, abstract reasoning, independent learning, and personal expectations.

As pointed out in a recent National Science Report:

This shift in emphasis is significant for educational research and development, and therefore, ultimately, for education itself. In the past, many teachers and persons in the disciplines concerned with the substance of education were unable to take seriously behaviorist psychology's seemingly simplistic view of what is to be learned and how it is to be learned. The new cognitive psychology accords much more closely with common views of teaching and learning, while at the same time providing a scientific basis for improving our understanding of these processes, and thus, far improving education.

Cognitive science is beginning to be applied directly to education in a number of ways. Reading comprehension is coming to be understood as a fitting of what is being read to the context and conceptual structure of the reader's existing knowledge, rather than as an isolated assimilation of new information. The nature of mental processes involved in solving problems in mathematics and science, by both novices and experts, is being elucidated, and we can expect better means of learning and teaching problem-solving skills. The subtle processes of self-monitoring and self-control that are common to skills in comprehension, problem solving, and learning of complex knowledge are being studied in a burgeoning branch of psychology called "metacognition." Teaching children to monitor their own comprehension and to take action when they do not understand, an ability characteristic of skilled readers, is proving to be a powerful instructional technique.

Without appropriate research and organizational mechanisms to test some of the new theories on teaching and learning (being generated by cognitive scientists in classroom settings over a wide range of age and grade levels with pupils with varied cognitive aptitudes), the likelihood that developments in this discipline will be systematically applied to instruction at the classroom level is very low.

This failure will have serious consequences, of which a few need to be mentioned. First without a deeper understanding of the cognitive consequences at classroom level, it will be impossible for computer advocates to make scientifically defensible claims about the effectiveness of computer-based instruction compared to more traditional modes of instruction. Second, without hard, verifiable data documenting the cognitive benefits of computer-based instruction, no educational policymaker can justify more than a token investment in computers. To act otherwise, especially in the face of other pressing needs, and in the shadows of past promises of technological breakthroughs that never materialized, would be to act irresponsibly.

Third, in the absence of a strong research base, it will not be possible to develop rules, protocols, and procedures for the design and evaluation of educational sofware. Needless to say, unless steps are taken to ensure more rigor and accountability in the area of software development, its current chaotic state will continue indefinitely.

In short, computer-centered reform strategies based on anticipated results rather than demonstrated accomplishments, large investments of scarce resources in the absence of compelling return-on-investment analyses, and the development of intelligent software by talented amateurs working in an environment where knowledge is noncumulative are all more likely to produce apparitions than solid achievements.

Deepening our understanding of the cognitive costs and consequences of computer-based instruction is necessary but not sufficient. Knowledge of cognitive science must be joined to knowledge of the schools. Expertise in the development of hardware and software, buttressed by appropriate sensitivity to the problems associated with the introduction of technology into complex, change-resistant bureaucratic systems, must be joined with detailed knowledge about the culture of schools and vagaries of the school change process. This point cannot be overemphasized. Too often would-be school reformers assume that schools are passive respondents to proposals for improvement, passive consumers of technology ever on guard for good ideas.

To ergonomics, the art and craft of adapting computers to the needs of pupils, then, must be added "organomics," the art and craft of adapting computers to the realities of the social structure of schools. Knowledge of hardware and software must be tied to information on the selection, training, and evaluation of teachers; to the complex web of bureaucratic rules and rituals that sustains the educational complex; and to the forces that influence curriculum decision-making, resource allocation, and school-site organization.

If we know only one truth about the education industry, it is that innovations, especially of a technological nature, neither easily nor automatically enhance the educational enteprise. Knowledge of the workday world of teachers, the pressures they face and the social structure in which they operate are essential elements for linking invention and innovation to improvement.

Analyzing the process of school change, Seymour B. Sarason identifies two types of school regularities: overt behavioral and programmatic. An overt behavioral reevaluation, for example, would be the rate at which teachers use computers in their mathematics classes or the rate at which students use computers in doing their mathematics homework. An example of an overt programmatic regularity is the fact that for every school day from the first grade on, pupils are expected to learn something about mathematics.

Following Sarason, the questions would-be school reformers need to ask, once these types of regularities have been identified and described, are "How is this particular regularity justified?" and "From what universe of alternatives of action was this regularity chosen?"

In his book, *The Culture of the School and the Problem of Change*, Sarason says:

Any attempt to introduce a change into the school involves some existing regularity, behavioral or programmatic. These regularities are in the nature of intended outcomes. It is a characteristic of the modal process of change in the school culture that the intended outcome (the change in the regularity) is rarely stated clearly, and, if it is stated clearly, by the end of the change process it has managed to get lost. It certainly was not an intended outcome of the introduction of the new math that it should be taught precisely the way the old math was taught. But that has been the outcome, and it would be surprising if it were otherwise.

Discerning overt behavioral or programmatic regularities requires that one look at the school culture from a nonjudgmental, noninterpretive stance, a requirement that is not natural to us. We are so used to thinking about what other people are thinking that we pay little attention to what there is to see.

Some might argue that the problems I've been talking about—the lack of adequate implementation strategies, the general neglect of schools as complex social organizations, and the segregation of research on cognitive science, school change, and computer design—once identified, will be resolved through the routine operation of the open market. This assumption—which we feel is mistaken—leads to questions such as the following: Why not rely on the open market to bring together critical elements? Why not simply encourage independent researchers to conduct their research on the impact of computers in the classrooms and encourage computer manufacturers and software developers to produce hardware and software? Why not leave teachers and learners alone to make decisions regarding resource allocation and instructional change on the basis of available information?

In response to these questions, we note that we have not one market in which critical elements and information are exchanged, but several. There are also other problems.

First, current research on the cognitive consequences of computer-based instruction is frequently unintelligible to both teachers and computer manufacturers. This is an understandable consequence of the specialized market in which such activities are undertaken.

Second, new research is meaningful to practitioners only when brought together and interpreted in relation to existing theory and practice in the field. Finally, research results are frequently inaccessible to the practitioners themselves. In part, this is due to the publication formats of specialized "markets" and the conventional reliance on obscure journals, conference proceedings, or in the case of government-funded research, reports prepared for funding agencies, but not for school district officials, (or—heaven forbid!—for teachers and principals at the school-site level to whom the information might be useful).

For all of these reasons, the so-called free market—which is, in fact, several specialized and isolated marketplaces—is not likely to produce the revolution that many predicted.

To reduce the gap between promise and performance of computer-based education, we propose that the computer industry join with selected schools of education to take the initial steps in forming a major research center on computer-based instruction.

Such a center would have a fourfold purpose. First, it would advance our knowledge of the cognitive consequences of computer-based instruction, through well-conceived, systematic, cumulative, and targeted research efforts.

Second, it would identify barriers to the optimal absorption of computers into the mainstream of routine instruction, particularly those obstacles that can be removed through the development of student-centered—as well as teacher-sensitive, educational software.

Third, such a center would more effectively link existing knowledge of computer-based instructional systems, including research on pupil-machine interaction, to current instructional practice (especially in subject areas such as mathematics and science, where research results indicate improvements in instructional effectiveness are most likely).

And fourth, it would serve as a bridge among the computer-manufacturing industry, the university research community, federal and state education policymakers, school district curriculum and instruction specialists, and professional groups representing elementary and secondary school teachers. A center would give these groups an institutional setting where they could work together on an ongoing basis to explore systematically the pedagogical and organizational consequences of the use of computers in routine instruction.

The center could evolve into a landmark collaborative enterprise uniquely capable of deepening the scientific basis of our knowledge of computer-based instruction. The center would also serve as a forum through which we could increase understanding of other technology-driven educational reforms that brought with them high expectations but then failed because scientific rigor was not coupled with organizational and policy sophistication.

Eventually, it would become both visible and useful to researchers throughout the nation. Like the many other cooperative research efforts involving industry and education, the center would both produce research directly (through a core resident staff), and provide resources for others to do work that required special resources.

Professor Nam P. Suh, director of the Laboratory for Manufacturing and Productivity at the Massachusetts Institute of Technology, is thought by many to be the exemplar of university-private sector research collaborations. She writes the following in a recent book, *Cooperative Research*.

Cooperative research is a worthy concept to consider because it enables universities and industry to accomplish tasks and generate ideas, which cannot be done without cooperation. Sometimes people think that if one spends a given sum of funds for research and development, the outcome will be the same regardless of where the work is done. However, we have found that new ideas that can radically improve productivity and/or quality of products are rarely created by the people who have been nurtured in a given culture. Clashing of different cultures and concepts is an indispensable prerequisite in formulating new trains of thought. Few major innovations of the past several decades, including instant photography, xerography, the laser, and solid-state devices, came from the people who were in the fields.

I believe that it will only be through the kind of collaboration of which Professor Suh writes that we will be able to bring about the real revolution in education that has been so long promised.

Appendix III

Annotated Software Bibliography

Algebra arcade. (1983). Mick, D., Konnemann, M., O'Farrell, R., & Isaacs, J. Wadsworth Electronic Publishing Co.

An educational game that helps reinforce graphing and calculating algebraic expressions. For the Apple II family.

AppleWorks. (1986). Cupertino, California: Apple Computer, Inc.

An integrated program featuring wordprocessing, database, and spreadsheet capability. For the Apple II family.

Balance of power. (1985). Northbrook, Illinois: Mindscape, Inc.

Balance of Power is a geopolitical game which provides an instructive simulation of global power politics. For the Apple II family.

Bank street writer. (1982). Smith, F.E., and the Bank Street College of Education. Developed by Intentional Educations, Inc. Broderbund Software.

This word processing program introduces the user to composing and editing on the computer. For the Apple II series.

Boxer. (1986). diSessa, A.A. (Principal Investigator) Developed at the University of California, Berkeley. Funded by the National Science Foundation.

Presents an alternative image—programming as a way for nonexperts to control a reconstructible medium, much like written language, but with dramatically extended interactive capabilities.

CMU tutor. (1986). Sherwood, B.A. and Sherwood, J.N. Developed at Carnegie-Mellon University.

A programming environment for advanced-function workstations, including features for the development of educational software such as picture and graph drawing, animation, menus, and mouse input. Runs on IBM RT, Sun 350, MicroVax, and Macintosh.

experLogo. (1984). Santa Barbara, California: ExperTelligence, Inc.

The LOGO computer language with Macintosh standard text and graphics interface. This software features list processing, use of arrays, and greatly increased speed. For the Macintosh.

Filevision. (1986). Software by Telos. An application developed by Carl Berger of the University of Michigan, at Ann Arbor.

A decision-planning program for college students that encourages revision and reflection. For the Macintosh.

Geometry supposer. (1985). Schwartz, J.L. and Yerushalmy, M. Pleasantville, New York: Sunburst Communications, Inc.

Allows students to construct and manipulate geometric forms, providing direct experience in testing conjectures quickly. For use on Apple computers. For the Apple II family.

Green globs and graphing equations. (1982) Dugdale, S. and Kibbey, D. at the University of Illinois. Pleasantville, New York: Sunburst Communications.

A package of four activities which include generating graphs from equations and writing equations from graphs. In Green Globs, for example, students enter equations to create graphs that will hit thirteen green globs scattered randomly on a grid. For IBM and the Apple II family.

Guide. (1986). Dougan, G. Bellvue, Washington: OWL International, Inc.

The first commercially available "hypertext" for the Macintosh. A tool for writing and reading electronic documents, with features that capitalize on the advantage of the screen over paper. Provides improved word processing, outline, and help systems. For the Macintosh.

HBJ historian: The Spanish in California. (1986). Copeland, W. D. Orlando, FL: Harcourt, Brace, Jovanovich Publishers.

This simulation casts students in the role of historian and asks them to generate and test hypotheses, as historians would, to a historical problem. Students access a data base of documents -- diaries, personal letters, government reports -- and are guided by a tutorial which emphasizes historical inquiry. Many features of the program were designed to allow efficient teaching of the complex task of historical investigation to students in regular secondary classrooms. For the Apple family.

Karel the robot. (1981). Pattis, Richard E. Department of Computer Science, Stanford University.

Designed to be covered at the beginning of an introductory programming course, prior to the study of a computer programming language. Runs on the Apple II family.

KIDNET. (1986). Originated by Robert Tinker and funded by the National Science Foundation and the National Geographic Society.

A telecommunications network project which allows elementary school children to participate in science experiments, share results, and analyze patterns and trends in data.

Learning tool. (1986) Kozma, R.B., and Roekel, J.V Ann Arbor, Michigan: Arborworks, Michigan.

Incorporates principles of cognitive psychology to help students learn any subject. The concept of the "electronic notebook" may be used for organizing notes, writing term papers, and study. For the Macintosh.

LISP intelligent tutoring system. Developed by psychologists and computer scienctists from Carnegie-Mellon University. Available from Advanced Computer Tutoring, Inc., Pittsburgh, Pennsylvania.

Students attempting to solve problems using LISP receive guidance and feedback from this system. Runs on workstations with the VMS or UNIX operating systems.

MacChemistry. (1984). Sierra Madre, California: Fortnum Software.

Simulates titration, references a periodic table, creates a reference library for aiding the production of publications using chemical symbols, subscripts, superscripts, and other graphic representations useful in chemistry. For the Macintosh.

Macintosh Pascal. (1984). Lexington, Massachusetts: THINK Technologies, Inc.
An interpretive, highly interactive programming environment for the Pascal Language. Exceptional ease of use and advanced debugging features make it an effective tool for learning and using Pascal. For the Macintosh.

Multi-Plot. (1986). Tinker, R. at the Technical Education Resources Center (TERC) in Cambridge, Massachusetts.
A simulating environment that allows students to test a model for data for Microcomputer Based Laboratories and other investigations.

muMATH-80. (1982). Rich, A., & Stoutemyer, D. Honolulu, Hawaii: Soft Warehouse, Inc.
MuMATH-80 is a symbolic mathematics processing system that allows the user to perform a wide range of mathematical operations from simple arithmetic to complex operations in the areas of algebra, trigonometry, and calculus. MuMATH manipulates mathematical symbols to arrive at solutions to many of the problems posed in high school algebra and the first two years of college mathematics. As the hand-held calculator relieves one from the tedium of arithmetic, computer algebra programs such as muMATH release students from the often tedious and distracting details of solving problems, affording them and their teachers the time to reflect on conceptual issues. For the Apple II family.

MORE. (1986). Winer, P., Baron, D., and Winer, D. Mountain View, California: Living Videotext, Inc.
Idea processing, outlining, and desktop publishing for the Macintosh.

Notes: A decision support tool for reading and writing. (1986). Neuwirth, C. M., Kaufer, D. S., & Gillespie, T. Pittsburgh, Pennsylvania: Carnegie-Mellon University, Center for Educational Computing in English. (Technical Report No. CMU-CECE-TR-1)
This program allows writers to take electronic notes from either online, electronic sources, or offline, printed ones. The Notes program is specifically designed to alleviate the difficulties and inconveniences that writers experience when they try to acquire and organize information from different sources. For the IBM RT, Sun, MicroVax, and Macintosh.

Paintworks plus. (1986) Activision.
Uses colors, shapes, patterns, brushes, and text to design screens. Animation of drawings is also possible. For the Apple IIGS.

Print Shop. (1986) Broderbund.
Creates and prints multicolored, detailed signs, greeting cards, banners, and letterhead. For the Apple IIGS.

Project tool/chest. (1986). Yakov, M.E., at Rutgers--The State University. New Brunswick, New Jersey.
AppleWorks tools for classroom use. For the Apple II family.

"Raiders of the Lost Ark" curriculum. (1986). Dr. Robert D. Sherwood, Nashville, Tennessee: Vanderbilt University, Peabody College, The Learning Technology Center.
Use of interactive videodiscs from feature films such as Raiders of the Lost Ark to create problem solving environments in mathematics and science. Brief segments of the film are used with computer generated graphics and text overlay. Topics demonstrated included the concept of density and the skills of estimation and use of standards in mathematics.

Robot odyssey. (1984). Menlo Park, California: The Learning Company.
This program allows users to design chips and build robots to accomplish various tasks. For the Apple II family.

Rocky's boots. (1982). Menlo Park, California: The Learning Company.
Machine-building activities using components in a simulated electric current and Boolean Algebra based logic framework. For the Apple II family.

Sketch. (1986). Trowbridge, D., Larkin, J., and Scheftic, C. Pittsburgh, Pennsylvania: Center for Design of Education Computing at Carnegie-Mellon University.
A systematic approach to curve-sketching, emphasizing a step-by-step procedure for transforming a simple expression into a more complex one and then transforming the ... accordingly. This program is written in CMU Tutor. For the Sun, IBM RT, Mic ..., and Macintosh.

STELLA. (1985). Hanover, New Hampshire: High-Performance Systems, Inc.
The problem-solving tool that allows people to think about complex problems without getting lost in mathematics. The STELLA software accomplishes the marriage of systems dynamics and the graphing capabilities of modern computers by allowing the user to create a model with a system diagram and then solve the model. For the Macintosh.

Temperature Grapher. (1983). Bannasch, S., et al. Pleasantville, New York: HRM Software.
Using temperature probes, this program allows students to generate a display of temperature in real time on a line graph. In addition, HRM has produced probe systems for light, ph, sound, and motion. For the Apple II family.

The voyage of the Mimi. (1984). New York: The Bank Street College Project in Science and Mathematics.
"The Voyage of the Mimi" combines the media of television, print, and software in an integrated approach to science and mathematics. The study of whales, presented in a context that is compelling to students, provides an organizing theme that can be explored from a variety of scientific disciplines. The television series brings the real world into the classroom in a combined dramatic/documentary format that reveals science as a human activity conducted by recognizable people and subject to considerations of human values. The print and software components allow students to act on their own motivation and to explore further the bits of the natural world they have glimpsed in the television program. For the Apple.

Credits

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Page 16, Figure 2. Hayes, J. (Ed.,). (1986). *Microcomputer and VCR usage in schools 1985-86*. Denver, Colorado: Quality Education Data (Q.E.D.)

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Page 18, Figure 6. Becker, H.J. (June, 1986). *Instructional Uses of School Computers*. Baltimore, Maryland: The Johns Hopkins University, Center for Social Organization of Schools.

Page 32, Figure 7. *Task Force on Teaching as a Profession* (Ed.). (1986). A nation prepared: Teachers for the 21st century. Washington, DC: Carnegie Forum on Education and the Economy.

Page 35, Figure 8. Linn, M. C. (1987) Establishing a Research Base for Science Education: Challenges, Trends, and Recommendations. *Journal of Research in Science Teaching*.

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