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ABSTRACT

Designed to assist science educators in improving preservice/inservice teacher education, this yearbook contains resources and ideas addressing the integration of recent research into a format suitable for practitioners and students. Topics of the papers included in this volume are: (1) applications of microcomputers in science teaching; (2) telecommunications; (3) optical storage systems; (4) computer based learning; (5) the status of hardware and software; (6) a review of research; (7) philosophical and psychological positions; (8) technology in elementary and health education; (9) cooperative learning; (10) the "Voyage of the Mimi" project; (11) implementation theory; (12) staff development; and (13) teacher preparation using technology. A number of specific projects are described in individual papers. Over 300 references are included. (CW)

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1988 AETS Yearbook

Information Technology and Science Education

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Foreword

The ERIC Clearinghouse for Science, Mathematics, and Environmental Education is pleased to cooperate with the Association for the Education of Teachers in Science in producing this Yearbook.

We invite your comments and suggestions on this series.

Stanley L. Helgeson
Patricia E. Blosser

ERIC Clearinghouse for Science,
Mathematics and Environmental Education

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Preface

As the United States changes from an industrial-based society to an information society, the goals, purposes, and methods of American education are evolving. In response to this societal and economic change, more than 100 national and state reports have called for a reform in education that emphasizes the development of critical-thinking skills, problem solving, knowledge utilization, scientific and technologic literacy, and computer literacy. Because rapid advances in information technology are the driving force behind the information revolution, computer literacy is now recognized as a basic skill, together with reading, writing, and arithmetic.

Information technology and science education share the platform of the educational reform movement. Science education, redefined as education in science, technology, and society, is one plank that supports the citizens who will participate fully in a society and culture that have a scientific and technologic infrastructure. Information technology, another plank, enables us to access the enormous volumes of scientific and technologic information and to synthesize and produce useful knowledge from it. Information technology, therefore, has forced new goals for education that have students learn about information technology (what it is, what it does, and how it affects society) and become proficient in using information technology in the pursuit of knowledge to improve the effectiveness and efficiency of learning. To meet the challenge of educational reform, contemporary science curricula at all grade levels must integrate information technologies into traditional print and hands-on materials.

This yearbook examines the overlap of information technology and science education. The first five chapters present a vision of how information technology can enhance science education. Chapters six through eight present the status of information technology in science education and discuss the relationship between them. Chapters nine through fourteen discuss how we can improve the use of information technology by teachers and students in science classrooms.

Chapter 1. Bob Tinker and Seymour Papert describe tool applications of the microcomputer that help students "do real science." Chapter one includes an overview and examples of MBL, word processing, spreadsheet, database, graphing, data analysis, modeling, drawing, and telecommunications. They focus on what exists and what the ideal package should look like (an integrated tool).

Chapter 2. Cecilia Lenk describes ways students can use telecommunications to learn and do science. Cecilia uses specific examples of projects—such as *NGS Kids Network*, *the Voyage of the Mimi*, *CompuServe*, and *AccuWeather*—to illustrate how students can use telecommunications.

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Chapter 3. Bob Sherwood describes applications for students that use optical storage technologies—such as laser disk, interactive laser disk, and CD ROM. Bob illustrates his presentation with examples of extant materials for science education. Discussion includes how these technologies affect the delivery of instruction now and in the future.

Chapter 4. Paul Horwitz describes applications of computer-based learning for science education. Paul describes those applications with the most importance for science education in depth and illustrates them with examples of programs and projects.

Chapter 5. Carl Berger describes how teachers and science educators can use the information technologies described in chapters one through four. Carl provides examples of extant materials and projects to illustrate the discussion.

Chapter 6. Bill Baird summarizes data from surveys on the status of use of hardware and software by teachers and students. The major focus is on the status of use of information technologies in science education.

Chapter 7. Kevin Wise presents a review and synthesis of the research on information technologies and science education. The review covers applications described in section one. Since the major issue is that there is insufficient research to fully explain the effects of information technologies, a major focus is on describing what we have learned and areas for which we have insufficient information to form conclusions.

Chapter 8. Marcia Linn develops an argument for why information technologies will make a difference in science education. Marcia draws on research studies but also on a philosophical position and psychological theories to build the argument.

Chapter 9. Rodger Bybee and Jim Ellis describe the recommendations for a technology-oriented elementary science and health curriculum. The authors give special attention to the form and function of a classroom learning environment.

Chapter 10. Roger and David Johnson describe how teachers can use cooperative learning to improve student learning with information technologies. Roger and David give special attention to the efficiency and economy of cooperative learning with expensive equipment such as microcomputers. The major focus is on how teachers implement cooperative learning.

Chapter 11. Laura Martin, Jan Hawkins, Samuel Gibbon, and Regan McCarthy describe a teacher enhancement project that is tied to the *Voyage of the Mimi* materials. They discuss how they designed the curriculum to integrate information technologies into instruction, what technologies the curriculum includes (Voyage I and II), and how they are designing their materials for teachers to increase integration.

Chapter 12. Bob James explains how theories and results from research on implementation and the change process apply to helping teachers use information technologies. Bob describes the CBAM model as one model for implementing innovations; the focus, however, is on how to design projects to increase implementation.

Chapter 13. Paul Kuerbis and Susan Loucks-Horsley summarize the literature on staff development, including peer coaching, and relate the findings to preparing science teachers to implement information technologies.

Chapter 14. Jim Ellis describes models and strategies for inservice and preservice preparation of science teachers in information technologies used in a variety of projects. Jim focuses on *ENLIST Micros,* a BSCS teacher enhancement project funded by NSF.

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Bob Tinker and Marcia Linn made many helpful suggestions in the identification of authors. The chapter authors brought the yearbook to life. Joan Hillrich designed and produced the yearbook. Rob Warren helped ensure that the text followed standard writing style and English usage.

Appropriate to the theme of the Yearbook, we used information technology to produce the camera-ready copy for printing. The authors submitted their manuscripts on paper and on disk. The authors entered their manuscripts on systems compatible with either an IBM PC or Macintosh computer. We converted the files on the disks for use with WordPerfect 4.2 for the IBM PC. We made all revisions to the manuscript with WordPerfect and then produced the final copy using Xerox Ventura Publisher 1.1 and a HP LaserJet 500+ for desktop publishing. To improve the quality of the print, we produced the text on 8.5 by 11-inch paper and then reduced it to the 5.25 by 8.5-inch format before you.

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Tools for Science Education [1]

Robert F. Tinker
Seymour Papert

INTRODUCTION

The Educational Crisis

Numerous indicators h e signaled that math and science education are in serious trouble. Over the last five years the dual problems of poor student performance and lack of qualified faculty have been well documented in many studies (Hurd, 1983). Thirty-two major reports, starting with *A Nation At Risk* were listed in *Education Week.* Two representative statistics serve as reminders of the seriousness of the problem:

- U.S. calculus students score below calculus students in 11 countries, earning less than half the score of English, Japanese, or Hong Kong students (Second International Mathematics Study).
- U.S. biology students score below biology students in 13 countries, among which are Italy and Poland (Second International Science Study).

The troubled state of science education is al o apparent in our students' distaste for science. Surveys of high school students reveal that although the students believe that science is a valuable discipline (McKnight, Travers, and Dossey, 1985), they tend to dislike science (Hurd, 1983). Paradoxically, the same students have responded that they like the content of science outside of school, that is, they enjoy visiting science museums and aquariums. Even science majors in college

[1] Some of the materials incorporated in this work were developed with the financial support of the Technical Education Research Centers, Inc. through the National Science Foundation grants DPE-8319155, MDR-8550373, and MDR-8652120 and with equipment donated by Apple Computer.

have expressed doubts about the lasting value of certain academic science courses, and they too fall into the trap of simply memorizing formulas and reproducing them on the exams (Lochhead, 1976).

Facts-and-Formula Science Education

The evidence strongly indicates that something is basically wrong with mathematics and science instruction in today's schools. A drift towards increased content expressed in texts and tests, driven by the growth of science and a demand for results and measurable progress, has trivialized science education. Most students have fundamental misconceptions about science that remain unchanged by instruction (Halloun and Hestenes, 1985; Clement and Lochhead, 1979; McCloskey, Caramazza, and Green, 1980; Minstrell, 1982, Trowbridge and McDermott, 1980). Many teachers are unaware of these problems and attempt to teach concepts that are far above their students' level (Greenfield, 1979; Lochhead, 1976; Trowbridge and McDermott, 1980).

The level of many students' performance is appalling—they often cannot read graphs and cannot solve simple ninth grade algebra problems, even after passing courses that supposedly cover this material. If students have failed to acquire the rudiments of math and science from earlier courses that purport to teach these topics, then additional or advanced instruction in the same mode will continue to fail to improve the performance of the vast majority of students. "For young people who have not fared well in school, a regimen of 'more of the same' may result in less learning" (Grant Foundation, 1988).

The problem with any subject at any level is that there is too much to teach and too little time in which to teach it. In planning a curriculum, if you merely make a list of the key vocabulary and a few critical classes of problems that you want students to learn, you will already have far too much content for whatever time is allocated. It is easy to create a course which is a rushed survey of facts and formulas that few students will understand deeply. The texts which cover so much and the standardized tests which measure breadth so much more easily than depth, all create a pressure to cram more into courses that is hard to resist. This pressure is inevitable, because the textbooks are merely a concatenation of many teachers' lists of their favorite topics. Further, no textbook publisher can afford to leave out a topic that is important to someone and the tests are based on the courses and textbooks.

The resulting facts-and-formula approach to teaching not only fails to convey the softer side of science, but it often gives the students a completely erroneous and negative view of science. The students learn that trajectory problems use a particular group of equations, but they have forgotten why these equations are used or what their relation is to Newtonian mechanics. These students have never had any time to think about the challenge non-linear dynamics makes to Newtonian determinism. Even students who do well report that they "really do not understand it," and hence come away with a sense that they are not interested in science, and are probably unsuited for it.

Most teachers acknowledge that there is much more to teaching a science course than vocabulary and a series of problem types. Their students ought to get a sense of what it is like to be a scientist; they need laboratory experience as an antidote to book learning. They ought to have a sense of the social and ethical issues raised by science, and an idea of the history and culture of science. Most importantly, as the amount of scientific knowledge explodes and the fraction of science that can be taught in any course shrinks, they should learn to learn. But these "soft" topics are usually consigned to benign neglect. By definition, "soft" topics are hard to quantify and measure, and really will not help the kids on the exam.

Thus, the bulk of science instruction proceeds with facts-and-formula courses only superficially altered from generation to generation because that is what everybody else is teaching, that is what the tests measure, and that is what defines the prerequisites to the next course.

Although there is debate on the source and cure of the larger social forces that are at the root of these trends, there is widespread agreement that the proximal problem is that students are not being actively engaged in learning. They passively listen to lectures, skim huge, poorly written texts and have decreasing access to laboratory experiences. Because learning is an active process that requires attention, active participation, communication, inquiry and thought, it is not surprising that these trends have resulted in poorer student performance. Learning science, like the conduct of science itself, must be active. It is a verb, not a noun.

Thus, it is important to view the potential of technology in the light of its ability to stimulate active learning. To the extent that technology can do this, it contributes to the solution of pressing educational problems; to the extent it fails, it becomes part of the problem.

Constructionism

> Piaget stated that, "*I'm convinced that one could develop a marvelous method of participatory education giving a child the apparatus to do experiments and thus discover a lot of things by himself....For me education means making creators....*"

The antidote to the facts-and-formula approach is a constructivist perspective that posits that students learn best through active engagement in their own studies in an environment that encourages them to construct and communicate their own knowledge and understandings. *Constructionism* (Bringuier, 1980), a term coined by Papert (1988), is a banner which serves as a rallying point for a constructivist educational theory and an instructional strategy that emphasizes student project work, creativity, autonomy, and communication. This term suggests a vision of how school could be better, and of how technology could be used to facilitate the improvement of science education.

Students who are thoroughly engaged in original projects, having selected the topic, decided on the approach, performed the research, drawn the conclusions, and communicated the results, are doing science. They are seeing science not as a noun, an object consisting of facts and formulas, but as a verb, a process, a set of activities, a way of proceeding and thinking. Thus, a constructionist educational framework not only is good pedagogy, it is good science. It can convey not only the content of science but its process. In this model, communication about their work and about the process of learning itself with peers, teachers, and collaborators is an indispensable part of a student's learning.

The most important product of the past two decades of work on educational technology has been the emergence of a vision of what information technology has to offer. The constructionism theme is useful to capture what has gone right in the application to date of computers in schools, to understand what has been most powerful in the actual uses of the new technologies. The conventional wisdom that computers in education have been disappointing might be unimpeachable in a statistical sense, but it is catastrophically misleading in a deeper sense. If one looks at the peaks of what has been done and not at the averages, and if one looks beyond the immediate effects on scores, it is quite evident that existing technologies (software as well as hardware) are capable of supporting dramatic changes in educational productivity. New and better technologies could, of course, offer even greater support. The critical issue, however, is not making new technologies but learning how to mobilize technologics of unprecedented power—including the computers we already have—as instruments of educational change.

Earlier thinking focused on technology as supporting the more rote and mechanical aspects of learning. The new vision focuses on using technology to support excellence in learning. In our vision, students would tackle much harder problems, they would work on larger-scale, more meaningful projects, they would have a greater and more reflective responsibility for their own learning, and they would be able to work in a variety of styles whose differences reflect gender, ethnicity or simply individual personality. Much of the earlier thinking saw the computer as replacing at least some of the functions of the teacher. The new vision sees the technology as supporting excellence in teaching; it seeks enhancement—not replacement—of the teacher (Papert and Tinker, 1988).

Second-Order Effects of Technology

The bottom line of educational change must be what the individual student learns. But it is technocentric to judge the use of computers only by the immediate effect of interaction with an individual student. In the best implementations, technology enters the culture of the school and becomes woven into learning in many more ways than its original promoters could possibly have anticipated. When computers are brought into a school, they become part of a system and exert unanticipated influences on the culture of the school and on relationships among people in it.

In Ladue Junior High School on the outskirts of St. Louis, Missouri, an unlikely set of teachers got together to develop a joint educational project: the physics teacher, the physical education teacher, and the shop teacher. The project was to develop a workshop for students on robotics, a topic which had aspects with appeal to each of the three teachers. The physical education teacher was interested in body movements, the shop teacher in building things, and the physics teacher in some underlying theoretical issues. The project had an importance beyond what was specifically learned in the robotics workshop. The fact that these three teachers were doing something together carried a message for students, a message that one could formulate much too crudely as recognizing that "nerds" and "jocks" might have more in common than they think.

The robotics project provides a simple example of what can be called second-order effects of the computer presence. The school did not spend thousands of dollars on computers specifically so that students could have the experience of witnessing a spontaneous alliance among three teachers from what are often the most radically separated departments. Computers are usually introduced to achieve quite specific educational objectives, and their first-order effects are measured by looking at how well these objectives are achieved.

Second-order effects occur when the presence of technology allows needed curriculum changes to be instituted. By providing new intellectual tools; by removing some of the drudgery; by fostering communication, by creating multiple, alternative representations; by offering new kinds of interactions, technology permits a host of new options. These options allow one to improve science education in directions that were clearly needed prior to the advent of technology.

The development of valuable second-order effects is not an automatic consequence of the presence of computers in a school. Indeed, in many cases the management of the introduction of computers is not conducive to the appearance of such effects. The technology makes the change possible, but people choosing a constructionist approach make it happen.

Second-order effects are not necessarily small or inconsequential. For instance, it may be that through the use of appropriate graphic representations, ninth grade students can understand calculus concepts well enough to use computers to set up and solve complex dynamic systems. This ability forces a reconsideration of the math sequence which, in turn, might permit much more quantitative science courses that could cover complex, realistic and interesting topics. This kind of second-order effect is probably much more important than any consequences of the first-order effects usually used as arguments to get computers in the door.

Software Tools that Enable

The focus on constructionism simplifies our task enormously. Technology by itself cannot correct the serious trouble in which science education finds itself, but it can be an indispensable part of a constructionist solution.

The vast majority of software designed for science education supports facts-and-figures instruction. Such software is relatively easy to create, easy to find, and easy to integrate into instruction. Anyone interested in that sort of software needs a comprehensive survey with evaluations, which can be found in TESS, The Educational Software Selector. Order the software that you think you want and review it quickly when it comes in. If it does not fit your needs, return it; no respectable distributor will fail to accept returns within a reasonable period of time. There is a role for software that supports fact-and-formula science, just as there is a role for fact-and-formula science. Simulations, tutorials, drill-and-practice, when well constructed, do work. They lead to improvements in student performance, and some efficiencies in classroom management.

If we seem to lack enthusiasm for this class of software, it is because the path to better science education will not be found by trying to improve facts-and-formula instruction. The appropriate technology enables constructionism, not drill. The constructionist approach to education is not fundamentally new, but the advent of telecommunications and inexpensive microcomputers adds new dimensions to the concept, allowing it to be a more powerful learning strategy while simplifying its implementation. The technology that best supports constructionism is tool-like, because tools are general, powerful, flexible, and easily used. The most effective use of constructionist software tools is to engage students in projects with the maximum feasible student independence and ownership of these projects.

Technology has something to offer for every aspect of constructivist student activities. It can expand the range of possible projects; offer new opportunities for collaboration and communication; simplify acquiring and displaying data; provide mechanisms to control experiments; increase the sophistication of the theory-building, modeling, and data analysis; provide new outlets for creative expression; and grant access to vast databases of information. Without the technology, practical issues of classroom management and limitations in the scope of potential student projects make student-centered activities difficult to offer and sustain. Technology gives students a wide range of tools they can apply to their investigations, and new collaborators with whom to communicate and learn. Furthermore, teachers' imagination and background can be stimulated and expanded with mentors and collaborators on networks.

The technologies that offer this involve a few tools that are easily mastered:

- *Communication tools.* Word processors and telecommunications packages, preferably integrated, combine writing, reading, database searching, and electronic communication. This combination is easily the most important set of tools for academic and business research and communications, and represents the most accessible tools for students.
- *Interface tools.* When interfaced so that it can control and measure the environment, the computer is a powerful aide for investigations. Microcomputer-based labs (MBL) and interfaces to mechanical systems like LEGO/Logo and the Capsela IR link allow the students to easily record a wide range of phenomena and control the conditions under which these measurements are made.
- *Theory-building tools.* Spreadsheets, graphing and data-display utilities, microworlds, and modeling environments are computer-based computational tools that increase a student's ability to create and understand theories. This ability greatly enhances the potential learning that a student can derive from a project.
- *Creativity tools.* Word processors, video interfaces, music and graphics tools, and hypermedia all give students new ways to express themselves. This ability greatly enhances student communication, an essential part of the constructionist model.
- *Database tools.* Telecommunications packages, CD ROMs, and videodisks all give students access to unprecedented volumes of information. Hypermedia tools make that access easier and more responsive to a student's investigations.
- *Programming tools.* Programming languages continue to be important because they give a student the greatest control of computers, putting that resource at the student's disposal in service of student-originated

activities. It is important to note that programming options are just below the surface in powerful applications like HyperCard, many word processors, and more advanced databases. As a result, programming concepts are increasingly important.

While many of these tools are available on the microcomputers found in schools, their systematic use to empower students has not been widely explored nor followed to the conclusions that will inevitably alter and expand the curriculum.

There are many practical advantages of technology-enhanced, constructionist educational strategies based on these tools:

- *Adaptable.* Learners with different styles and abilities work comfortably together on projects and long-term activities.
- *Interdisciplinary.* Projects often require input from a variety of technical fields, use many forms of communication, and profit from the creative arts.
- *Integrative.* The students see how disciplinary studies fit together to solve problems and address issues.
- *Pre-professional.* The students' constructionist activities and their use of technology tend to mirror those of the adult world and thus give the students an unusually accurate view of the professions.
- *Motivational.* Activities selected by students and pursued in depth can be extremely interesting and can call on skills and motivation that standard classroom instruction leaves untapped.
- *Effective.* Constructed knowledge that comes from self-selected topics and self-directed inquiry has unusual staying power.
- *Efficient.* The proposed use of technology offers the greatest chance for major improvements in learning "efficiency," using a definition that honors the amount of deep learning and problem-solving skills that students acquire.
- *Implementation ease.* The small number of tools make them easier to purchase, distribute, learn, and support. Because these tools are available for all computers, one is freed from the need to support one family of hardware.

The constructionist approach is applicable across the curriculum, at all levels and in support of all disciplines, although it tends to knock down curriculum boundaries. In the sections that follow, examples of constructionist tool use, including Logo, the NGS Kids Network, LabNet, microcomputer-based labs, and spreadsheets will be presented. Logo has been perceived as advancing problem-solving and, specifically, elementary mathematics. But Logo can be used through graduate school; LogoWriter projects foster language arts; LEGO/Logo involves robotics, engineering, and science. The Kids Network is designed as an elementary science curriculum, but by involving kids in studying and communicating about important social issues, such as acid rain and waste, schools use it to support their instructional goals in social science, reading, writing, and mathematics. Labnet is a secondary and college version of the Kids Network, extending the idea of student-scientist collaborations to older students. The analytical techniques developed in the TERC Modeling Project have been used in courses in mathematics, history, biology, chemistry, physics, physical science in grades 9-12.

EXAMPLES

Microcomputer Based Labs

An approach TERC has termed microcomputer-based labs, or MBL, converts a microcomputer equipped with a small collection of transducers and general-purpose software into a universal instrument. The sections describe what has been learned about MBL.

Educational Use of Computer Interfaces

The computer is seen as an indispensable lab tool in science research, but it has taken years of persuasion, first by TERC and then many other innovators, to get educators to see the advantages of using the computer in the teaching laboratory. Variously known as "microcomputer-based labs," "MBL," "probeware," or "laboratory aids," these computer applications are beginning to be seen as a valuable part of science eduction.

Microcomputer-based labs—the use of microcomputers for student-directed data acquisition, display, and analysis—represent one of the most promising new developments in science instruction that emerging technologies have enabled. With appropriate hardware and software, the microcomputer-based laboratory gives students unprecedented power to explore, measure, and learn from the material environment. This power enables the earlier and more thorough treatment of science topics while also fostering process goals. Constructionist use of MBL could show the way to substantially reorganized and revitalized science curricula in which much more science was covered much earlier in ways that increased both content and an appreciation of the process of science.

Problems with Labs

"Science Lab." The very words evoke unpleasant memories of boredom or fear in most students. The lab is a place of goggles and white smocks where normal common sense is suspended in favor of that ineffable "scientific method," which seems to consist of numbers, lab books, and odd equipment. The experience is usually unpleasant and uninstructive because the students, while physically active, are actually almost always intellectually passive. The developer of the lab has worked out the problem, equipment, technique, and analysis; all that remains is for the student to follow the instructions. The materials seem to have no relevance to what is going on in the classroom. In fact, one wonders why some teachers persist in such an arcane ritual.

The reason, of course, is that we believe what we say about labs, even if their implementation falls short of the ideal. It is in laboratories that students experience the stuff from which theories and abstractions are made. Laboratories are the testing ground of theory and the springboard to greater abstractions, at least they ought to be.

Inadequate labs are often the result of limitations in funds and scheduling. The students cannot select their apparatus because stocking alternative apparatus is out of the question; there can be little experimentation, because reagents, expendables, and delicate equipment are expensive; extensive computations may take so much time that there is none left for exploring; students are unlikely to have time to develop analytical techniques because there is a less-than-obvious "best way," often highly evolved to match the apparatus and hand calculation.

Educational Importance of MBL

These problems can be circumvented by using a more general MBL approach for measurement and data analysis and by using the computer to speed the computations and leaving students the choice about what computations to employ. General measurement techniques avoid using special-purpose, inflexible and expensive apparatus and enhance the range of a student's choice. By reducing time spent on calculations, more time is available for "messing around" and experimenting.

This is the promise of MBL. One can now give students a flexible instrument that was only a dream a few years ago; an instrument that can measure force, light, pressure, temperature, heart rate, speed, acceleration, response time, brain waves, muscle signals, and many, many other phenomena in the world about us. These measurements can be performed by powerful, general-purpose software that speeds analysis and provides real-time feedback. MBL can make meaningful science instruction possible earlier and at a much more profound level than many educators would believe possible.

Part of the importance of MBL stems from a decreasing role that lab experiences play in science education. In spite of the undeniable importance of experiential learning in science, the pressures of budget, scheduling, staff, back-to-basics and safety are making labs increasingly rare at all levels of education. At present, microcomputers and videodisks represent another threat to laboratory science by providing clean, safe, and inexpensive lab simulations, now available for most common school laboratory exercises. While simulations are useful, particularly when they permit flexible experimentation otherwise impractical due to cost, time scale or safety, *real* laboratory experiences must become a larger and more valuable part of every student's science education.

MBL Can Be a Natural Extension of the Senses

One of the important aspects of MBL, particularly for very young children, stems from the way in which it can connect abstract measurements directly to a child's senses. By simply giving students a sensor that measures temperature and immediately graphs it as a function of time on the screen, even very young students can, within minutes, learn how to control the temperature recorded, how to generate interesting graphs of temperature against time, and how to interpret those graphs. What is going on is that these students are "calibrating" what they see on the screen against their own sensory perceptions of temperature. They immediately learn that there is a close similarity between what they sense is hot and what causes the graph to rise.

Almost as quickly as they learn to understand the probe, the students encounter situations in which something seems to go wrong. Attempting to heat the probe, they put it in a glove, which they know is hot. The probe does not seem to

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record properly and yet they quickly can test whether something is wrong by touching the tip of the probe and seeing the temperature rise again. Why aren't gloves hot? Immediately important scientific questions are raised that can lead to further investigation and learning. In fact, one of the most interesting aspects of the use of MBL in classrooms is the number of "what if..." questions it can stimulate. The students begin—without prompting, without long lectures about the scientific method—to apply their common sense and elucidate upon the phenomena they observe. That is the essence of science and we see science happening at a phenomenal rate around microcomputer-based laboratory instrumentation.

Making a Computer Into an Instrument

With the addition of interface electronics, even the simplest computer can be used to gather and analyze data. The interface consists of transducers, analog circuits, and analog-to-digital converters. The transducer detects some physical input and converts it to an electric analog signal. This signal is then processed by analog circuitry to produce a signal that is convenient for the next component. This signal is finally converted by an analog-to-digital converter into a digital signal, which the computer can then use. The computer stores these data in memory and can process them just as any other numbers can be processed. The computer can control all aspects of the data-gathering process including its initiation and timing. With suitable transducers, the data gathered can represent force, pressure, time, temperature, light level, humidity, air flow, water flow, position, velocity, acceleration, and much more.

The computer with a laboratory interface is a powerful and flexible instrument. Using a graphical output to display results that it has accumulated, it becomes a storage oscilloscope. Using the timing capabilities that are inherent in all computers, it can be a timer that measures the time between external events, or a frequency counter that counts the number of external events in a fixed period of time. By simply displaying the voltages and currents that it senses, it becomes an ammeter or a voltmeter.

Because these functions are realized as part of a single computer, they can be combined to create versatile measurement and control systems. The computer can transform gathered data and generate displays that are more meaningful and easier to interpret than outputs from conventional instruments.

MBL hardware and software for use in teaching can be constructed from common parts, from kits, or purchased. MBL is increasingly available commercially, although there is a wide range of performance and cost, and no single system yet combines the power and flexibility that is possible. The Northwest Regional Laboratory (1986) produced a good review of MBL and developed useful criteria for its evaluation. TERC provides current information about MBL material and workshops.

Misconceptions Concerning MBL

A computer used with laboratory instruments is sometimes described as "emulating" or "simulating" instrumentation. This terminology is misleading, because it seems to imply that the computer is not really the instrument. It is easy to confuse this description with the idea of a simulated laboratory, in which experiments are not actually performed, but simulated with software. It is more accurate to say that the computer with MBL hardware and software is just as real an instrument as an oscilloscope or light meter.

More thoughtful critics have criticized MBL as automating the lab and consequently stifling a student's thought and initiative. This is a danger posed not by MBL itself, but by its implementation. Like any technology, MBL creates options, and one option is complete automation. One can imagine a parody of MBL, in which the students would turn on the computer and watch it pick up a ball, drop it, measure the distance and time, compute the acceleration of gravity and print out the result. One can imagine a similar technology configured as a general-purpose photogate counter and timer that would be used in many explorations of motion, among them falling balls. These two approaches to the same technology and educational goals would have completely different educational outcomes that can be traced to differences in educational theory, not to MBL. This is why it is important to stress a constructionist approach to the options that technology offers.

Features of Constructionist MBL Applications

A good implementation of MBL supports constructionist applications by being a flexible and responsive tool. A Crescent wrench is a good model for MBL tools. This is the adjustable wrench that has a knurled worm gear near its movable jaw. Its operation is obvious and simple; the knurling invites finger adjustment of the jaw opening. Designed for tightening and loosening nuts, it can also be used as a hammer, bottle top opener and window prop. It can be used by young and old, learning-disabled, and Nobel prize winners, for both simple and sophisticated jobs. There is no instruction manual packed with it and there is no right or wrong use of it. It is relatively unobtrusive and rarely the focus of much attention. And, while it helps remove nuts, it certainly does not remove them automatically. The choice to use it, its setting, and its manipulation require thought and planning by the user.

There are several performance characteristics of microcomputer-based laboratory instruments that make them useful tools analogous to the Crescent wrench:

- *Ease of control.* MBL instruments can be designed for easy control by students. Prompts, menus, explanations, and dialogues should be used to help the student control the instrument.
- *Intelligent operation.* Some basic operation should be possible as soon as the application is started. The software should respond intelligently to the probes and actuators selected.
- *Fast response.* Data must be collected, stored and displayed in real time in a convenient and obvious format, so that students can easily comprehend the result of any action or change.
- *Display flexibility.* Outputs should be available in many forms: tables, graphs, histograms, or three-dimensional projections.
- *Modularity.* Both the hardware and software should adhere to a set of standards and conventions so that the same ideas and the same equipment can be used in many different applications.

Research on MBL

The capabilities of MBL have broad applications to science teaching. To begin to explore the implications of these capabilities, Tinker and Barclay (1983) initiated a series of clinical classroom trials of MBL in the fall of 1980. The primary goal of this work was to determine whether elementary and junior high school students could use MBL, and whether its use could facilitate cognitive development in science. Additional goals were to develop instructional strategies adapted to the capacity of MBL and to observe whether there were any sex-based preferences for this approach.

The results of the exploratory research were quite encouraging. Students in grades four through eight were able to understand MBL and use it to understand scientific phenomena. The students demonstrated a keen interest in the experiments; the participating teachers were impressed with the ease that students mastered the technology and the richness of the learning that ensued. The students were attracted to the equipment; through play and exploration they quickly and naturally learned to control it. With guidance, these explorations stimulated an enormous number of questions which, in turn, led to both discussions and further exploration. Tinker and Barclay detected no sex bias in student preference, use, or learning.

Since that initial research, numerous studies have increased our understanding of MBL and its educational value. MBL applications have been carefully studied in classrooms. Qualitative observations confirm that by reducing the time and effort required by repetitive operations and calculations, MBL helps the student understand the relation between phenomena and their representations (Zuman and Kim, in press). Quantitative studies have also confirmed the value of MBL. In a recent study at several high schools and colleges, physics students showed significant increases in understanding classical mechanics as a result of short exposures to MBL (Thornton, 1988).

One strand of educational MBL research has focused on graphs, since many MBL applications use graphs at the primary output display. Because it is well known that most entering freshmen have difficulty interpreting graphs even if they can produce them, questions were raised about starting at the 4th grade with MBL applications that used graphs. It turned out that, because of the dynamic nature of real-time applications, students learned the conventions of graphing very quickly in MBL applications, and, as a consequence, easily learned how to interpret graphs. Research (Brassell, 1986) has shown that high school physics students' graph comprehension went up measurably in one 40-minute exposure to the HRM *Motion* unit. The result depended on the real-time nature of the display—neither software with a 20 second delay nor non-computer activities resulted in measurable learning. This research indicates that graph production and graph interpretation are separate skills and illustrates how conventional instruction focusing on graph production fails to teach comprehension. We are nearing a time when students could have a shoebox filled with a few dozen transducers that could measure a very wide range of physical phenomena. One or more of these could be plugged into a universal interface and be recognized by a single, powerful software package that would combine all the features of an expensive storage

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oscilloscope, function generator, pulse analyzer and a rack full of other electronics. This would provide the ideal environment for student-initiated projects.

Modeling

Although a major reason for developing computers was to solve differential equations numerically, it has only recently occurred to educators that this power could be used by students prior to mastering the full formalism of calculus, differential equations, and numerical techniques. One of the great challenges of science education is to find ways that enhance a student's abilities to build a theory. Information technologies should have a role in this; for the same reasons that MBL fosters the experimental side of science, the appropriate tools should be able to foster the theoretical side. The ability of computers to generate numerical solutions of complex systems should be an important part of this.

Models and simulations are commonly used in science education. Most software in these categories is based on the idea that the developer puts a model into the software, then the students learn about the model by varying one or more parameters. This can be a useful experimental exercise but it rarely helps a student understand the internal model theoretically. A more valuable computer application comes from engaging the student directly in constructing models and exploring the consequences of different models. We have named this much more challenging approach modeling.

A large class of physical models are dynamic systems, requiring the solution of coupled, non-linear equations with time as the single independent variable. Dynamic systems crop up in all the natural and social sciences in many cases in which a model is needed to predict the future behavior of a system, whether the system is a simple projectile or the world economy.

Research at TERC has developed strategies to make this class of problems accessible to students as early as ninth grade (Zuman and Weaver, 1988). In one approach, the students can specify the problem using *STELLA*, a software package that uses graphical metaphors that capture the essential mathematical ideas without the overhead of the formalism. This approach is an outgrowth of techniques developed at the Systems Dynamics group at M.I.T., educational pioneers who for years have used a hydraulic metaphor to represent systems of non-linear differential equations. They have used this metaphor to help business students who lack an understanding of the mathematical formalism, explain and understand complex dynamical systems. The key symbols in this system are the valve and tank, which incorporate the intuitive ideas of calculus. The tank acts to accumulate or integrate the quantity that flows in the pipe, and the pipe flow represents the rate of change or derivative of the quantity in the tank.

From an educational perspective, we believe that same thing happens for calculus that we have seen for graphing skills—there is a decoupling between a student's formal learning and understanding. Most introductory physics teachers report that students who have a formal background in calculus cannot really use calculus because they fail to understand it. The converse seems to be possible with suitable software: students can understand calculus intuitively before mastering its formalism.

While *STELLA* gives a glimpse of what future software might be able to do, modern spreadsheets are almost as easily used to solve comparable problems. Spreadsheets that can be linked to graphical output provide an extremely powerful environment for exploring numerical solutions to differential equations. Spreadsheets explicitly show the calculations, are easily set up and modified, and provide quick, dynamic graphs that make it easy to explore the effect of parameters on a model.

We have also had young students use spreadsheets to solve dynamics problems. Students like spreadsheets, probably because a spreadsheet shows all the calculations and thus seems less magical than the corresponding *STELLA* model. Spreadsheets may be easier for many students who are not comfortable with the highly linear thinking required by programming languages.

The solution of dynamic systems with software like *STELLA* and spreadsheets gives a broad range of students the tools with which they can understand complex systems. While not completely general, these tools do allow students to participate in the theoretical side of science in a way that nicely complements the MBL's ability to allow students to participate in experimental science. The ease of understanding this important class of dynamical problems makes it more likely that the students can gain theoretical insights from their own investigations.

A very wide range of problems from all the scientific disciplines can be solved using this approach. Furthermore, the problems can be complex, realistic, and interesting, not just limited to ideal and unobtainable situations. The results are available quickly, and the structure of the model is easily modified, so there is little penalty for constructing different modeling ideas. This gives the students easy control over their models and enhances their understanding.

System dynamics does not represent a universal approach to modeling and theory-building. Important dynamical problems can be found in all fields, so it provides a powerful and instructive starting point for young theorists. Other, more general tools are conceivable. Spreadsheets are very well adapted for creating and solving a broad range of models, and programming is the ultimate tool, capable of expressing any model. Highly graphical and interactive programming languages like Boxer might be able to combine the features of all these computational environments.

Approaches such as these challenge the traditional math and science curriculum. If ninth grade students starting with an algebra I background can understand and generate numerical solutions for complex problems, then we must question the validity of the five-year sequence of algebra II, pre-calculus, calculus, differential equations and, finally, numerical methods. Further, we must re-think the content of science courses, much of which has been simplified because the developers presume the students lack the mathematical skills to solve realistic, complex problems. In fact, we must question the implicit assumption that a student must be protected from interesting, complex scientific problems. Science students need to learn how to tackle complexity, and how to find out what they need to know and to learn it.

Logo and Languages

Learning programming is the same activity as using the computer to express oneself; babies do not first learn to talk and then express their feelings and desires.

Why Program? Several arguments are usually put forward for including programming in science instruction. The argument too often put forward, that programming is the appropriate response to the call for computer literacy, is finally falling into disfavor, none too soon. Better arguments are:

- *It improves thinking skills.* There seems to be a strong affinity of scientists for programming, and obvious similarities in the linear, careful thinking styles required in both science and programming.
- *It aids learning.* Many educators believe that students do not really understand a concept until they can explain it to something as stupid as a computer.
- *It is essential to scientists.* This is a pre-professional argument based on the widespread use of computers and programming in science.
- *It is the ultimate tool.* Students who undertake their own projects often need the computer to do more than available software allows.

Whether these arguments are convincing depends on your educational philosophy. From a constructionist perspective, the last is most important, since tools are essential for a student to work independently.

Programming and Learning. Learning to program creates opportunities for constructionist educational experiences, but does not automatically cause them to happen. Technology creates opportunities that can be exploited for educational gains in the right learning environment. Perhaps programming creates the widest possible field for independent student learning because it gives the greatest and most flexible control over computers.

The first author had an early sobering experience on how the presence of technology does not guarantee good educational experiences. The TERC staff offered many programming-oriented workshops for educators in the mid 70s, often starting with Logo-like graphics programming problems. One day my son came home from school with one of the programs used in our workshop that must have been passed from a participant through several steps, ending up with my son's teacher. While the program survived the diffusion process intact, the educational philosophy in which it had been offered did not, because the task my son had was to memorize the program!

Viewed from the perspective of the enabling power of programming activities, the search for cognitive gains caused entirely by programming is off the mark. The educational virtues of programming have been hotly debated, and these debates have been carried to ridiculous lengths. Papert, Luehrman, and other advocates of the use of particular programming languages are frequently misquoted as holding almost mystical belief in the educational power of languages. Speaking about Mindstorms, (Papert, 1981) the second author insists that "The book did not mean to suggest that learning Logo or programming per se would have any particular cognitive effect or in any other way be sufficiently useful to justify the trouble. One thing that the book did mean to suggest was that learning

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to program would make possible experiences..." that were constructionist (Papert and Tinker, 1988).

Strategies for Using Languages. There are several difficulties in using programming in science instruction and relying on student programming:

- *Variable student abilities.* The ability of students to accomplish the highly linear tasks involved in programming seems to vary. Thus, programming could be a barrier to learning science for some students, and a barrier that is not related to a student's ability.
- *Variable student backgrounds.* The students in any one science class will have widely variable backgrounds in programming, both in terms of level and languages. This makes it difficult to require a given level of programming for any course
- *Course time investment.* If you cannot require a programming prerequisite, then perhaps you can teach programming in the course. This means, however, that class time must be devoted to learning to program, which reduces the coverage of science.
- *Distracting details.* Programming activities often require attention to details that are not central to understanding science. For instance, in programming a temperature grapher, the students could easily devote days to writing the graphing software without advancing their understanding of heat and temperature.

These arguments together seem fairly convincing and probably account for the low utilization of programming in pre-college science instruction. Moreover, programming represents such a powerful tool that it should not be abandoned so quickly. The use of programming should not be seen as an all-or-nothing decision. By providing technical support in the form of templates, sample programs, and subroutine libraries and by using programming in a project-oriented context, it is possible to overcome all the objections listed above.

The idea behind using technical support is to simplify programming by providing some of the structure and distracting details, so that the students can concentrate on the issue more central to their understanding. For example, one can provide a student with general-purpose graphing procedures so that generating a plot is as simple as getting the data into a prescribed form in a variable and then using the following command (in Logo): plot :data

"Plot" would call on a large block of code that would be supplied. This example illustrates the value of good programming languages. One can treat "plot" as a though it were a primitive, built-in command. On the other hand, it is available to be "opened up" should any student wish to improve on it or simply find out how it worked. By supplying a set of subroutines or procedures like "plot," it is possible to steer the students away from tedious and scientifically uninteresting programming tasks toward the essential core concepts. Many other similar strategies can be used in programming-like environments, all of which result in relieving the student of less-relevant details. For instance, when using *STELLA* and *Excel*, TERC staff have provided partially completed models and spreadsheets.

The result of this strategy of technical support is that students do not have to be expert programmers to gain the benefits of programming. As a consequence, programming requires less time and less preparation. This obviates many of the arguments against using programming in science courses.

The Search for the Best Language. The suggestion that programming should be taught raises contentious questions about the best language and the appropriate grade level. The importance of programming languages is that they are media for expression; and judged by the ease of expression, some languages and implementations are better than others, depending on what one wants to say. For example, the expression

```
plot new_data
```

which could be a valid code in several languages, including Logo and HyperCard, is simply easier to understand than the equivalent BASIC, even with REM statements:

```
10 GOSUB 1000: REM RECORD DATA IN T(I), I=1,2... NP
20 FOR I=1 TO NP: Y(I)=T(I): NEXT I: REM TRANSFER THE ARRAY TO Y(I)
30 GOSUB 1200: REM PLOT THE ARRAY Y(I)
```

To an outsider, Logo wins this test of expressiveness hands down. Many people, however, have learned to express themselves quite well in less elegant languages, such as BASIC, Forth and assembly language.

Many newcomers to programming become passionate about their first language, because whatever it is, the increased expressiveness it confers leads to a sense of elation and misplaced commitment to the language. This passion has probably fueled the arguments about the best language. As computers gain power, languages are becoming more similar, and the search for the best language becomes even more meaningless. For instance, True BASIC has no line numbers, is quickly compiled, permits named subroutines and has a rich control structure. Judged by its ease of expression, True BASIC seems further from primitive BASICs than from Pascal.

Not only are languages becoming more alike, but sophisticated applications are increasingly using programming concepts. Many word processors, databases and specialized applications look like anything but a programming language on their surface, but have programming just beneath the surface for the advanced user who needs greater performance or flexibility. For example, at first blush, HyperCard appears to be a friendly, icon-based database system. But inside its buttons, fields and cards one finds "scripts" which are part of a beautiful, structured, object-oriented programming language. As a test of its flexibility, the author built a complete graphing and dynamic system solver in HyperCard script. Boxer, a programming language under development that has been billed as the next step after Logo, will further obscure the distinction between applications and programming.

This blending of applications and languages means that programming concepts will continue to be important for advanced users, but will not be essential for most. It also means that it will be increasingly easy to pick up programming ideas in many different contexts. Because there are decreasing differences between

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languages, it probably matters less what language is used than that the language be easily expressive.

Collaborative Science

Telecommunications can bring students, mentors, and scientists together to cooperate internationally and conduct projects that are much more complex and sophisticated than any one student could handle alone. The first large-scale curriculum based on collaborative student investigations is the NGS *Kids Network* developed by TERC and published by the National Geographic Society. Designed initially for grades four through six, the project features six-week units, each of which engages the students in measurements that in return result in data that can be meaningfully shared. Probably the most important feature of these units is that the results are not known in advance and there is a scientist who participates in the experiment and who is interested in the results and can communicate this interest to the students. More detail about this project and other ongoing telecommunications-based projects can be found in Chapter 2.

The TERC *Star Network* will be the next step in creating sophisticated collaborative science projects that combine the telecommunications of the *Kids Network*, the experimental power of MBL, the theoretical power of theory-building tools and the power of programming to give high school and college students an opportunity to participate fully in science exploration and discovery. Focused on a project lab and linked through a telecommunications network, the students will be guided into undertaking their own projects by first having them participate in ongoing monitoring networks.

An Example: Seismology Projects. An example will help clarify how these technologies could foster individual work on collaborative projects. One of the bulletin boards in the *Star Lab* network designed for student experimentation might contain ideas about possible projects. One of the proposed projects on the bulletin board might be the establishment of a network of seismic stations. When a moderator notices a sufficient level of interest in that idea, a separate bulletin board could be set up on seismology. A group of experts and mentors would be located to join the bulletin board. Designs for a simple, low-cost seismograph which the students could easily build would be solicited from participating students and scientists. One can imagine a design using an MBL interface to scan real-time data for significant events. The computer could record interesting events and send these into the network. If there were any major events during the operating time, the students could use their data to locate epicenters and to estimate the magnitudes of the events.

If the students did no more than successfully construct, calibrate and maintain a seismic station designed by someone else and observe data from the network of which they were a part, they would have a realistic and rewarding introduction to research. But this experience could easily be the opening to a much richer experience. It would be natural for the students to want to improve their station. Through the network, a group of students might begin identifying various problems in the seismic station design and agree to divide the attack on these problems. For instance, one subgroup might investigate alternative seismic detectors and experiment with their construction and placement; another group might

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look at the problem of synchronizing the stations. Another subgroup might look at the software required and see whether any existing software could be adapted, or whether new programs have to be made. In either case, good programmers would have to be identified and asked to create the required software. Along the way technical help might be sought through the moderator of the subgroup who might find a consultant who had previously volunteered and been listed in the network. Once the techniques were decided upon, each of the participating experimenters would set up one of the basic stations and evaluate it. They could prepare a report on their progress and make suggestions on future improvements. The report could be submitted to another bulletin board responsible for publishing, and be peer reviewed by other students participating in the network. The very best articles might be published.

As with so many projects, the more students work on them, the more they are led into interesting science from a broad range of fields. City students might record trucks and develop projects around road wear from heavy loads. No analysis of earthquakes is complete without understanding the difference between compressional and shear waves, ideas that are important in all kinds of wave propagation studies. Dispersion, the nature of the earth's core, the effect of pressure on wave speed, reflection, refraction, and attenuation are all concepts that might interest a student who is trying to understand data that have been collected. Other students might want to continue improving the apparatus, and might study improved electronic or even optical methods for measuring small displacements. The curious student might stumble across contemporary research on gravitational wave detectors or interferometry. Other, more empirically oriented students might try for increased electronic gain, only to discover problems with noise and drift, which might stimulate an investigation of the nature and origin of noise. The students who are trying to improve the mechanical construction of the seismograph might raise questions of natural frequency and period, elasticity, and ringing. Finally, the students would be naturally lead into considering the social implications of their data-collecting capacity. Can they record underground nuclear tests? What is the relation of seismic monitoring to the Nuclear Test Ban Treaty? As is often the case with projects, even the most narrowly conceived project leads naturally to a very wide slice of science; in this case, mechanics, heat, sound, electronics, planetary science, and disarmament.

Collaboration is itself important educationally. Most contemporary science and engineering advances require wide-scale collaboration, increasingly facilitated with telecommunications. The model of the isolated researcher making a solo breakthrough fostered by awards and biographical sketches was probably never accurate, but is now completely misleading. It is important to teach students skills required for collaboration and to convey the message that technical fields are collaborative. This may have profound career implications for minorities and women and could be important in policy decisions in which any student might participate as a citizen.

Technology Makes It Possible. As the seismology example shows, collaborative projects have advantages over individual projects. Students and teachers who lack the necessary skills to complete all aspects of a project can still contribute to original work. Thus, telecommunications technology fosters collaboration and reduces the demand on each student. Students are engaged in all aspects of scientific research, including experiment design, background research, analysis, and communicating their results. The latter is a particularly important and often neglected part of teaching about science; practicing scientists must not only make original contributions, but also convince others of their value. Most important, the collaboration allows students to contribute to contemporary problems and to contemplate their social implications. The collaborative project gives students a unique and accurate glimpse of contemporary engineering and scientific research.

It might seem that seismology was a particularly fortunate example. However, there are a large number of exciting projects in ecology, astronomy, atmospheric science, and the social sciences, in which a geographically dispersed network of participating student scientists would provide equally exciting projects. The students could monitor the pH of rain, atmospheric, or water pollutants; the spread of animal pests; radioactive fallout; atmospheric ozone concentrations; epidemics; or the use of agricultural fertilizers. They might study a regional problem, such as water pollution in Boston Bay. In addition, there are a large number of potential collaborative projects that do not use location as an important variable, but take advantage of the large number of experiments that can be performed jointly. Examples include examining plant physiology under carefully controlled conditions (perhaps using the computer to monitor and maintain fixed levels of variables, such as temperature, light, and humidity) or performing experiments on learning or cognition that require a large N. Finally, there is a large class of experiments that are just plain difficult, where the collaboration effected through the network would put the students with similar interests in contact with one another and would enable them to work on the same problem together.

Another interesting possibility for collaboration enabled by telecommunications involves student access to research data, experiments and instruments. For example:

- There are vast quantities of ocean surface temperature data available that students might be able to access and use as the basis of original analysis.
- Long-distance student participation in underwater exploration using a remote submersible has been proposed. An explorer in the Mediterranean would transmit pictures and control the submersible with audio input from the students.
- Telescopes can be controlled remotely and their images transmitted using telecommunications. This creates the possibility of student-run observations. With patience and good software, the students could discover supernova and other time-varying events.

The three technologies—telecommunications, MBL, and modeling tools—all contribute to make collaborative student projects much more feasible and manageable. Telecommunications permit meaningful collaboration that reduces the demands on a student and the responsibilities of the classroom teacher. MBL greatly expands the range of potential experiments by providing powerful, general instrumentation. Modeling and analytical tools expand the range of problems that students can realistically understand.

While advances in each of these technologies are desirable and expected, they are already sufficiently powerful to make large-scale student collaboration feasible. The chief impediments are, as usual, not technological. Schools are not aware of this exciting possibility or, if they are, they are not convinced that a constructionist alternative to traditional instruction is justified. Also, the collaboration will not happen automatically, it must be organized. Significant funding is needed to convince schools of the value of collaborative science and to launch initial collaborations. Once started, these networks could probably be self-sustaining and grow to make project work a regular part of the curriculum for all students.

A CLOSING THOUGHT

The transformation of science education sketched out here is not going to happen easily. It will require major changes in values, philosophy, evaluation, curricula, and scheduling. The magnitude of these changes makes the program seem hopeless. Yet technology has presented us with certain escape from the mediocrity into which science education has fallen. It would be defeatist to ignore this opportunity because it is difficult.

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2

Doing Science Through Telecommunications

Cecilia Lenk

Science depends on communication. To do science today requires collaboration with other scientists—sharing information, discussing and disseminating results, and collectively generating new ideas and new directions for research (Jennings et al., 1986). Since the early 1970s scientists and engineers have used wide-area telecommunications networks to facilitate and expand communications with each other. Networks, such as BITNET, CSNET, and ARPANET, link universities, government agencies, and other research institutions throughout the United States and provide gateways to international telecommunications networks. Within the scientific and engineering communities, daily use of such networks is becoming commonplace, making it about as easy to communicate with a researcher in Sweden as it is with a faculty member down the hall. Indeed, so great is the need for communication among scientists and engineers, that Jennings et al. (1986) suggest that those researchers without access to such networks are seriously handicapped in their work.

Students who are learning science have the same need to communicate and collaborate as do professional scientists and engineers. To learn about science, to do science, and to effectively develop an understanding of what science is, students, too, need access to current information, and they must be able to work together on problems. And, just as it has in the professional scientific and engineering communities, telecommunications can facilitate the learning and doing of science for our students. By using telecommunications networks, students can move outside the walls of their classrooms and schools, expand their experiences in science beyond textbooks and classroom lab exercises, and address real-life problems and issues.

In this chapter, I shall discuss ways that students are using telecommunications to do and learn science. The projects described here range from those involving a few schools to projects involving schools across the United States and around the world. Using telecommunications in science education is in its infancy. Therefore, the services and projects discussed in this chapter include both those currently available as well as ones still under development. Finally, this chapter is by no means a complete survey of everything that is going on in this area. Such a survey would be rapidly out of date. Rather, I have included a sample of the types of telecommunications activities that are being done today that enhance science education. The goal is to stimulate your ideas and help you put telecommunications into practice in your schools.

A Brief Introduction to Telecommunications

Telecommunications simply means communicating across distances. In its broadest sense this definition includes communication by radio, television, telephone, and telegraph. In this chapter, however, telecommunications refers only to sharing information between computers.

To communicate using a computer, you need a modem and communications software. You also need access to a telephone line with a modular jack. Many school phone systems can easily be used for telecommunications. To determine if your phone system will work, call your local phone company.

The modem connects your computer to a telephone line. You use communications software to tell the computer and modem what to do. When you send information to another computer, your modem converts digital signals from your computer into tones. These tones travel between the computers along telephone lines or satellite relays, much like an ordinary voice telephone call. When the tones reach a modem attached to the receiving computer, its modem changes the tones back into signals the computer understands. Similarly, when your computer receives information from another computer, your modem translates the audio signals into digital information.

Information between computers travels quickly. Typical modems transmit at 300 or 1200 baud. At 300 baud, a modem transmits 30 characters per second, at 1200 baud, 120 characters per second.

For more information on the basics of telecommunications and the equipment and resources you need to begin telecommunicating, see *Apple Education News* (1986), the *Telecommunications Planning Guide for Educators* (1988) and Clark (1988). These articles are easy to read and will help you get started in telecommunications.

Telecommunications in the Science Classroom

With a computer, modem, communications software, and a telephone line you can –

- access commercial databases and information services,
- get up-to-the-minute weather data,
- join discussions on bulletin boards and computer conferences about science topics,
- communicate using electronic mail, and

- do collaborative research with other students across town or around the world.

To organize our discussion of how these telecommunications activities are being used in science education, we can roughly divide them into two groups –

- accessing information using databases, information services, and weather data services; and,
- sharing information through bulletin boards, electronic conferences, electronic mail, and collaborative research projects.

Accessing Information

Databases and Information Services. Access to current information is integral to both learning and doing science. One problem that frequently comes up when students gather information, whether for a paper or as background to a laboratory investigation, is that they often have limited library resources. The reference books and textbooks available to students may be out-of-date or simply have little or no information on such current science topics as AIDS or the greenhouse effect and the 1988 drought.

Telecommunications opens up a tremendous world of information to students. Using commercial database and information services, such as CompuServe, DIALOG, or Dow Jones, the students can research topics in science, health and technology. These services provide a variety of resources, including encyclopedia entries, abstracts, or the full text of periodical articles, bibliographies of books and periodicals, and wire service news stories. The information available from these services is current. Wire service news stories about science and science-related topics appear within hours of an event. On CompuServe, *Grolier's Academic American Encyclopedia* is updated every thirteen weeks (Mendrinos, 1987).

Elementary through high school students can effectively use database and information services to find information. An article in *Apple Education News* (1986) describes how, working with a librarian, sixth graders in San Mateo, California use Grolier's Encyclopedia on CompuServe to find information on such topics as whether twins have similar dreams and agriculture in the Soviet Union. In Wayland, Massachusetts, high school students regularly use DIALOG, Dow Jones, and CompuServe to research such current science topics as Agent Orange, gene therapy in the treatment of phenylketonuria (PKU) and Supernova 1987A (Sapienza, 1988). In both these examples, the students found information about current science issues that would be difficult to find in many textbooks or reference books.

Using database and information services can do more for students than simply giving them up-to-date information. As Sapienza (1988) and Mendrinos (1987) point out, these telecommunications resources can also help students develop their problem-solving skills. Database and information services can open up a world of information, but they can also create a maze which is frustrating for students and expensive for schools. Therefore, to find the information they want, the students must conduct well-organized searches that require careful planning well before they begin using these services. Mendrinos (1987) suggests that combining traditional print resources, such as card catalogs and the *Reader's Guide to Periodical Literature*, with the newer technologies of CD ROM and telecommunications is an effective way to help students learn to narrow their topics, find appropriate keywords and synonyms, and organize their search to find the information they want.

Weather Data Services. Telecommunications also gives students access to up-to-the-minute weather data through such information and database services as CompuServe and the McGraw Hill Information Exchange (MIX) or via specialized weather data services, such as AccuWeather and the National Geographic Weather Machine. A student can collect weather data from these services throughout the day and collect information that is more detailed than newspaper, radio, or television weather reports. For example, the National Geographic Weather Machine provides data on temperatures at different altitudes above the earth's surface. Furthermore, data such as temperature, wind direction, or barometric pressure can be displayed as maps on the computer screen. Using such maps, the students can easily follow the movement of weather patterns across the United States or see the jet stream.

Weather data from these services is easily integrated into earth or physical science classes. High school students in Lexington, Massachusetts regularly use hourly weather information from AccuWeather, including detailed maps of New England, as part of their earth science class (D. Di Felice, 1988, personal communication).

Sharing Information

Bulletin boards, computer conferences and forums, electronic mail, and collaborative research projects are all ways that students can use telecommunications to share information with each other. *Sharing information* includes a wide range of types of communication from discussions to collaborative research projects and collective problem-solving.

Bulletin Boards, Electronic Conferences and Forums. In addition to being sources for public-domain science and mathematics software, bulletin boards, electronic conferences, and forums allow students the opportunity to participate in group discussions about science topics and issues on science. These discussions can be relatively small-scale, for example, on a bulletin board system within a single school; or international in scope, through the forums and special-interest groups available on commercial information services, such as CompuServe.

Discussions, whether on bulletin boards, forums, or electronic conferences, are organized around topics. System operators or moderators who oversee the conversations and the participants themselves generate these topics. Within a topic area, the students can post questions or comments about the topic, read other participants' contributions, and respond to remarks.

Conversations can range from simple requests for information to extensive dialogs on a wide rage of issues. Bulletin boards, forums, and electronic conferences bring together a diverse group of people who have a variety of perspectives. Participants in a discussion can include other students, teachers, professional scientists, and interested laypersons. For example, a high school student who needed information for a debate on AIDS posted a request in the education form on THE WELL and received an avalanche of useful help from other participants

(Apple Education News, 1986). With state funding, seven towns in eastern Massachusetts have developed a bulletin board on Boston Delphi (R. Mendrinos, 1988, personal communication). Using this bulletin board, middle school students from these communities are discussing critical environmental issues, such as nuclear energy, water pollution, and acid rain. Science Experts On-Line on the McGraw-Hill Information Exchange (MIX) lets students ask professional scientists questions about their work. Recent science experts on MIX have included astronomers, meteorologists, and zoologists (G. Weekly, 1988, personal communication).

Collaborative Research Projects. Perhaps the most exciting area of telecommunications in the science classroom is the development of collaborative research projects. This is where student science becomes real science. Projects such as *WaterNet, The National Geographic Kids Network, The Plant Growing Contest* on MIX, *The Long Distance Network,* and *The Intercultural Learning Network* give students the opportunity to be scientists. These projects combine hands-on activities and discovery with collaboration and sharing through telecommunications.

WaterNet. Funded by the Department of Education, Clancy Wolfe and Carl Berger of the University of Michigan are developing *WaterNet,* a telecommunications-based study of water pollution that involves high schools in the United States, West Germany, and Australia. By studying actual pollution problems in their local river systems and sharing information with others on the network, Berger (1988, personal communication) hopes the students will not only develop an understanding of this critical environmental problem but also a sense of social responsibility that will motivate them to participate in the solving of their local water problems.

Using a curriculum developed by science, computer education, and social studies teachers, *WaterNet* combines telecommunications with microcomputer-based laboratory tools (MBL), databases, spreadsheets, graphing packages, and interactive computer simulations. Students gather water-quality data from their local rivers by using MBL tools and commercial water-quality kits and measure such variables as temperature, turbidity, pH, and dissolved oxygen. Then, using CONFER II, a conferencing system on the University of Michigan's mainframe computer, the students share the results of their tests with other participating schools.

The results from all schools became part of a database that grows as each group of students contributes data. Working with this database, the students use the electronic mail and conferencing facilities on CONFER to question each other about the data from different river systems, to discuss the implications of the results, and to suggest new approaches. In other words, they are scientists!

In order to further their understanding of the factors involved in determining environmental policies, the students also use interactive computer simulation to study a hypothetical river. According to Berger, students use knowledge that they have derived from their experience working with real data to make informed decisions about their hypothetical river and quickly learn how their decisions alter its fate.

The Intercultural Learning Network. *The Intercultural Learning Network* includes secondary schools and groups of college students in the United States, Japan, Israel, and Mexico. According to Riel (1987), "the goal of the project is for students from different cultures to use each other as resources for learning more about themselves and the social, cultural, and physical world." Although activities on the network are primarily in social studies and language arts, classes on the network have integrated science into these curricular areas. The science projects jointly undertaken by network participants include both observation-based activities as well as collaborative problem-solving activities (Levin and Cohen, 1985, Waugh et al., 1988).

Levin and Cohen (1985) and Waugh et al. (1988) describe several observation projects, including, Boiling Hot and the *Crescent Moon Observation Project.* In Boiling Hot, the students write down their expectations of the temperature at which water will boil. They then conduct experiments to measure the temperature at which water actually boils and share these data among schools; discussions begin on the network about other students' procedures and experimental errors. Is a measurement of 99.9° C the same as 100.1° C? With data from schools at a variety of locations, students ultimately develop an understanding how altitude affects the temperature at which water boils.

In the *Crescent Moon* project, the schools share data on what the first quarter moon looks like in their area. *Boiling Hot, Crescent Moon,* and similar observation projects on the *Intercultural Learning Network* give the students the opportunity to see similarities and differences in data from different locations and to develop and test hypotheses to explain these patterns.

The *Water Problem Solving* project is an example of a collaborative research project on the Intercultural Learning Network. In 1985 and 1986 students from schools in the United States, Mexico, Japan, and Israel studied the problem of shortages of drinking water by collecting data on their own communities' water supply (Levin and Cohen, 1985, Levin et al., 1987, Waugh et al., 1988). After analyzing the similarities and differences in how communities obtain water, the students looked at the feasibility of adapting solutions used in other parts of the world to solving their local water problems. Other problem-solving projects on the network include studies of severe weather conditions, animal and insect pests, pollution, and energy.

Students on the *Intercultural Learning Network* also share written reports of their work through *TeleScience Chronicles,* an electronic journal. In fact, a project is not considered complete until a written report is published in the Chronicles (Waugh et al., 1988). Interestingly, in a related study on students' writing, Cohen and Riel (1986) found that the students' writing was far better when they wrote to their peers on the network than when they wrote compositions on similar topics for grades!

The AT&T Long-Distance Learning Network. Involving about 350 elementary and secondary schools in the United States, West Germany, Holland, France, Australia, Canada and Japan, the *Long-Distance Learning Network* combines geography, social studies, language arts and science activities (M. Riel, 1988, personal communication) Classrooms are grouped into "Learning Circles," each circle consisting of approximately 10 classes. There are two types of learning circles on the network: Publishing Learning Circles, which participate in collaborative writing projects including journals and newspapers; and, Researching Learning Circles, which conduct cooperative research projects in geography, social sciences, and science. Although Researching Learning Circles focus on collaborative projects, the final goal of each project is to achieve a written report of the group's work.

Science and science-related topics that Researching Learning Circles have studied include food, the sky, water, animals, and humans and their environment. The members of the learning circle design the project they will conduct. Participants suggest ideas for projects and the group decides on which ones it will do. For example, recently a Learning Circle interested in food shared data on what foods were unique to their areas, what foods were common to all areas, what a family with a 10-year old was likely to have for dinner, how long it takes to cook dinner, and how much fast-food costs.

Participants in the *Long-Distance Learning Network* also receive a printed newsletter, the LDL Newsletter. Through the newsletter, the Learning Circles and *Long-Distance Learning Network*'s staff contribute stories, share ideas about projects, and get answers to technical problems.

The Plant Growing Contest, McGraw-Hill Information Exchange (MIX). In January and February, 1988, several elementary schools in the United States and Canada participated in a plant-growing contest on the McGraw-Hill Information Exchange (G. Weekly, 1988, personal communication; Schrum et al., 1988). The University of Minnesota supplied the corn seeds which all the classes planted on the same day. Then, using MIX, they sent measurements of the height of the corn to the other participating schools every two or three days. Students in each class experimented with water, light, and fertilizer in an attempt to grow the tallest corn plant. In addition, using the network, the students could ask professional scientists about their strategies and share their results with the scientists. Through the plant-growing contest, the students not only develop an understanding of what a plant needs to grow, but also learn how to design scientific experiments.

The National Geographic Kids Network. With funding from the National Science Foundation and the National Geographic Society, the Technical Education Research Centers, Inc. (TERC) are developing the *National Geographic Kids Network*. This telecommunications-based science curriculum for grades four through six currently involves about 200 schools in the United States, Canada, Israel, and Argentina. In April, 1989, 1000 schools will participate in the project. When the materials are published in late 1989 or early 1990, National Geographic plans to have 10,000 schools on the network.

Each six-week *Kids Network* unit focuses on a different current science topic, such as acid rain, land use, weather, health, or water pollution. Through a series of hands-on activities, the students will collect data, for example measuring the pH of their local water, and then sharing these data with other schools that also use the telecommunications network. The *Kids Network* software lets the students display their own data and the combined results from all schools as tables, graphs, or maps. Using these multiple representations, they can look for patterns in the data and compare their own findings with the national picture. The students can also use electronic mail and ask each other questions about the results and discuss their ideas of what the data mean.

A professional scientist doing research in the area of the unit works with the students. Using the network, the *unit scientist* sends electronic mail letters to the schools, commenting on the students' data and suggesting ways in which they might want to look at their data. The unit scientist also answers questions about the unit, again using electronic mail.

Combining hands-on activities, cooperative inquiry, meaningful scientific problems, and telecommunications, the goal of the *Kids Network* is to have the students do science. According to Foster et al. (1988), "through the *Kids Network* curriculum activities, students learn about specific content areas (e.g., geography or acid rain); however the emphasis is on having students *do* science by asking good questions, collecting both quantitative and qualitative information, and learning to use this information to answer significant questions."

How Telecommunications Enhances Doing and Learning Science

From this brief survey of some of the ways telecommunications is being used in science classrooms today, several common themes emerge. First, telecommunications expands the amount of information accessible to our students. Whether the students are searching a database for recent articles on radon, using a weather service to find the 6 AM barometric pressure data for the United States, or planning a research project on solar energy with students in Australia, our students can easily get the information they need by using telecommunications networks.

Second, telecommunications promotes collaboration and communication between individuals, within a class, or among classes on a network. Students who use database services must work closely with librarians and teachers to plan their search strategies. A class preparing pH measurements to send to another class must collectively decide how to gather the information and how to best organize it so that others understand it. Classes from California and Israel working together on a water resources project must collaborate in developing an understanding of the similarities and differences between their communities, so they can work together to solve the problem of getting adequate water supplies.

Third, telecommunications promotes an interdisciplinary approach to science. In these telecommunications projects, language arts, geography, and social studies are integrated in relevant and meaningful ways into science activities. If you are sharing data with classes in Millstadt, Illinois and Noatak, Alaska it becomes important to know where those places are and what those places are like. In addition, electronic mail letters easily integrate language arts into the science curriculum.

Finally, telecommunications expands the boundaries of the classroom. Using telecommunications networks, students can explore problems such as acid rain or water pollution, which are more relevant and meaningful when studied by geographically dispersed classes. In addition, students must work with people who have different opinions, which gives the students the opportunity to view problems from a variety of perspectives.

In a recent editorial on the potential for telecommunications networks to change education, Ohler (1987) points out that the complexity of our world and the vast amounts of information we need to use to find solutions to problems make it crucial that students learn to work together effectively. Telecommunications networks not only give students access to the information they need to make informed decisions, they also give students the ability to communicate and collaborate as easily with their colleagues in Mexico as with the class across the hall.

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3

Optical Technologies: Current Status and Possible Directions for Science Instruction

Robert D. Sherwood

While educational researchers have focused on microcomputer-based systems for instruction during the past decade, the use of optical-based technologies—such as videodiscs and compact disc, read-only memory (CD ROM)—has only recently become an area of interest in science education. This chapter, therefore, considers the use of optical technologies in science education. The chapter addresses the following three questions: (1) What are the major hardware and software technologies currently under use in the area?, (2) From the perspective of cognition, why might the use of the technologies provide learning environments that may be especially useful for science instruction?, and (3) What are some future directions in technology and learning theory that may have an impact on instruction?.

To address these questions, I have divided the chapter into three major components. These include (1) video-based systems, (2) data-based systems, and (3) integrated systems. For each component, I shall discuss hardware and software requirements and present a rationale for why these types of systems could be important for instruction.

VIDEO-BASED SYSTEMS

Within the area of video-based optical technologies, the discussion centers around the use of laser videodiscs. While some of the applications mentioned may be implemented with videotape, the limitations of tape—most notably the relatively long period of time needed to access portions of a tape—make it unsuitable for most interactive projects. To help you learn more about this subject, I have provided a listing at the end of this chapter of resources for, vendors of, and publications on videodisc technology.

Short History

Videodiscs have a mixed history in the home market. In the late 1970s video publishers introduced two types of discs, the laser videodisc and the capacitance videodisc. The capacitance disc had a very brief history with little acceptance by the consumer market. Its developers quickly wrote it off, and it has disappeared from the video marketplace. During the early 1980s, the laser videodisc went through a slack time of consumer interest in the United States, mainly due to the inability to record on the discs. Additionally, the rapid decrease in the price of video cassette recorders (VCRs) allowed many to purchase a VCR. This placed competitive pressure on videodisc players.

Consumer acceptance of videodisc players, however, has increased in the past three years, and consumers are using a substantial number of videodisc players in the home. Lower costs on disc players for the home market (in the $500 level) as well as a major growth in the number of titles available on disc have assisted the growth of the market. Futhermore, videophiles have touted discs as technically superior to tape. The technical capabilities of videodiscs have sparked interest in the U.S. market, but the discs have had a stronger presence in Japan than in the U.S. Currently, as with the VCR, Japanese companies design or produce all videodisc players.

Technical Characteristics of Videodisc Players and Videodiscs

Videodisc technology requires the use of a low-intensity laser to read microscopic pits in the aluminized substrate of the disc. The disc player itself is made up of three major components: (1) a turntable-like arrangement that spins the disc at a precise number of revolutions per minute, (2) an optical laser with mirror and photo-receptor arrangements that read the laser beam the disc reflects, and (3) microchip electronics that convert the reflected signal to standard video and audio outputs. The systems are generally reliable and maintenance free. Most problems are due to alignment of the laser beam, which results from improper shipping.

The discs are of composite materials with the aluminized center covered by a clear, tough plastic. This outer cover allows handling of the discs without concern for finger prints or even small scratches in this plastic coat. Durability is especially important for classroom use, because the students may be the users of videodisc products. Discs can be damaged, however, by dropping them on edge or subjecting them to high temperatures that may warp them.

Because a laser beam is all that touches the surface of the disc during play, the image quality does not deteriorate, even after thousands of plays. This is an improvement over videotapes that wear out if played many times. Early discs had some problems with substrate separation, which resulted in poor picture quality, but with recent discs (produced in the last two or three years) this has been a very rare occurrence.

Laser videodiscs are currently available commercially in two major types: Constant Angular Velocity (CAV or "standard play") and Constant Linear Velocity (CLV or "extended play"). CAV discs provide up to 30 minutes of running video per side of the disc or, more importantly for many instructional segments, up to 54,000 still images. The major advantage of the CAV disc is the ability to search to any frame on the disc (either a still image or a frame from a motion segment), and freeze on that frame. The image from a freeze frame is extremely clear as compared to that of a normal VCR. Furthermore, you can advance the frames one frame at a time to show action sequences. When played as a motion segment, these individual frames represent very small increments in time (1/30 of a second) and therefore allow careful examination of motion sequences.

While a later section will discuss the possible instructional use of videodiscs in detail, I shall whet your appetite here. One project is investigating movie how students can use the freeze-frame capability to study motion (Sherwood and others, 1987). For example, in the movie "The Empire Strikes Back" (available in CAV), a sequence shows Luke Skywalker being pulled up by a hoist from the ground to the bottom of a "Walker" (a kind of high-tech tank). By placing a clear grid over the monitor and using either a stop watch or the frame numbers themselves, the students can calculate if the hoist is pulling Luke at constant velocity or if he was accelerating as he went up. The freeze frame capability allows the student to start at the beginning of the shot, see the action, and then freeze the action at the end.

The hand-held controller for most disc players can perform all of these start-and-stop commands, or a computer can control the player. Various other options, such as slow-motion forward or reverse, are available with CAV discs. Searching to any spot on the disc is done simply by typing in the frame numbers on the keypad of the controller or on the keyboard of the computer and selecting the "search" option. The amount of time the player needs to find a particular frame varies with the distance on the disc from the current frame to the selected frame and the capabilities of the player, but is usually less than one and not more than six seconds. Discs that publishers have produced specifically for instruction — including experimental or prototype discs — are always CAV discs.

For ease of manipulation of the video, CAV discs have particular advantages over CLV discs. CLV discs do not allow one to freeze frames (except with some very new digitizing players). Additionally, CLV discs do not have frame numbers but do have time units (minutes and sometimes seconds) encoded on the disc. Therefore, searches on CLV discs can be only to the nearest *minute* on some CLV discs. One can search recent CLV discs to the nearest *second*, which provides searches that are close to the level of CAV discs. The big advantage of CLV is that the disc can hold up to 60 minutes of running video per side of the disc. This is an obvious economic advantage for commercial disc producers in that the number of discs needed for a film is reduced. The CAV version of "Raiders of the Lost Ark," for example, is on three discs (the film is slightly longer than two hours), while the CLV version is on two discs.

Some of the most recent videodisc players have introduced methods to provide freeze-frame with CLV discs. The Pioneer LD-S1, introduced in late 1987, can freeze a frame on CLV discs. As with many areas in video electronics, the technology to digitize video images has reached a level that is commercially attractive. The LD-S1 player digitizes the screen image when the still command is given from the hand controller or computer. This produces an excellent still image from any

CLV disc. As is shown in table 1, which indicates cost and performance characteristics, this ability comes at a price. The LD-S1 has a current retail price of approximately $1,600, as compared to some home models that start at as little as $500.

In summary, disc players have evolved in the past ten years by providing more features at a reduced cost. The major vendors include Pioneer, Sony, and Hitachi. Current figures show Pioneer leading the market but with serious competition from other vendors. Table 1 shows some representative players, approximate costs, and features.

Computer Control and Interfacing

Table 1
Characteristics of Recent Pioneer Videodisc Players

Player	Computer Interface	Approx Cost	Comments
LD-V2000 Below	8-Pin DIN	$590	Note 1
LD-V4200	RS-232C	$900	Note 2
LD-V6000	RS-232C	$1800	Note 3
LD-V6000A	RS-232C	$1800	Note 4
LD-S1	8-Pin DIN	$1600	Note 5

Note 1: Designed for the "home" market it can be controlled when connected to parallel port of MS-DOS computers, drivers and cables from such vendors as Visual Database Systems. It can search CLV discs to the nearest second. Wireless Remote.

Note 2: A moderately priced machine with a good computer interface capability. Many sources for cables and drivers because of the standard RS-232C interface. It can search CLV discs to nearest second. It has some text overlay capability built in 8 lines by 20 characters. Wired Remote.

Note 3: An "industrial" player with faster access time than 4200. No CLV time search.

Note 4: An upgrade to the 6000 player with even faster access time and more features built into player. It does have CLV time search to nearest second.

Note 5: A high end "home" player with one very large advantage, it can freeze-frame CLV discs by digitizing the image. The computer interface is the same as the 2000 model and earlier "home" models form Pioneer although the player has additional capability.

Source: Videodisc Monitor, October, 1986 and Pioneer Electronics USA.

There are a variety of options for controlling the videodisc player with external devices. As mentioned previously, the simplest method of control is to use the hand-held controller for the disc player. For group settings (such as a whole class), this is a good alternative. A higher level of control is to use a microcomputer to control the videodisc and to use a two-screen system—one screen for the video and one for the computer. A variety of companies produce such controlling programs (Optical Data Associates, Videodiscovery, and others). Most publishers developed these programs with the idea that students would work with the programs in a manner similar to computer-assisted instruction, which includes asking questions and interpreting student responses. These systems, therefore, were courseware-authoring systems.

Some authors (Williams, 1988), however, have developed menu-based programs that allow instructors or students to illustrate important concepts by sequencing a series of video segments or stills. For example, several presentations by members of the Learning Technology Center at Vanderbilt have used William's program to show short video clips from discs that illustrate projects and concepts under development at the center.

Specifically, the presentations have shown video segments of students before and after a particular instructional intervention to audiences of pre- and in-service teachers. While the student could have been described in words, the presentation of the short segments of pre-intervention video allowed the instructor to ask the teachers what they noticed about the prior abilities of the student, thus engaging the teachers in thinking about how to provide an effective intervention rather than just in passive listening. Following the discussion of the pre-intervention video, the instructor provided a presentation on the intervention (with video illustrations) and culminated with a video of the student in a post-intervention evaluation. The teachers could see the marked improvement in the student, which lead to a discussion of the results and future research and development plans.

A later section will develop a rationale for the use of menu-driven programs, but the general goal is to allow teachers and students to use the computer to locate and use short video segments on a videodisc. The program allows the user to name specific segments and to indicate starting and ending frames (or times). The program arranges the specific segments in a menu from which the user may select. Once selected, the computer can direct the disc player to play the segment and stop as the author indicated in the program.

Some authoring systems also allow an instructor to develop programs for controlling large-group presentations. Apple Computer recently introduced "Hypercard," which is a program that allows the MacIntosh computer to control videodisc players in this manner. With Hypercard, users can author multimedia presentations tailored to their needs or use programs that third-party companies (such as the Voyager Company) have prepared for commercially available videodiscs.

In terms of cost, menu programs are relatively inexpensive. For example, the Voyager Videostack is approximately $50; the interface cable to hook the videodisc player to the computer is an additional $25. Costs are similar for IBM compatible computers (MS-DOS operating system) from such companies as Visual Database Systems. Authoring systems usually cost $200-$300.

You can obtain more sophisticated presentations with systems that provide for integration of video and computer images on one screen than with the two-screen system of computer control in the foregoing description. During the past three or four years, companies such as Video Associates Laboratories have made available this higher level control—the overlay of computer generated text and graphics over video from videodisc players—for MS-DOS environments. The technology has the computer combine the video from the computer and the video from the videodisc player into a display that simultaneously contains both images on one screen. This has generally been accomplished with the use of hardware such as "daughter" boards added to the graphics card in the computer and software drivers. In addition, to achieve the graphics overlay capability you must use special monitors that allow this dual input. All of these factors result in systems that cost substantially more than two-screen systems. A minimum system with just an overlay card and monitor (not counting the computer cost) will be $2000-$2500. Futhermore, some companies produce specialized systems for computer-controlled video—such as Matrox, Sony View, and IBM Infowindow—that triple these levels of cost.

While costs currently are high, the capabilities of overlay systems are very enticing. You can design windows in the video screen so that the student can view only those areas of a video image that you want to emphasize. The overlay system can mask all other areas of the video image with a solid color. Many specialized systems (such as Infowindow) have touch-sensitive screens that allow users to simply touch areas or images of objects on the screen to control the video or the direction of the program. Other systems use point-and-click devices ("mouse") in place of the touch screen. In addition to masking video images with color, these systems can overlay high resolution graphics and text on the video material. The text can explain the images, provide directions for using the program, or ask questions about the learning material.

The developers of the hardware as well as other commercial companies (Allen Communications, Campus Technology, Goal Systems, Courseware, Inc., On Line Computer Systems, Warren-Forthought, Inc., Interactive Technologies Corp., and others) provide authoring systems for these overlay systems. The authoring programs for overlay systems are sophisticated and powerful but the cost may also reach the $2000-$3000 range. Cost factors of both the hardware and software make the one-screen systems with overlay unavailable for most school-based projects.

Traditional Views of Videodisc/Student Interaction

Levels of interaction in videodisc environments have generally followed the classification scheme of Daynes (1984). These levels include Level 0 in which the students playback the video material linearly with little or no interaction. Level 1 involves using a remote control to play selected motion segments at normal speed or as slow or fast motion. The remote also controls selection of audio channels, forward and reverse scanning of motion and still segments and viewing still frames (if possible). The techniques I mentioned in a previous section, using the hand controller found with most disc players, is an example of level-1 use.

Levels 2 and 3 involve using microprocessor technology to control the videodisc player. With level 2 systems, the manufacturer builds the microprocessor into the disc player. The microprocessor contains a code that provides computerized control of some of the functions of the videodisc player. In level 3, the computer is external to the videodisc player. The level 3 system has some of the features of graphics and text overlay capabilities I discussed in the previous section.

Many developers have based much of the instructional design of videodisc technology on psychological and instructional paradigms from other technologies (see Smith, 1987, for a review). Many of these paradigms have strongly emphasized an information processing model—presenting students a segment of instruction and then asking questions on that segment. If the students are successful, they continue to a new sequence of instruction that should build on previous work. Developers have used this method in several interactive videodisc programs, many of which are for military applications (Smith, 1987). While the technology for presenting the material is new, the instructional design features of many of these programs have not changed from earlier work in programmed instruction and computer-based instruction. The overall effectiveness of such programs is still an active subject of study, although some evaluative studies have shown positive results (Hasselbring and others, 1987).

Developers are exploring two new directions in the use of video. The first new direction is using the large storage capability of the videodisc to provide visual databases of science phenomena. Major vendors of visual databases include Optical Data Corporation and Videodiscovery. Teachers can use these discs with either Level 1 or Level 3 systems to provide examples to students of phenomena and concepts that may be very difficult to provide in textual materials—such as numerous examples of geologic formations, biological specimens, or complex physical systems. Students can use software provided by the companies or created by students or teachers to conduct searches of the video database.

A second direction of work is the development of simulation activities that use video (Lehman, 1986). Researchers have developed simulations for several science areas, including physics (Zollman and Fuller, 1982), chemistry (Smith, Jones, and Waugh, 1986; Brooks, 1988) and several areas of biological and health science (Leonard, 1987). For example, activities have included the video simulation of experiments that allow students to control titration and other laboratory activities. The highly interactive nature of simulations is best achieved through level 3 systems, even though some video simulations compromise with level 1 or level 2 systems. As with other modes of simulation, the video presentations allow students to manipulate situations that may be too expensive or too time consuming for school laboratories. Video production costs and the need for level 3 systems increase the costs for such projects; however, if many students can use the system, the cost per student interaction may be reasonable.

Alternative Views on Using Video in Instruction

Recent research in cognitive psychology has led to consideration of alternatives to the rather traditional views of how and why video might be important in instructional settings. Bransford, and others (in press) have presented a model called "Anchored Instruction" that draws upon research results and studies they have conducted to present a theory for creating instructional anchors, many of which involve video. The following discussion focuses on anchored instruction and how it relates to video and science instruction.

Ineffective Versus Effective Instruction. Before considering the concept of anchored instruction, consider some problems with many traditional approaches to instruction. The basic problem is that traditional instruction often fails to produce the transfer of concepts to new problem-solving situations that most educators would like to see. If this is indeed a major problem, are there examples of instructional circumstances that do successfully achieve transfer and can give insights on how instruction might be made more effective? These successful examples might serve as models for designing new instructional approaches.

Bransford, and others, give several examples of the transfer of concepts from one field to another, including the following derived from the history of science. They note that the invention of logarithms was a major breakthrough, not just for mathematics, but more importantly for early astronomers (circa 1600), who were working with very large numbers. The relevance of this invention to their work was quite clear. The astronomers actively sought particular knowledge because it had direct relevance for important problems—problems that they experienced daily and that were important to them.

In many educational settings there is an absence of features that were present in the case of the astronomers. In particular, students often have not had the opportunity to experience the types of problems that are rendered solvable by the knowledge we teach them. They treat the knowledge as ends rather than as a means to important ends.

In a study by Sherwood, and others (1987), they asked college students to explain how knowledge of logarithms might make it easier to solve problems, why logarithms were invented, and what good they do. The vast majority of the students had no idea of the uses for logarithms. They remembered learning them in school but they thought of them only as math exercises that one did in order to find answers to logarithm problems. They treated them as difficult ends to be tolerated, rather than as exciting inventions that allowed a variety of problems to be solved.

There are hundreds of additional cases in which information is understood as ends rather than as tools for effective problem solving. Some examples are algebra and variables, the concept of pH in chemistry, and the relationship between classic literature and the current world, just to name a few. The common denominator in all of these cases is that new information is treated as facts to be learned rather than as knowledge to be used. Students can not easily transfer knowledge learned as isolated facts to new problem situations.

Some Consequences of Acquiring Information as Facts Versus Tools. It is useful to explore some of the disadvantages of educational experiences that encourage the acquisition of mere factual content rather than tools for problem solving. A major disadvantage is that rarely do students spontaneously use information stored as facts to solve problems. Instead, as Whitehead (1929) suggested many years ago, the knowledge remains inert. In educational settings, failure to access and use potentially relevant information result in failure to transfer.

In recent years, a number of researchers have explored the inert knowledge problem by using laboratory experiments that control a variety of variables related to learning. Examples include Asch (1969), Brown (1986), Gick, and Holyoak (1980, 1983) and Perfetto, Bransford, and Franks (1983). In this latter study an especially important finding was obtained. The researchers provided a treatment group with some especially useful information for solving a particular set of written problems. Much to the surprise of the researcher, the problem-solving performance of the treatment group was not significantly better than the performance of the control group at solving the written problems. In short, relevant knowledge was available to the informed subjects but this knowledge remained inert. Other researchers have found similar examples of failures to use available and potentially valuable knowledge to solve problems, when subjects are not explicitly informed about its relevance for a particular task.

A Theoretical Framework that Emphasizes Conditionalized Knowledge. In his 1980 article on problem solving and instruction, Simon provides a theoretical framework for thinking about the failure of students to access information and for clarifying what it means to acquire knowledge as a tool. Simon argues that the knowledge representation underlying competent performance in any domain is not based on simple facts or verbal propositions but is instead based upon productions. Productions involve "condition-action pairs that specify that if a certain state occurs..., then particular mental (and possibly physical) actions should take place" (Anderson, 1987, p. 193). Productions thus provide information about the critical features of problem situations that make particular actions relevant. Simon notes that many forms of instruction do not help students conditionalize their knowledge, to acquire knowledge in the form of condition-action pairs mediated by appropriate goal-oriented hierarchies rather than as isolated facts. For example, he argues that "...textbooks are much more explicit in enunciating the laws of mathematics or of nature than in saying anything about when these laws may be useful in solving problems" (Simon, 1980). It is left largely to the student to generate the condition-action pairs required for solving novel problems. Thus, students may learn the definition of statistical concepts such as "mean," "median," and "mode" and how to compute them. This knowledge is important, but it provides no guarantee that students will know if a particular statistic is the appropriate one to use.

The Concept of Anchored Instruction. Anchored instruction is a model that helps students develop useful knowledge rather than inert knowledge. At its heart, the model emphasizes the importance of creating an anchor or focus that enables students to identify and define problems and to attend to their own perception and comprehension of these problems. Once you have created the anchor, you can then introduce information that is relevant to their anchored perceptions. The major goal of anchored instruction is to enable students to notice critical features of problem situations and to experience the changes in their perception and understanding of the anchor as they view the situation from new points of view.

Anchored instruction begins with a focal event or problem situation. Ideally, the anchor will provide students with a general goal—for example, planning a trip to the South American jungle or improving the efficiency of a business— that involves a variety of related subproblems and subgoals. Effective anchors should also help students notice the features of problem situations that make particular actions relevant.

Case-study approaches to instruction provide one illustration of anchored instruction. They have been used in business schools for some time, for many of the reasons I have mentioned. In case-study approaches, students begin with cases that represent problems to solve. As the lesson introduces the students to new concepts and frames for thinking, they see the effects of this information on the problems they confront.

Programs such as Lipman's *Philosophy for Children* (Lipman, 1985) and Wales and Stager's *Guided Design* (1977) are also excellent illustrations of anchored instruction. Lipman's program centers around novels involving children who encounter a number of problems in their everyday lives and at school. The children learn to use a variety of philosophical methods for exploring these problems. In *Guided Design*, the students are introduced to relevant knowledge from experts; the knowledge is also presented in the context of working on interesting, complex problems that the instructors present.

In the programs above, the focal events or anchors are almost always presented in a verbal format. This format is fine for a number of purposes. There are advantages, however, of providing video-based anchors rather than relying on a purely verbal mode.

As an illustration of the preceding argument, imagine a student in clinical psychology who learns to diagnose clients based on verbal descriptions such as "The client is slightly anxious, mildly defensive," etc. Verbal labels such as "slightly anxious" and "mildly defensive" represent the output of an expert's pattern-recognition processes. If students do not develop similar skills of pattern recognition, their ability to diagnose based on verbal labels will be of little use in the real-world environment. Here, pattern recognition depends on visual and auditory cues rather than on prelabelled events (Bransford, Sherwood, and Hasselbring, 1988).

One advantage of using video anchors is that they contain much richer sources of information than are available in the printed media. Gestures, affective states, scenes of towns, and music usually accompany the dialogue. Therefore, there is much more to notice in video than in books. This increase in opportunities for noticing increases the possibility of finding relevant issues, which are embedded in the video. Video anchors provide opportunities to encourage instructional situations that emphasize problem finding and problem representation rather than to always provide pre-set problems to students. In addition, the richness of video information can help students appreciate how their perception and comprehension change as they consider the video from multiple points of view.

A second advantage of using video anchors is closely related to the first. Often, the realistic presentation of dynamic, moving events facilitates comprehension of such events. Young children may need to see waves and strong winds to deeply understand these concepts; older students may learn better by viewing moving scenes that illustrate acceleration versus constant velocity than by reading text and looking at static pictures. Johnson (1987) has recently completed a very interesting study with young children using video that shows the advantages of video over purely verbal presentation.

A third advantage of using video is related to my previous discussion of the importance of conditionalizing one's knowledge. Without knowledge of the appropriate "triggering conditions," students will not access and apply relevant knowledge. Simon (1980) notes that, often, our educational systems fail to develop the pattern-recognition abilities necessary to specify the condition side of condition-action pairings. It is often difficult to develop skills of pattern recognition when one teaches primarily in a verbal mode.

The capabilities of videodisc technology enhance the advantages of using video. As I noted in the section on technical characteristics, to take advantage of the rich information on videodiscs, students can play frames in slow motion or can freeze frames clearly for detailed study, or they can scan the video rapidly to look for important events. Teachers can locate and replay scenes to illustrate particular points or to invite class discussion. Teachers or students can easily juxtapose and contrast segments of video that are not contiguous to develop pattern recognition skills.

Initial Studies of Anchored Instruction. During the past several years, the author and colleagues have conducted a number of studies to explore aspects of the concept of anchored instruction. Researchers have conducted a study of anchored instruction in mathematical problem solving (Bransford, Hasselbring, Barron, Kulewicz, Littlefield, and Goin, 1987). In this study, the math problems that the researchers provided the students involved finding the length or width of an object given its proportional relationship to a standard with a known length or width. Video from the first ten minutes of the movie "Raiders of the Lost Ark" provided an especially rich context from which to begin. The video was supplemented with effective mediational based teaching. For example, students were encouraged to create visual and symbolic representations of problems, and they received individualized feedback about the strengths and weaknesses of their approach to each problem. The researchers compared the effects of learning using the video context to the effects of learning in a control condition in which students received teaching that was similar in format but more individualized than the teaching they received in school. The control group did not receive the video treatment. Overall, the results of the mathematics study were very encouraging. The students who received the anchored instruction showed a great deal of improvement. In contrast, the students in the control condition showed very little improvement. The treatment group improved not only on problems that referred to the Indiana Jones context; they improved on out-of-context problems as well.

In terms of science studies, Sherwood and others (1987) reported a study of college students that indicated that having a meaningful context within which to learn improved the learning of science information. The information consisted of

13 short passages that might be encountered in middle and high school science classes. Topics, such as (a) kinds of high-carbohydrate foods that are healthy versus less healthy; (b) the use of water as a standard for measuring the weight of liquids; and (c) the density of metals such as gold, lead, etc., were included. The context for the experimental group was the first 10 minutes of the film "Raiders of the Lost Ark."

The results included large differences in the students' spontaneous use of information. The students who had simply read facts almost never mentioned specific information about the material they had read. Their answers tended to be quite general. The students in the second acquisition condition, which used a contextual base, made excellent use of the information they had just read. For example, when discussing food, most of them focused on the importance of its nutritional contents—a feature that the students identified as important as a result of exposure to the contextual base. Overall, students who received information in the context of a problem were much more likely to remember what they read and to use it spontaneously as a basis for creating new sets of plans for a journey to a desert area in the western part of the U.S. in order to search for relics in Pueblo caves. In an earlier study, researchers found similar results on the recall of science information with seventh and eighth grade students (Sherwood, and others, 1987).

In a more recent study, Sherwood, Kinzer, and Carrick (1987) conducted an experiment with sixth grade students that was similar to the preceding experiment with college students. While they did not obtain recall of the science information by the video group as well as they had in previous experiments, they did see significant differences in the students' ability to explain how various types of science information might be useful to them. For example, a student's answer from the anchored instruction group to the question of why the weight of liquids is important was "If you go on a hiking trip and carried water with you, you would need to know how much you can carry." As noted previously, it was argued that the opportunity to view information as means to important ends helps students learn about the conditions under which knowledge is useful This increases the chances of the students using that knowledge spontaneously to solve new problems that they confront later.

Students as Producers of Knowledge. The preceding discussion focused on situations in which we as teachers can help students identify and define important problems that we provide. An important part of problem solving, however, involves the ability to identify and define one's own problems (Bransford and Stein, 1984; Sternberg, 1985). Schools often overlook these aspects of problem solving, in part because they are difficult to teach.

In their work with middle school students, Sturdevant and others (1987) found that students are highly motivated by creating products for computer-controlled videodisc. One reason is that the products are professional looking because they include high-quality video from professionally made videodiscs. This increases the audience's interest, which in turn increases positive feedback. Students therefore take a great deal of interest in creating products that are of high quality.

Three fifth grade girls created a product they called "Snake Shop" to use with a computer-controlled videodisc. It was a very creative "advertisement" for a pretend snake shop that the girls supposedly owned. In producing the product the girls had to find appropriate scenes of snakes (they used scenes from the "Raiders of the Lost Ark" segment where the ark is found in a tomb containing snakes), as well as create written text to go with the scenes. The final product is a very engaging production that humorously describes the snakes in their shop, how to take care of a snake from the shop, and how they will package and deliver the snake.

The preceding example of a student-produced product involved a creative story. Teachers can also focus the assignments so that students' products are related to particular academic content. In this way, students can learn information in their texts and readings while combining this information in a way that is unique. For example, another group of students in the study by Sturdevant and others created a program about light. By using segments from the movie "Star Wars" they were able to illustrate some important concepts about light; for example, that our sun is a star that gives off light. While this fact could be read in a science textbook, the use of a very short video segment, tied with text, appears to make learning this type of information more meaningful and interesting for the students who produced the video and for the other students who watch the production.

On-going Projects. In an on-going study, Risko, Kinzer, and Vye (in preparation) are using anchors based on "The Young Sherlock Holmes." Just as Sherlock is a master at attending to significant details to solve crimes, the researchers encourage the students in this middle school project to "play Sherlock" and check the details of the Sherlock movie for authenticity. Students can then create presentations for other class members and other classes as well. By looking for interesting issues, students should learn to find and define their own problems. Once they have identified particular issues, the students should develop important skills for finding and presenting information.

Another project on anchored instruction involves the production of videodisc materials rather than the use of extant movies. Extant movies have facilitated research that has provided important information. The "Invitations to Thinking" series (Bransford, and others, in press), however, is designed to make use of research results based on extant video to design new video. The researchers will also study these products to develop general principles for designing anchors.

The first video for the series is a river adventure. The researchers designed the adventure especially for teaching mathematical thinking, although teachers could also use it to teach about a number of additional topics. The video begins with a group of students who win a contest that allows them to use a houseboat for a week. Students must do all the planning for the trip, including plans for water, food, and gasoline. They must also tell the people at the boat dock the size and height of their boat, plus the time of day they plan to arrive, the amount of time they will stay, and whether they will need water and fuel. Included on the video are pictures of the boat the students will use, examples of another group using the boat to go down the river, illustrations of charts for navigation, and so forth. After seeing a video introduction, the students must determine the types of problems they need to solve to plan effectively. They are therefore encouraged to identify and define their own problems.

To summarize, the overall goal of anchored instruction is to overcome the problem of inert knowledge by allowing students to experience changes in their perception and understanding as they are introduced to new bodies of information. Students may realize that, initially, they failed to identify important issues, failed to define the issues from a more fruitful perspective, or failed to come up with strategies to solve the problems that were the most efficient and accurate. They therefore treat information as a means to important ends rather than as ends-in-themselves. As I have argued, this leads to a greater appreciation of the value of information and a greater tendency to use it in new situations when it is appropriate.

I also argue that there are advantages of using video anchors that are on a videodisc controlled by a computer. This increases the amount of information available to students and makes it possible for students to develop the pattern recognition abilities necessary to function in particular environments. In addition, with the capability available to students to develop video presentations, they should be in a better position to learn by teaching. Furthermore, their peers should be better able to learn from the student-developed videos, because the presentations are clear and interesting to watch.

DATA-BASED SYSTEMS

Optical storage systems that are data-based center around the Compact Disc Read Only Memory (CD ROM) technology. While the technology has been implemented for over three years on a commercial basis, recent announcements by a number of major companies such as Microsoft (Johnston, 1988a and 1988b), Apple (Meng, 1988), GE/RCA (Wilson, 1987a), and Tandy (Patton and Stone, 1988) have resulted in renewed interest in this technology and possible applications to instruction.

CD ROM uses an optical technology similar to that of videodisc in that both use laser systems to read (but not write) information encoded on a disc. CD ROM differs in that the disc is smaller, the same size as the popular CD audio discs (5 inches). The major advantage of CD ROM is the large amount of information that a developer can store on a disc. While total capacities have some variability, the usual storage maximum is approximately 550 megabytes. Given that the newest 3 1/2 inch floppy discs hold 1.44 megabytes, the storage capacity of one CD ROM would represent more than 380 floppy discs. These large storage capacities have allowed companies to develop such titles as Grolier's *Electronic Encyclopedia*, *Small Business Consultant* from Microsoft which contains over 220 U.S. government publications about starting and operating a small business, auditing reference materials, and similar title (Johnston, 1988b).

Several vendors produce CD ROM drives for MS-DOS computers and Apple has recently introduced a drive for MacIntosh systems (Flynn, 1988). Drives remain somewhat on the expensive side with the Apple drive listed at $1200 and the MS-DOS drives in a similar range. Microsoft has taken a lead in developing both hardware and software standards for CD ROM systems. It markets a CD ROM extension for MS-DOS systems and has proposed a file format that might be adopted by the International Standards Organization (ISO). Apple might accept this standard in its CD ROM player.

For instruction, libraries are using CD ROM technology for information sources such as Educational Resources Information Center (ERIC), Dissertation Abstracts, and PsyLIT. With appropriate software, students are able to search these sources by subject and author without connecting to a remote computer facility, as was required previously.

Classroom applications have developed slowly, because the developers of the technology, until recently, have not agreed on standards and have limited the titles to those that have relatively wide appeal. Promising directions for classroom applications include large databases that students can search for information in science, social studies, and other disciplines. A good objective might be to develop systems in which students could produce multimedia presentations using video, textual data, and audio.

Variants of CD ROM

Two areas of development are occurring with CD ROM. One of these is the use of Write Once Read Many Times (WORM) drives and discs. These systems allow data to be written once to the disc but read many times. A low intensity laser burns the pits into the disc and another reads the information. People use the systems typically for situations where storing large archives of information is especially important. The media is very stable after writing, offering longer life than tape or floppy discs and also faster access. Costs remain high, with drives in the $1600 to $6,000 range, depending on storage capability (200 to 600 megabytes) and access speed. The technology also has suffered from a lack of standards in both hardware and software formats—each vendor's drive is different. By marketing a WORM drive (Cummings, 1988), IBM has added some stability to the market.

A second CD ROM variant is Compact Disc Interactive (CDI) developed by Phillips. This media offers a mixture of audio, data and limited full-motion video. It appears to be directed toward the home market with players, which would contain a microprocessor, being able to play audio disc that might also have up to five minutes of full-motion video.

INTEGRATED SYSTEMS

DVI Technology

Even though videodiscs produce high quality video and CD ROMs store large amounts of data, the integration of these two optical technologies has taken a major effort. To produce full-motion video requires the manipulation of an extremely large number of picture elements on a monitor, especially if the video is to be digitized so that a program or user can manipulate it. The David Sarnoll Research Center, Inc. (formerly GE/RCA labs) has developed such an integration of video and CD ROM technologies in a system they term digital video interactive (DVI). The system can compress full-motion video so that up to 60 minutes of it can be stored on a five-inch CD-ROM disc and then can decompress it as the system plays it so that the video (with multichannel audio) has good resolution and is completely manipulatable by software. DVI technology has progressed far enough that several major software companies (Lotus, Intel, Microsoft) and hardware manufacturers (Hitachi, NEC, Olivetti) have endorsed it as a standard for future developments (Johnston, 1988a).

In terms of instructional applications, the very interesting work of the Center for Children and Technology at Bank Street College in developing a DVI prototype (the *Palenque Project*) gives some glimpses into what may be the future of multimedia in instructional environments (Wilson and Tally, 1987; Wilson, 1987a and 1987b). The prototype allows children to explore a Maya ruin in the Yucatan called Palenque. As described by Wilson and Tally (1987), the six major components of the prototype are:

1. *VIDEO OVERVIEWS* are used to introduce the prototype and the three major modes of Palenque: Explore, Museum, and Game.
2. *EXPLORE MODE* involves a journey which encourages exploration and open-ended discovery by allowing users to "walk" or "run" around the archeological site at Palenque. Users indicate with a joystick in which direction they would like to travel and which places they would like to visit. Information "zooms" into places of interest, 360-degree pans and tilts, and a dynamic you-are-here map all complement the "walking" feature of Explore Mode. Thus, in this component of Palenque the information is stored and accessed spatially, so that users must "walk" to locations on the site to learn more about them.
3. *MUSEUM MODE* is a multimedia database of information relevant to the Palenque site. The information includes text, still photographs, drawings, motion video, graphics, sound effects, and audio narration. Users browse through theme "rooms" to learn more about such things as Maya glyphs and the tropical rain forest. In the museum, information is hierarchically structured and accessed thematically so that users can browse through categories of information presented in greater or lesser detail, as desired.
4. *THREE CHARACTERS* are incorporated into the Palenque prototype: a young teenager and an archeologist from Bank Street's *The Voyage of the Mimi* TV show, and an archeologist from National Geographic who specializes in Maya studies. These characters serve as companions, guides, and content experts.
5. *SIMULATED TOOLS* are available to users to help in the exploration of the Palenque site and museum. These include a camera, an album, a compass, a tape recorder, and a magic flashlight. The magic flashlight allows users to "see" buildings as they looked before reconstruction began or in the days of the Maya.
6. *GAMES and ACTIVITIES* are available in the museum. These rooms, such as putting back together fragmented glyphs and constructing one's own jungle symphony (p. 3).

The Palenque prototype was developed for children age 8 to 14. Many students have used it during the development process and after the prototype was completed. Wilson and Tally (1987) provide a discussion of the formative evaluation methods and results that they obtained during the project. Generally, they found very positive student acceptance of the multimedia experience, with students very highly motivated to try a variety of explorations with the prototype. As

DVI matures and more powerful (and less expensive) computer systems are available to interact with the multimedia materials, a whole range of possible "adventures" or "explorations" may be possible for students to experience or develop.

THOR-CD Technology

The most recent announcement (Patton and Stone, 1988) that possibly offers a new dimension to optical technologies is that of Tandy High-Intensity Optical Recording Compact Disc (THOR-CD). The major difference in this technology is that it can repeatedly record, play, store, and erase music, video, and digital data. This appears to address the major problem of optical storage, the inability for the end user to record and erase. While Tandy expects that consumers will first use the technology for music, they expect that the system will be able to record and erase hundreds of megabytes, possibly as soon as April 1990.

The combination of DVI technology with THOR technology might have major influences on how educators might produce, use, and manipulate video, data, and audio for instruction. Systems that allow teachers and students to produce video, digitally encode it, store it and manipulate it for playback offer possibilities for developing conceptual anchors and production systems. In turn, this could help prevent students' acquired knowledge from becoming "inert," thereby being useful for new problem-solving situations.

CONCLUSIONS

The rapidly-changing environment of optical technology offers numerous directions for the future of video, data, and audio in instruction. As with other areas of educational technology, the knowledge of models of student learning and interaction with the technology may advance the technology development. Research and developmental activities that draw on the current knowledge in cognitive psychology and integrate that knowledge into developing new uses of educational technology offer major benefits for the instructional process.

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Falls Church, VA 22046
(703) 241-1799
An expensive journal but very informative on the industry.

Instruction Delivery Systems
Communicative Technology Corporation
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Journal of Instruction Development
Learning Systems Institute
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4

ThinkerTools: Implications for Science Teaching

Paul Horwitz

INTRODUCTION

The story is told of an encounter, back in the colonial days, between an English settler and an Indian. The settler, who was a university-educated gentleman, and who wished to impress the savage with his superior culture and learning, took a stick and drew a small circle in the dirt. He pointed to it and said: "This is what you know." Then he drew a much bigger circle, entirely enclosing the smaller one, and said proudly: "And this is what I know." The Indian stared at the two circles for some time in silence. Then he pointed away from them, out toward the looming forest and the mountains towering in the distance. "And that," he said gravely, "is what neither of us knows!"

The widespread availability of a computing power that would have seemed miraculous a generation ago is creating a genuine shift of patterns in many sciences. Researchers in meteorology, mathematics, cosmology, and psychology (May, 1976; Devaney, 1985; Schulman, 1986; Skarda, 1987) have discovered, independently and largely through the use of computer-based modeling and experimentation, remarkable regularities that underlie the complex, seemingly random behavior of nonlinear systems. Realistic, computer-generated models of molecules and their interactions are enabling chemists and biologists to examine and manipulate the details of reactions at the sub-Angstrom, sub-picosecond scale (McCannon, 1987). It is increasingly obvious that mathematical models, coupled with interactive computer graphics, are extremely powerful tools for scientists in every field.

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Less well recognized, but an equally powerful force for change, is the availability of significant computing capacity in the schools, which has the potential for narrowing the gap between the two circles alluded to in the opening anecdote. That story makes a point that science educators rarely explicitly acknowledge: scientists and students of science are more alike in what they do not know than they are different because of what they do know. Moreover, the widespread presence of computers in the classroom has the potential for dramatically narrowing the gap between the two groups to the point where along some dimensions the gap is almost non-existent. More importantly, it has made it possible to introduce students at a very early age to powerful methods of scientific inquiry that mimic, where they do not actually replicate, those methods employed by professionals. In the remainder of this paper, I shall elaborate on these two points.

I take as my point of departure my recent experiences, in collaboration with Dr. Barbara Y. White, in developing and using a new curriculum, and associated computer software, named *ThinkerTools* (White, 1987). Sponsored by the National Science Foundation, *ThinkerTools* was an educational research project that taught middle school students the elements of Newtonian mechanics and, in the process, introduced them to powerful methods of scientific inquiry and inductive reasoning. The next section of this paper describes the project in sufficient detail to provide a suitable context. Following that, I describe several incidents from the *ThinkerTools* project and use them to illustrate my point. The last section presents tentative conclusions.

Description of ThinkerTools

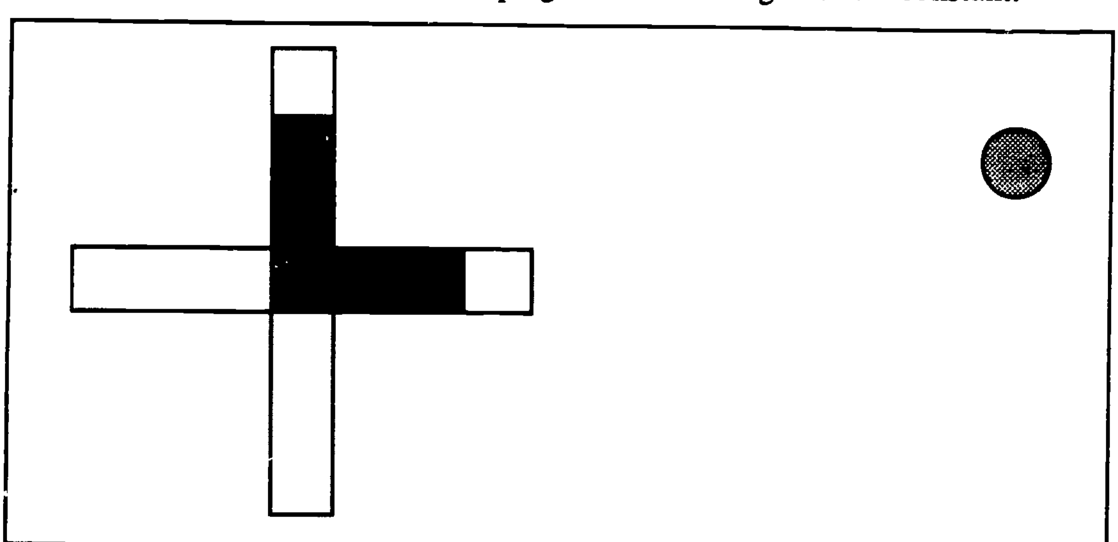
This section provides a brief description of the *ThinkerTools* project and the resulting curriculum and software. The next section describes some results from that project that are most relevant to the subject of this paper, to which readers already familiar with *ThinkerTools* should proceed directly. Readers at the other end of the spectrum, for whom the description below is too sketchy to be of much value, might find it informative to peruse a detailed description by White (1987).

ThinkerTools was a two-year project supported jointly by the Applications of Advanced Technology and the Instructional Materials Development programs, both of which are within the Science and Engineering Education Directorate of the National Science Foundation. *ThinkerTools* lasted from October, 1984 through September, 1986. Starting from the failure of many traditional high school and college physics courses to adequately teach their subject matter (Caramazza et al., 1981; Clement, 1982; Di Sessa, 1982; Larkin et al., 1980; McDermott, 1984; White, 1983), the goal of the project was to explore the feasibility of teaching students at the sixth grade level enough Newtonian mechanics to enable them to understand and reason accurately about the effects of forces, acting singly and in combination, on point masses. The project resulted in the production of a mini-course, or module, consisting of detailed lesson plans. The mini-course covers six to eight weeks and deals, in sequence, with the effects of impulses in one dimension; their generalization to two dimensions, including the concept of vector addition; the transition from sequences of discrete impulses to the limit of continuous forces; and the nature and effects of a velocity-dependent frictional force and a constant, uniform gravitational force.

In addition to the lesson plans and other curricular material, the project produced software that included a set of computer-based activities that led students gradually through the sequence of topics. These activities were generally in the form of simple video games, in that they typically called for using a joystick to manipulate computer-generated graphic objects. Many of these games were introduced to the students with specific instructions and goals, but some were presented as open-ended learning environments, and still others were used primarily as demonstrations of effects that had already been observed in classroom experiments.

The developers designed the *ThinkerTools* software to be a "physics erector set" in the form of a high-level, special purpose language in which games, demonstrations, and other activities may be easily created, run, edited and stored as files for later use. To maximize the efficiency of running time and speed, the developers implemented the program entirely in native machine code. It runs on the Commodore 64 computer and makes full use of the impressive graphics capabilities of that machine. Although the Commodore is only an 8-bit computer and can be purchased for as little as $150, it is quite capable of running simulations of complex many-body systems in real time, and it can animate graphic representations smoothly and realistically.

All the systems that *ThinkerTools* can simulate are built out of a small number of very simple components. The basic component is the "dot"—a computer-generated graphic object in the form of a colored disk—that represents a point mass. The students can directly manipulate dots by using a joystick that controls the fire of a simulated rocket engine in any of four orthogonal directions. The rocket engine produces an instantaneous impulse of a given, fixed size and, if the fire button is held down, will produced a stream of such impulses separated by a fixed interval of time. When a student first uses the system, the impulses are quite large and the time between them is appreciable (approximately .75 seconds). At later stages in the curriculum, both these quantities may be repeatedly halved, resulting in a gradual limit process in which the action of the joystick approaches that of a continuous force, while keeping the time-averaged effect constant.

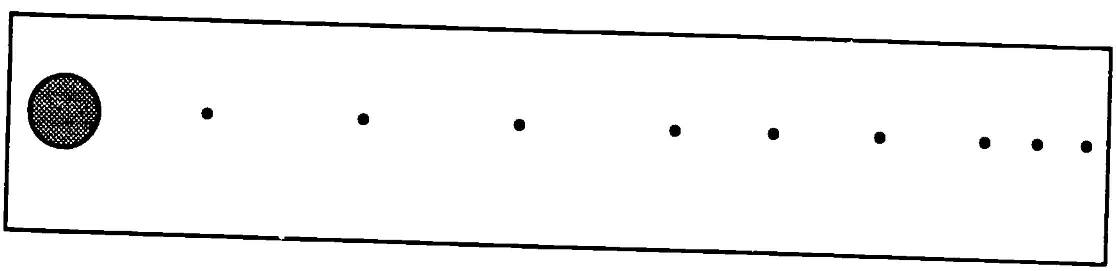


In addition to the dots, other physical objects, such as "walls," can be part of the *ThinkerTools* environment. The interaction of dots with walls has a limited set of alternatives. In one mode, dots "explode" when they hit a wall, so that walls serve mainly to constrain the motion of the dots. In other modes, dots may bounce off walls elastically (though this option was not used in the curriculum), or may have more complex consequences such as starting timers, incrementing counters, or even "turning on" such external forces as gravity or friction.

The computer may represent the velocity of any dot by means of a device called a "datacross." This is a pair of crossed "thermometers" denoting the horizontal and vertical components of the dot's velocity. In the situation depicted on the previous page, for instance, the dot is travelling at a 45 degree angle to the right and up.

In addition to the datacross, the computer also represents velocities in *ThinkerTools* by having dots leave "wakes." A dot can turn a pixel on at its present location, changing it from the background color to the color of the dot, at preset, fixed time intervals. As the dot moves across the screen, it will leave a trail of pixels. Both the time interval between the setting of pixels and the total number of pixels to be set can be fixed in advance. Thus, after 200 pixels have been turned on in this way, the first pixel may be erased as the 201st is turned on, and so forth, so that the total number of pixels set is always 200. (If a dot is moving so slowly that it does not move from one pixel to another during the time interval between settings, fewer than 200 pixels will actually be set and the wake left by the dot will be shorter. This leads to an interesting representation for velocity, as described below.)

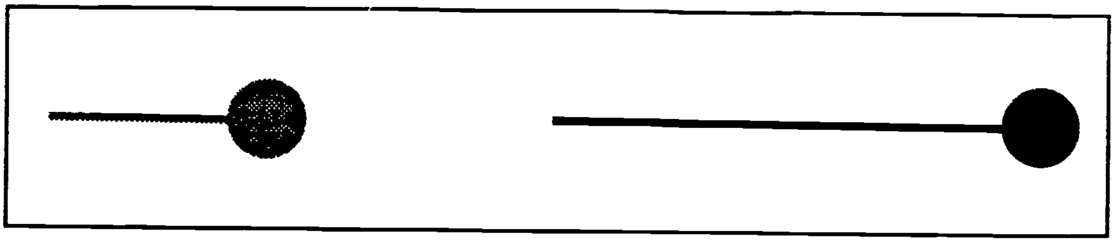
Defining the wakes in this way leads to two useful new representations for motion. If the time interval between pixel settings is long enough, the wake will be displayed as a dotted line, the spacing of which provides a record of the velocity of the dot.



In the picture above, the first three pixels were evidently drawn when the dot was moving with one unit of speed, then an impulse was applied and the next three pixels represent two units of speed, finally another impulse was applied and resulted in the placement of the final three pixels.

An alternative representation results from a choice of parameters in which the time interval for drawing pixels is chosen to be so short that the wake looks like a continuous line, but in which the number of pixels drawn is small enough so that the *length* of the wake represents the dot's velocity.

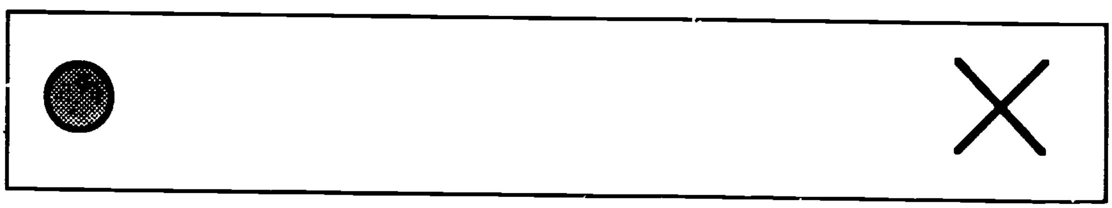
In the picture on the next page, the dot on the right is moving twice as fast as the one on the left.



Finally, the number of pixels drawn may be set to be infinite, in which case the wake never erases itself. This setting is useful in tracing out orbits and other periodic or quasi-periodic motion.

The developers quite carefully planned and controlled the students' interactions with the software. As the students reach each new topic in the curriculum, instruction generally follows the following four steps:

1. First the teacher asks the students to make predictions about simple idealizations of real-world situations. For instance, the teacher might ask them to "imagine that we have a ball resting on a frictionless surface and we blow on the ball. Then, as the ball is moving along, we give it a second blow, the same size as the first, and in the same direction. Would the second blow change the speed of the ball? If so, how?" The answers to questions such as these are tabulated by the teacher, who does not comment on their correctness. The students do note, however, that there is not universal agreement on the answer to such simple questions.
2. The students solve problems and perform experiments in the context of a computer microworld, such as the one depicted below, in which the dot can be given impulses only in the horizontal direction and explodes



when it hits a wall. The activities in this microworld involve passing the dot through the X with a specified speed, after which the dot and the X move to a new spot and a new speed is specified. In later, more complex microworlds, additional functionality, such as motion in two dimensions, and tools, such as arrows that denote the position of the dot, are added to the microworlds.
3. The students are given a set of possible "laws" purportedly governing the behavior of the microworld they have been studying, and are asked to determine which of these are correct and which can be proved incorrect by demonstrating their falsity in at least one situation. An example of an incorrect law would be: "The dot always speeds up when you give it an impulse to the right." Correct laws include: "If the dot is moving to the right and you give it an impulse to the right, it will speed up," as well as the more general law: "The impulses add to and subtract

from the speed of the dot like numbers – impulses to the right add and impulses to the left subtract," which makes use of the convention that velocity components to the left are considered negative. Subsequently, the students are asked to rank the set of correct laws by answering the question: "If you could only remember one of these laws, which would you choose?" In the ensuing discussion, the students compare the laws with respect to predictive power, range of applicability, conciseness, and clarity.

4. The students are asked to apply the law they have chosen as "best" to the predictive questions that were posed at the beginning of the cycle. Where the law fails to predict real-world phenomena accurately the students are led to impute this inaccuracy to the presence of complicating effects, such as frictional forces. Where possible, within the limitations of time and available equipment, simple classroom experiments are performed illustrating these effects. Finally, the complicating effects are added to the microworld, which improves the match between its behavior and that of the real-world phenomena it models.

ThinkerTools Discoveries

The *ThinkerTools* curriculum had two complementary goals. At one level, in its treatment of Newtonian mechanics, starting with problems in one dimension and building up to trajectories in a gravitational field, it could be considered a standard introductory physics course, albeit with some changes stemming in part from our effort to take into account the students' prior knowledge and misconceptions. Seen in this light, the computer simulations served primarily to motivate the students and to give them the ability to observe and manipulate concrete representations of abstract concepts.

But *ThinkerTools* also had the complementary goal of getting the students to "think like physicists" in the sense of inducing general laws from specific situations, reasoning from general principles, and making associations between phenomena on the basis of the underlying mechanics. White (1987) describes these two goals in greater detail, and the degree of success we had in achieving them. In this section, I go beyond the discussion contained in this reference and describe in some detail two aspects of the *ThinkerTools* experience that have not been emphasized elsewhere. In particular, I present some discoveries of "new" physics that have been made using the *ThinkerTools* software: one made by the students and one by the present author. The points I wish to make are that:

- physicists often don't know much more than even beginning students of physics, and that consequently
- to be effective, educational science software ought to be of genuine interest to "kids of all ages."

The two points above can be combined into just one: there isn't as much difference as is often supposed between teaching science – at whatever level – and doing research. In both activities, the protagonists – student and scientist, respectively – are attempting something quite difficult: to learn something new. In the student's case, one supposes that the new thing is already known, though not to the student; in the scientist's case, the knowledge is being acquired for the first time. This difference is not always very significant. What is often significant is the *manner* in which the student and the scientist go about their business. To the extent that they employ different methodologies and that different goals motivate them, they are likely to have very different views of the scientific enterprise. The student who memorizes the chemical symbol for iridium in order to regurgitate it on command differs in more than degree from the scientist who measures isotopic ratios of iridium in rocks in order to shed light on the untimely demise of the dinosaurs.

The main point of this paper is that the use of the computer may enable us, in many circumstances, to remove the barrier that often exists between "school science" and "real science," a barrier that has more to do with process and motivation than with content. We can do this by using the computer to acquire and process data, thus enabling students to perform and analyze experiments in ways that emulate the professionals. We can also do it by creating microworlds that abstract the appropriate concepts in compelling ways, and whose behavior the students and scientist can study with profit in much the same way. I shall illustrate this point by a few personal recollections of instances in which students and scientists have used the computer literally as a "thinker tool"—a tool to help them think about something—and in the process found themselves asking and answering questions they would never have thought of without its use.

One evening during the first piloting of the *ThinkerTools* curriculum, the sixth grade teacher who was working with the new material telephoned me to describe an observation she and the students had made earlier that day in class. They had been working with the one-dimensional microworld, and gone through the first three phases of the process described above. Thus, they had learned to manipulate the dot in such a way as to pass it through a target at a specified velocity. They had formulated a concise and powerful rule that enabled them to predict the final velocity acquired by a dot after an arbitrary sequence of impulses. They had also determined that frictional forces in the real world invalidate this simple rule, and had done a series of simple classroom experiments to investigate the effects of friction. Now, in the final step of the process, they were introducing a computer-generated frictional force into the simulation and were examining its effects on the motion of the dot. At this point, they made a discovery that I, the resident physicist and supposed subject-matter expert on the project, and the chief architect of the program they were using, had neither observed nor expected *a priori* on theoretical grounds.

What the students had learned was that if you give a dot two impulses simultaneously (to the right, say) and then let it drift, the friction will stop it in the same place as if you had first given it one impulse, waited for it to stop, and then given it another.

For the physics-minded reader, I must hasten to add that the particular force law we had chosen to represent friction on the computer was: $f=-kv$, in other words, a force *linearly proportional to the velocity*. This type of force law is not very common in nature (it corresponds, for example, to very low Reynolds-Number flow—the kind of thing you get when a very lethargic ant oozes slowly through a viscous medium like honey). In particular, it is neither a constant force (the form of choice for all known freshman physics texts that attempt to model sliding friction—commendable more for its ease of calculation than for any resemblance to actual forces), nor one proportional to the *square* of the velocity (the form that turns would-be home runs into routine fly balls, for example). *And the result that the students discovered holds only for such a linear force.* Which explains, though it does not excuse, why I was ignorant of it and did not discover it myself.

There is an interesting difference between Barbara White's and my reactions to this discovery and that of the students (and, for that matter, the teacher). We were considerably more curious about it, thought about it more, and generalized it in a way that did not occur to them. This difference is significant because it points up the fact that "scientific thinking" is more than observation and reporting of interesting phenomena. There is a kind of curiosity, and a sense of play in trying to solve some puzzle offered up by nature (or in this case by the computer), that was missing in the reaction of the teacher and class to their own discovery.

Because the distance that the dot will drift under the action of two impulses is independent of the time interval between them, it follows that, in a world of finite, equal-sized impulses, *the dot can only be made to stop in a finite number of (evenly spaced) locations.* For, if one impulse to the right moves it, say, one inch to the right, then two impulses, *whatever the time interval between them,* will move it two inches to the right, as will three impulses to the right followed by one to the left, 9 to the right and 7 to the left, and so forth. The same argument holds, obviously with respect to the up and down directions, and therefore the restriction to equal sized impulses, in concert with the linear friction law, have, in effect, quantized space, in the sense that the attainable "stopping locations" are not spread continuously throughout space, but are located at discrete locations.

That one can no longer stop the dot just anywhere once friction has been introduced is an interesting and surprising observation, but it is not one that either the students or the teacher made on their own. They did not carry out the generalization that they needed to notice that fact. Nor did they speculate on the following question: what happens when one progressively weakens the frictional force (by progressively reducing the constant k in the equation above)? How does the situation in which friction has been reduced to insignificance resemble that in which there is no friction at all? We know that in a world with no friction we can stop the dot wherever we want, so we might expect that with very little friction we could stop it *nearly* anywhere. In other words, we might anticipate that the "stopping locations" would move arbitrarily close to one another as the amount of friction was reduced. But that is not at all what happens!

Going back to our previous example, it is obvious that if we were to reduce the friction by one half the dot would drift two inches, rather than one, on the first (and every subsequent) impulse, so the stopping locations would be twice as far apart. As k tends to zero, therefore, the interval between stopping locations becomes infinite, and it is not possible to stop anywhere! In fact, in order to get the stopping locations to move closer together, as we originally expected them to do, we must *increase* k, rather than decreasing it. But clearly this does not approach the limit of zero friction.

Thus, we see that this simple problem of what happens under a linear friction law with quantized impulses is actually quite complex and may lead to some rather sophisticated reasoning about uniform approaches to limits. In other words, there

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is no such thing as a simple question, there are only simple answers! In actual fact, however, the students did not go very far on their own in investigating the discovery they had made, and it was so unexpected that Barbara and I did not fully capitalize on it, either. Still, it is rather remarkable that 12-year-old students were able to use the computer environment to make a genuine discovery, one that was unexpected by anyone, and that had interesting and non-trivial implications.

(By the way, the resolution of the paradox involving the zero friction limit is that although you may not be able to stop at any arbitrary spot, if the frictional force is weak enough you can arrange to move very *slowly* there. In other words, the unexpectedly non-uniform behavior of the limit is traceable to our insistence on singling out just those locations in space where the velocity of the dot can be made to vanish exactly. If we reduce this stringent condition, we can find a neighborhood of the origin in which the velocity can be made as small as we like, and as the friction vanishes, this neighborhood will become infinite.)

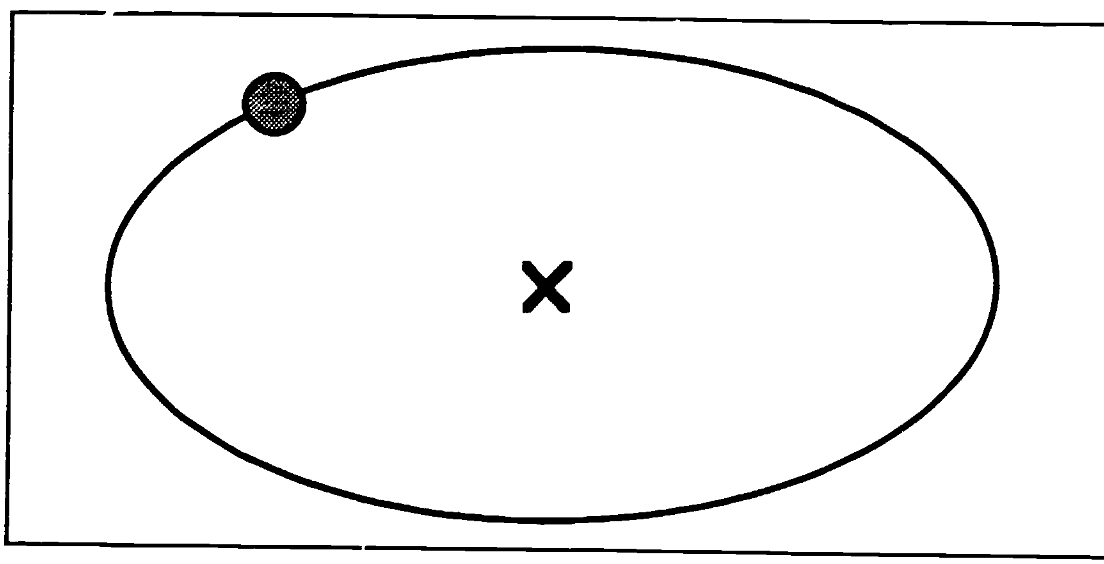
So that was the discovery that the students made. I made mine in a very similar fashion, namely by observing something interesting about the behavior of the computer. Of course, I know more physics than they did, so I was able to prove that what I had seen was *supposed* to happen, that it was, in fact, trivial in the sense that it was a consequence of $F=ma$. Furthermore, once I had proved it, I was able to generalize my observations to systems that the computer wasn't powerful enough to simulate. For students at the sixth grade level this would have been impossible, but the process could easily have been replicated, given suitable guidance, by a high school physics class.

When we first started on the *ThinkerTools* project, we had wanted to build a sort of "physics erector set" that would let one build physical systems out of arbitrary configurations of very simple components, set certain parameters like the strength of various forces and perhaps even fundamental constants such as the speed of light, and then turn the systems loose and see what they did. The physical components were to be very simple, indeed. There were only two of them, and we called them "dots" and "dashes." The dots were mass points and the dashes were massless rigid rods connecting pairs of dots. In an obvious extension of this environment, the dashes were to become springs of arbitrary stiffness, first linear and subsequently obeying some arbitrary force law. Out of these simple components, we figured, we could build almost anything.

It turned out, though, that simple computers like the Commodore or Apple II would be incapable of handling the dashes: the computations were too complicated to be done in real time. So we had to be content with putting in just the dots and a few external forces like gravity and friction. In fact, that turned out to be quite enough to support eight weeks of curriculum for sixth graders, so we were not stuck. But it was annoying that we hadn't been able to build the environment we really wanted, and after the project was over we made a first step toward implementing the missing dashes: we added an elastic force between the dots. In other words, we gave each of the dots on the screen the property that it attracted all the other dots with a force that varied linearly with the distance between them. Now we could create a universe of equal-mass dots connected together in pair-wise fashion with ideal, zero-length rubber bands.

The linear force that we added to *ThinkerTools* has been studied extensively since the time of Newton, so we certainly didn't expect it to contain any surprises. We were only putting it in so that we could have some fun playing with our physics erector set. One of the first things we tried was to put a dot on the screen and to attach it, via a computer-generated rubber band, to an immovable "peg," which we constructed out of one of the X's that we had used as a target in the games we had made for the kids. The X, not being recognized by the program as a movable object, just stayed wherever you put it, which was handy for observing things, since the dots had an annoying tendency to float off the screen if you didn't anchor them down.

If you place a dot and a peg on the screen and create an elastic force between them, the dot will just oscillate back and forth along a straight line. This behavior is so well known that it has even been given a special name. It is called simple harmonic motion. If you now give the dot a "push" in some arbitrary direction, using the joystick, it will go into an elliptical orbit with the peg at the center (not one of the foci) of the ellipse. If you have the dot leave a wake, it will trace out an orbit that looks like this:



This behavior, too, is well known and expected. It is in all the books. But, when you start adding additional dots, the situation becomes too complicated for the books, and things start getting interesting. Adding just one more dot, after all, means adding two more forces: one between the two dots and the other between the new dot and the peg. So the motion of the old dot is affected by the presence of the new one, and its orbit is no longer an ellipse. The orbit has been perturbed by the presence of the new dot, just as the earth's orbit around the sun is perturbed by the presence of the moon and the planets. But in the case of the dots all the forces are of the same strength, so the perturbing force is just as strong as the original dot-to-peg force, and we cannot neglect it in any approximation.

It is not surprising, then, that the motion of the two-dot system is complicated. In fact, it comes as no surprise that the dots trace out complex orbits that don't "re-enter," that is, they never come back on themselves and retrace the same path.

Instead, they eventually fill up a region of the screen, and I had fun trying to guess what shape that region ought to be, but before I could figure it out I tried adding a third dot, and that led to a very surprising effect. With three dots one must deal with a total of six forces: three between each of the dots and the peg, and three between the different pairs of dots. So the situation is even more complicated than before, and we might expect the motion of the dots to reflect that fact. It turns out, though, that the motion is much *simpler* in this case—in particular, all three orbits are re-entrant! They form closed curves that are more complicated than ellipses, in fact they often look quite different for each of the different dots, but all three dots retrace their respective paths exactly after a time interval that is the same for all the dots.

Naturally, I was very excited when I discovered this—I didn't understand it at all, but it was obvious that the simplicity in the behavior of the three dots was somehow buried deep inside the equations governing their motion. I tried four dots—the orbits did not re-enter. An obvious hypothesis occurred to me: maybe odd numbers of dots lead to re-entrant orbits and even ones don't. This turned out to be wrong—five dots don't re-enter, either. Nor do six, and that unfortunately exhausted my limited computing capacity. I had to fall back on solving the equations.

It turned out that it was quite easy to "predict" this phenomenon, once I knew it existed! It took about two pages of algebra to show why it happens. And once I had written the equations I could generalize the result. In particular, I could prove that—aside from one, which is a special case—you get re-entrant orbits whenever the number of (equal mass) dots is *one less than a perfect square!* So eight dots—each attached to the seven others, as well as to the peg, by a rubber band—will also travel in re-entrant orbits, as will fifteen, twenty-four, and so forth.

CONCLUSION

When we designed the *ThinkerTools* microworlds we had two primary goals in mind:

1. To create a sequence of simple environments, encompassing increasingly general physical phenomena, that students could manipulate directly and come to understand more or less completely;
2. To provide, within these environments, psychologically salient representations of such abstract quantities as velocity components, and to create activities that would lead the students to think about the microworlds in terms of these quantities.

Though we didn't realize it at the time, in retrospect it seems obvious that the microworlds we were building were sufficiently complex that students were likely to make discoveries about them that were unknown to us. This will become even more likely when students are given the capacity to build their own microworlds, and it is therefore essential that any curriculum based on computer microworlds anticipate such discoveries and be prepared to use them to promote scientific curiosity and exploration.

When the students discovered a peculiar property of the linear friction law we were caught flat-footed. We were unprepared to take full advantage of the discovery. The teacher reminded the class of what they had been taught about the "scientific method"—first you make a hypothesis, then you do an experiment to verify the hypothesis, and so on. But that was precisely what the students were *not* doing in this case—they had just been "playing around" and had discovered something interesting. They didn't have a formal hypothesis, and they weren't doing a controlled experiment, they were just having fun and exploring.

It would have been interesting, at this stage, if we had directed their exploration. We could, for instance, have challenged the students to stop the dot at some point on the screen that was in between "stopping points." What would they have learned from this experience? Would they simply have become frustrated and given up, mumbling something like "the computer doesn't work?" Or would they have realized that their inability to stop where we had asked them was related to the discovery they had made? Would they have thought of changing the strength of the computer-generated frictional force (which they already knew how to do), in order to try to solve the problem? If they had done this, what effect would they have expected it to have?

Unfortunately, we didn't do these things. We hadn't anticipated the discovery and were unprepared to follow up on it. In fact, Barbara and I were not even observing the class in which it happened. But perhaps it didn't really matter—the students had the experience, for the first and last time in most cases, of making a "real" discovery—one that neither we nor their teacher had known about ahead of time. The next day, Barbara and I visited the class to congratulate them. By coincidence, I was scheduled, later in the day, to give a talk about *ThinkerTools* to a group of former colleagues of mine—scientists and engineers from a nearby research laboratory. I promised the students that I would tell of their discovery and made the prediction that no one in this distinguished audience would know it in advance. And no one did!

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5

How Can Science Teachers and Science Educators Use Information Technology?

Carl F. Berger

The four chapters up to this point have described tools for science education—such as telecommunications, computer-based learning, microcomputer-based laboratories, and optical storage technologies. The authors concentrated on how students can use those information technologies to learn science. How can we as science teachers and science educators use those tools? To illustrate how you might adapt information technology to your own situation, this chapter describes what you can do with information technology in science teaching and research; also described are reviews of projects that demonstrate how teachers can use information technology. Hopefully, you will also generate some new ideas for your own work that you derive from reading this yearbook.

Rationale for Using Information Technology

We should not assume that just because we have new information technologies that we should use them. We might reasonably ask: "Why use this new technology at all? I'm overworked as is and the technology I'm currently using is doing a great job." In addition, it is unreasonable to think that every use of a microcomputer is a good use. How then should we select what to use? A better question might be, not what to use, but why, when, and how to use this technology?

You should consider using an information technology when:

1. The use of the technology makes your life easier.
2. The use of the technology improves the quality of your work (even if it doesn't make your life easier or it even makes it tougher).
3. The use of the technology helps you do something you couldn't do before.

If the use of the technology doesn't meet those criteria, then there may be another reason to use it—it is fun.

You should keep an open mind and maintain a positive attitude when considering the use of information technologies. Be receptive to change and be willing to try out new approaches to teaching and research. For some of us, however, being receptive is not the problem. All too often when we get a new piece of technology we try to use it with everything. We are like a child with a hammer who believes everything needs a good pounding. Rather than using that philosophy, we should first think of what we need to do and then evaluate the technology. As you read through this chapter and this yearbook, reflect on the tasks that you perform and ask: "Can I do (whatever the activity or task is) with...(whatever the technology is)? Can I do this task easier, faster, or better with...? Wouldn't it be fun to try this activity with...?" With this attitude and an open-minded view of the use of technology the ideas this chapter presents should make good sense.

Applications for Science Educators

There are many ways that you can use information technology to help you teach science or to conduct research in science education. A complete list is beyond the scope of this chapter; however, the following are important applications. You may use information technology to do the following:

1. Complete everyday tasks.
2. Understand and improve conceptions of science and science teaching. Information technologies can modify our own and our students' misconceptions, broaden our thin conceptions (those conceptions that, while being correct, are based on limited information and apply to a limited application of a concept), and introduce new conceptions of science and science teaching.
3. Manage data collection and complete tasks related to managing instruction.
4. Provide information resources that we couldn't otherwise access.
5. Help us to conduct research in our classrooms on how and what our students learn.
6. Assist in the production of instructional materials.
7. Provide for the reproduction of up-to-date materials for our courses. We can use information technologies to revise materials year after year so they are current rather than generate the materials from scratch each year or use old materials even though they are out of date and need revision.

There are information technologies that can help you with all of those tasks. Previous chapters introduced those technologies and how science students may use them, and by now you should be familiar with the concepts behind those systems. In this chapter, therefore, I shall focus on examples of their use by science teachers and science educators.

The selection of software and hardware are important considerations in the application of information technology in the classroom. All computers can run software that can be used for managing instruction or for organizing and analyzing information. Likewise, getting and connecting hardware putting together all the cables and peripheral devicec) are often major stumbling blocks in using some of the newest and most exciting technologies. The following sections will seprately present these software and hardware considerations.

SOFTWARE

Management Software

Management software is designed to help carry out the daily tasks or routines in the classroom, and is high on the list of software that makes teaching easier. Spreadsheet programs, which you can use to manage student grades, are at the top of that list. There are specialized grade-book programs that are very effective. A general spreadsheet gives us more control over the design of the grade book and can provide the flexibility that we often need in the science classroom where we record not only quizzes and tests but lab and other hands-on work.

Using an integrated package such as *AppleWorks* or *Microsoft Works*, we can develop a personalized grading system, generate reports for parents, and submit grades on disk (if the school permits). In a spreadsheet, we can record the student's grades as a row of data, just like in a grade book (Figure 1). Unlike a grade book, however, the computer can automatically weigh the scores, calculate

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1						Labs submitted				total				
2	ID	MID/60	%	INAL/3	%	C&B	PG&L	P&A	W&C	# c	PROJECT	%PROJ	SUM	
3	3344	60	100	33.0	100	1	1	1	1	4	10	100	100	A
4	4321	59	98	32.0	97	1	1		1	3	10	100	98	A
5	4242	57	94	33.0	100	1	1	1	1	4	10	100	98	A
6	1134	59	98	31.5	95	1	1	1	1	4	10	100	98	A
7	3321	59	98	31.0	94	1	1	1	1	4	10	100	97	A
8	3331	58	96	31.5	95	1	1	1	1	4	10	100	97	A-
9	3142	54	90	32.0	97	1	1	1	1	4	10	100	96	A-
10	2341	54	89	31.0	94	1	1	1		3	10	100	94	A-
11	2222	55	92	31.0	94	1	1	1	1	4	9	90	92	A-/B
12	1231	56	93	26.5	80	1	1	1	1	4	10	100	91	B+/A
13	2234	54	90	30.5	92	1	1	1	1	4	9	90	91	B+/A
14	1233	57	95	27.5	83	1	1		1	3	9	90	89	B
15	3431	57	95	24.0	73	1	1	1	1	4	10	100	89	B
16	4223	48	80	26.0	79	1	1	1	1	4	10	100	86	B
17	4343	48	80	24.0	73	1	1			2	10	100	84	B
18	4444	40	67	24.0	73	1	1		1	3	10	100	80	B
19	1322	52	87	23.5	71	1	1	1	1	4	8	80	79	C
20	3232	41	68	21.5	65					0	10	100	78	C
21	4312	31	52	26.5	80	1	1	1	1	4	10	100	77	C

Figure 1: A spreadsheet of student grades

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sub scores and means, and produce standard scores that are useful in developing both term and year grades. With another part of the integrated package, we can graphically display the distribution of class scores and indicate to students and their parents or guardians the location in that distribution of a particular student. Finally by setting up a merge file of information from the spreadsheet, we can prepare letters for students and parents that include information about the student's achievement that communicates clearly to parents, students, and administrators. As with any multipurpose tool each piece is less powerful than its independent counterpart, but the ability to transfer a piece of information in one function to another part of the package can justify its use.

The word processor and database components of integrated packages are also useful for managing instruction. Many teachers find the word processor to be the most valuable tool for processing information. We use word processors to prepare print materials, memos, correspondence, and newsletters.

Databases are useful for keeping equipment and chemical inventories, records of botanical and zoological specimens, bibliographies, and personal data on students. You may design and enter lists of materials into a database; conversely, some publishers and suppliers provide databases of their materials. The databases the publishers provide sometimes link their materials to the objectives of their program. Chemical suppliers sometimes provide databases that describe the chemicals and their quantities, identify the laboratory activities in which they are used, and recommendations for safe storage, use, and emergency procedures in case of an accident. Once the information is in the database, you may use the database to locate information and to organize the information according to particular characteristics. Some databases allow you to calculate simple statistics and to produce graphs.

Research Software

Some software makes it easier to do research. This group of software includes statistical packages, special data-display packages, course-building software, and modeling software. As Robert Tinker demonstrated in Chapter 1, these software packages are extremely powerful and can be very useful for us in generating experiments for students and broadening our own thin conceptions. It's fascinating to think of students thinking and talking with us about "R-squares" or the amount of variance of the dependent variable explained by one or more independent variables. Using powerful statistical software, a student could plot the data along with us and argue about the spread of data and individual data points that could produce a low R-square. Wouldn't that be exciting?

That example, however, highlights the sophistication that such software can bring to middle, junior, and senior high schools. We must use these tools to prepare students for the work place. Consequently, we must also develop techniques to teach the use of these powerful tools to our students.

We can use these same tools that we use with classroom experiments to solve practical classroom problems through action-oriented research. For the first time, we can easily carry out sophisticated research designs to determine what variables influence student learning, by adjusting classes for differences in students and investigating the variations in the way we work with these students. With this ease comes a warning: statistical analysis doesn't replace good research design. The results are only meaningful when examined using thoughtful research questions and carefully constructed research designs. Multivariate statistics might be complex and impressive, but when used improperly it can obscure any meaningful interpretation of the results. Science teachers and educators should encourage action research, but also ensure that such research is soundly designed.

For the teacher who is truly interested in classroom research there are new programs that help gather data on the behavior of the students. These programs automatically record the behaviors and display them in a fashion that is understandable to teachers and students. For example, Figure 2 displays output from a program that represents the ability of elementary students to estimate on a linear scale.

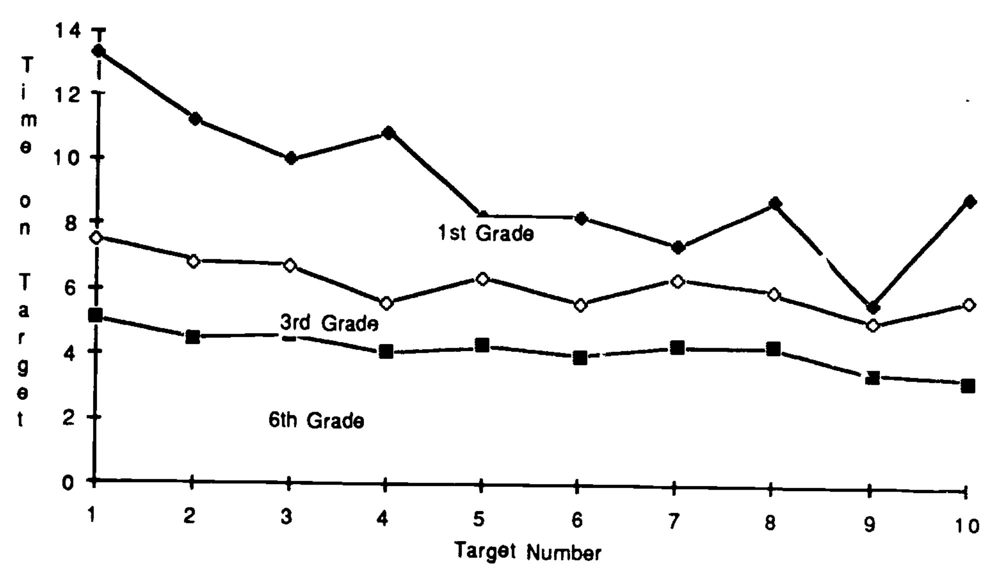

Figure 2: Student gathered data from a micrcomputer on elementary school student's ability to estimate on a linear scale

Software programs that introduce students to behavioral research techniques are entering the classroom, and from their use, it is obvious that students enjoy gathering and analyzing data on human behavior (including their own). Both students and teachers can conduct such research without the addition of any hardware beyond a basic microcomputer. To optimize the potential benefits of using technology in the science classroom, however, additional hardware becomes a requirement.

Presentation Software

Developing materials to present complex ideas can be difficult for any science teacher. Information technologies, however, can help in preparing our handouts, overheads, and other materials. By presenting the information visually, as graphical representations, information technology can represent the ideas in ways that make them easier to understand than oral or written communication. A good graphing program, a good drawing program, and a good desktop publishing program are tools that help us prepare effective presentations.

What makes a desktop publishing program so useful is its ability to integrate text and graphics in a very professional way. Figure 3 is a graph from a textual passage in an instruction manual on how to tell if your experimental data are appropriate.

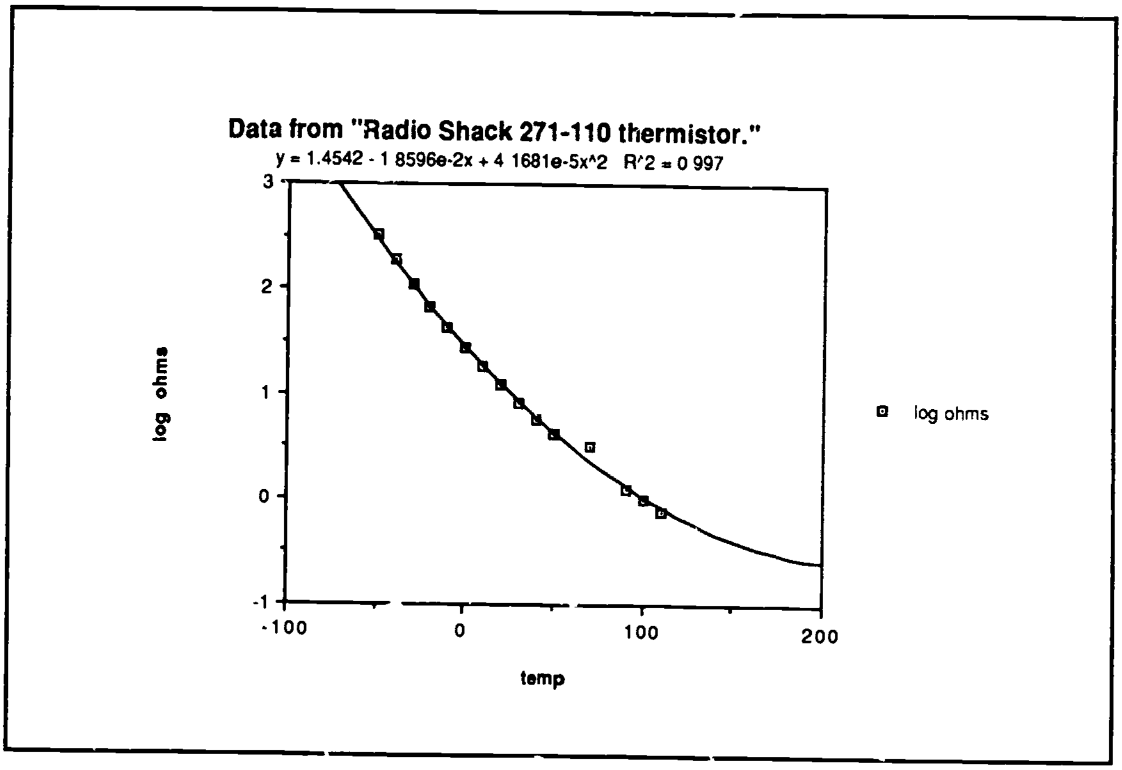

Figure 3: An integrated presentation of the analysis of student gathered data indicating a faulty data point

In such cases, a picture is truly worth a thousand words. The text describes that the Log of the resistance indicates that one of the data points is faulty. Even though we have r^2 greater than .995 (which means that 99.5 percent of the variation in temperature can be predicated by the resistance of the device—better than Ivory™ soap!), the graph makes it easy to see which is the faulty data point.

We can use graphing programs and drawing programs to represent information visually, which many people find much easier to understand than words. Graphing programs allow you to represent data in a variety of forms including bar graphs.

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line graphs, and pie graphs. Drawing programs allow you to draw pictures representing concepts such as food webs and energy transformation. You can integrate the graphs and pictures into textual explanations, using word processors and desktop publishing. You may also use the output from some simulation programs to illustrate presentations. With a large monitor or projection system, you can use the computer as a dynamic blackboard to illustrate demonstrations, oral explanations, and classroom discussions.

HARDWARE

The addition of peripheral hardware such as a modem, an optical storage device, an analog to digital converter, a video disc, or a tape recorder can expand the use of technology in classrooms beyond the commonplace to the cutting edge of information technology. Some of these peripherals are inexpensive and easy to use and others are expensive and hard to use. Unfortunately, these two variables are not closely related. In fact, an inverse relationship is appearing in which some of the inexpensive hardware is hard to use and the expensive hardware is easy to use. Apparently it takes complex equipment to make use easy. Prior to purchase, you should try out the hardware and software to make sure you can use it.

For example, connecting an inexpensive game paddle to the game port and entering a four-line basic program is sufficient to demonstrate analog to digital conversion with any Apple computer. To make such hardware easy to use and effective as a learning tool, however, often calls for sophisticated software.

On the other hand, connecting an expensive videodisc to a computer requires a complex program that makes it simple to use this technology. Once connected, the complexity of operating a videodisc player is simplified, and we can use the videodisc to illustrate lectures and discussions, as an audiovisual tutorial for science content, and to demonstrate science experiments.

The brand of computer often dictates the kind of software and peripheral hardware we can use. For example, hardware that connects analog to digital converters to Apple computers through the slots inside the computer will not work with other brands of microcomputers. Researchers, however, are developing analog to digital converters using serial ports, that can work with any microcomputer. Using such a serial port allows us more freedom and flexibility in the kinds of experiments we can do.

Analog to Digital Conversion

Analog to digital conversion allows a broad range of data gathering; however, it is just starting to be used in science teaching. For example, one teacher used the Apple game port and a short program to measure extremely high resistances. By connecting two alligator clips through wires to the game port, she was able to measure the resistance in a plant. On one dry day in winter the students noticed that as they talked to the plant the resistance changed. Rather than telling the students it was the proximity of their bodies that changed the resistance, the teacher used the phenomena to work up a short but effective unit on identifying and controlling variables with examples from such pseudo science areas as "plant auras" and "Kerilian photography." Thus for less than a dollar and a short program the teacher was able to use the microcomputer to help her present an

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important science concept. Introducing water to the plant is the variable that changes the resistance. This example illustrates how a teacher can use the computer to engage students in doing science and to help them discover a scientific concept. Microcomputers can be fun and can help us teach and our students learn science.

Telecommunication

Connecting our classrooms to the rest of the world is an exciting prospect for any science class. With telecommunications software and hardware, science students can use the microcomputer to communicate with students in other classrooms in their school and in schools throughout the world. In Chapter 2, Cecilia Lenk describes how science students can use telecommunications. Science teachers and science educators can use this same gateway to interact with other science teachers, science educators, and scientists. Several universities across the country have electronic conferences that help each other share information on issues such as curriculum, equipment, and safety. The dialogue in Table 1 effectively demonstrates the usefulness of an electronic conference. This dialogue is from the MSTA Forum sponsored by the Michigan Science Teachers Association, supported by the University of Michigan, and organized by Steve Shaffer, of Ann Arbor Schools, and Lawrence Stackpoole, of Detroit Public Schools. In the dialogue, one teacher has inquired about the safety of contact lenses in the lab and other teachers have responded to help resolve the problem. Notice that this is not a direct conversation but occurs over several days and even weeks. Also notice that Dale Wolfram probably has an older brand of computer because his comments are in uppercase.

Optical Media: Videodisc, videotape, and CD-ROM can make science teaching interactive. A teacher can use optical media in a demonstration mode to illustrate a presentation. Videodiscovery (1983) and Optical Data Corporation (1986) have produced discs that are visual databases of still and motion images that cover science topics. Sherwood (1986) has demonstrated how scenes from popular films, such as "Raiders of the Lost Ark," can help teachers explain science concepts.

Optical media, however, also can help science teachers improve their teaching. In one of the most interesting approaches, Mary Budd Rowe (1987), in a project supported by the Carnegie Foundation, produced the Science Helper K-8 that includes lesson plans for science activities on a CD-ROM. This disc includes more than 1,000 activities for Kindergarten through grade 8 from twenty-five years of NSF projects. To access the activities, you put the disc into a CD-ROM player attached to a microcomputer. You can locate individual activities by searching a database that is part of the disc. Imagine searching hundreds of lessons for particular topics of content, processes, and concept. The ability to enhance our curriculum is enormous.

The American Chemical Society (1986) has produced a videodisc that includes pictures and illustrations for how to build the hardware for microcomputer-based laboratory investigations. Other researchers have proposed using optical media training for teachers. Poor implementation of curricula and teaching strategies is one of the biggest barriers to improving science teaching. Many of the curricula

Table 1

Item 55 22:11 Jan 18/87 12 lines 16 responses
Dale Wolfgram
USE OF CONTACT LENSES IN THE LABORATORY

I HAVE SOME CONCERNS ABOUT THE WEARING OF CONTACT LENSES IN THE LAB. MOST COLLEGES DO NOT ALLOW STUDENTS TO WEAR THEM. ARE ANY OF YOU AWARE OF HIGH SCHOOLS WHICH HAVE TAKEN A SIMILAR STAND? I CAUTION MY STUDENTS NOT TO WEAR THEM ON LAB DAYS AND RATHER WEAR THEIR GLASSES, BUT MANY STUDENTS DO NOT OWN GLASSES. I PERSONALLY BELIEVE THAT A PERSON WEARING CONTACT LENSES SHOULD HAVE A PAIR OF GLASSES AS A BACKUP AND MY EYE DOCTOR SUPPORTED THIS POINT OF VIEW. HOW SHOULD WE HANDLE THE CONTACT LENS ISSUE? THE LAST TIME THE STATE CAME ALONG AND DICTATED THE USE OF SAFETY GOGGLES BECAUSE MOST OF US COULD NOT GET OUR ADMINISTRATION TO PURCHASE THEM UNTIL THE STATE PASSED A LAW. WILL WE HAVE TO WAIT FOR THE STATE TO PASS A LAW ON THIS ISSUE? I KNOW THERE WILL BE SOME HOSTILE STUDENTS AND PARENTS IF WE MAKE THIS A RE-QUIREMENT FOR WORKING IN THE LAB.

Related items: 78
16 responses
Jan 19/87 05:24
55:1) Dale Cryderman: Agreed! I also emphasize the need for glasses instead of contacts on lab days, but a definitive statement from MIOSHA or Dept. of Ed. would be helpful to underscore and enforce this safety step.
Dale C.

Jan 19/87 20:14
55:2) Peter Moskaluk: Yes a statement from MIOSHA would be a worthwhile one. Unfortunately the safety goggles mandate came as a result of some very serious incidents in labs. I hope that a state wide regulation would come before the fact.

Jan 20/87 07:52
55:3) Steve Schaffer: Although I have often heard that contacts were bad, I never heard very convincing arguments as to why. Maybe we need to build a strong case for them based on logic rather than statistics. Anyone want to give it a try.

Jan 27/87 20:36
55:4) Marie Rediess: I have had the same concerns about contact lenses in the lab. So far, the best that I have come up with for those students without glasses is to send a letter home warning their parents of the possible hazards, and requiring parental permission before they can participate in another lab. There has not been much grumbling yet, but it is a new policy with my class this year.

Jan 27/87 21:10
55:5) Steve Schaffer: Marie, could you VERY briefly summarize the possible hazards? I still don't have a very good feeling as to what they are.

Jan 29/87 19:20
55:6) Marie Rediess: The main concern is that if something splashes in the eye, the eye would spasm shut, making it impossible to remove the contact. The material would then be confined behind the lens and could not be washed out. A minor injury could turn into a major one if a hazardous liquid remained very long on the cornea. Also, many soft contact lenses are water soluble and will absorb vapors from the lab, especially organic compounds, and may cause irritation or injury. If the student is not wearing contacts, then the eye can be washed out. Hope this helps. I work primarily with formaldehyde compounds, and frankly, it scares me silly that someone might get splattered on the eye.

Feb 24/87 12:26
55:7) Steve Schaffer: Thanks, that is the best explanantion I have seen to date. If more explanations like this were made, maybe fewer people would wear contacts in a lab!

Feb 24/87 19:32
55:8) Marie Rediess: Unfortunately, it doesn't really work. I sent a letter home last week saying the very same thing. The mother said as long as the student was wearing goggles, she couldn't see how it could hurt to wear contacts. If the girl's eyes got irritated--well, she could just take them out. Most of the kids take me seriously though. What I wonder is whether the absorption is cleaned out the next time the contacts are sterilized or is it cumulative?

Feb 24/87 22:59
55:9) Richard Lewandowski: Sounds like a good lesson topic here. Solubility, reactivity, diffusion, and temperature in a plastic matrix with water solutions: would you be a walking experiment: Parents might be more supportive if you told them chemical degradation might force them to replace lenses more frequently.

Feb 25/87 20:51
55:10) Marie Rediess: Thank you, Richard. I'll try that approach, too.

Feb 27/87 17:55
55:11) Randall Raymond: That is an excellent idea for a science project as well. Thanks Rich!

Jul 22/87 01:31
55:12) Barbara Ellies: After teaching biology for many years and much dissections just this year one of my students was absent after 2 days of pig dissection. When she returned the next day her one eye was very red. Her mother had taken her to the doctor and had found that her SOFT CONTACT LENSES had absorbed the preservative vapors--I use pigs from Carolina packed in Carosafe. The girl was not upset but I was!

Dec 06/87 00:26
55:13) Dale Wolfgram: THANK YOU BARB. THAT IS WHAT I NEEDED, A CONCRETE EXAMPLE OF A CONTACT LENS ABSORBING VAPORS CAUSING EYE INJURY. I PLAN TO USE YOUR ITEM TO DOCUMENT THE NEED FOR A BOARD OF EDUCATION POLICY IN OUR DISTRICT. ARE THERE ANY MORE STORIES OUT THERE THAT MIGHT SUPPORT THIS STAND?

Apr 28/88 15:26
55:15) Dale Wolfgram: I WOULD LIKE TO KEEP THIS ITEM ALIVE. IF ANYONE HAS ANYMORE DATA TO SUPPORT THE BANNING OF CONTACT LENSES IN THE CHEMISTRY LABORATORY, I WOULD LIKE TO HEAR FROM YOU. GOGGLES DO NOT NECESSARILY PROTECT A PERSON FROM EYE INJURY WHILE WEARING CONTACT LENSES.

May 02/88 21:40
55:16) Richard Lewandowski: Below you will find the only hard reporting of potential damage to the eye of contact lens wearers I could find in a Knowledge Index search of ERIC, MEDLINE AND HEILBRON databases. I looked at others but had no hits on the keyword, contact lenses. After wearing contact lenses for over 28 years myself, in all types of science classrooms, I think there is far greater potential for damage to other moist tissues of uncautioned students in poorly vented areas. The only chemical damage I have sustained has been from incomplete rinsing of the enzyme that I use to clean my lenses, and that has been a temporary, 24 hours or less without wearing, problem.
Safety in the scanning microscopy laboratory: 1984 update. AUTHOR: Barber, V.C. CORPORATE SOURCE: Dept. Biol., Mem. Univ. Newfoundland, St. Johns, Newfoundland AIB 3X9, Canada JOURNAL: Scanning Electron Microsc., Issue 4, Pages(s) 1719-1722, PUBLICATION DATE: 840000 LANGUAGE: English ABSTRACT: Recently identified

hazards of osmium fixatives, formaldehyde (especially towards wearers of contact lenses), epoxy-resin embedding materials and photographic chemicals are described, and necessary precautions are stressed. (18 references) (L.C.F.) IDENTIFIERS: electron microscopy - scanning, safety in, review; hazards - in scanning electron microscopy laboratories, review; safety - in scanning electron microscopy laboratories, review

RESPONSE, FORGET, OR PASS:

DO NEXT?

developed during the last three decades have proven effectiveness but few teachers are using those materials. Optical media can depict classroom scenes that model a variety of approaches to teaching science, that demonstrate how to organize materials and manage the classroom, and that present background information on the concepts in the curriculum. Optical media can bring the science classroom to teachers who are learning new instructional methods as no other approach can. Using interactive video, an optical disc controlled by a microcomputer, teachers could explore scenarios on new approaches to teaching science.

CONCLUSION

This chapter describes only a few of the many ways science teachers and science educators can use microcomputers to manage instruction and to conduct research. The students do not get to have all of the fun. There are many applications of information technology that we can use to improve science teaching and learning for our students and ourselves.

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6

Status of Use: Microcomputers and Science Teaching

William E. Baird

INTRODUCTION

Between 1980 and the Spring of 1985, the number of computers in use for instruction in U.S. public and non-public schools increased from one or two thousand to over one million (Becker, June 1986). The speed with which schools have acquired microprocessor-driven tools is astonishing. Acquisition of hardware, however, is not equivalent to curricular innovation. Before classroom change can occur there must be teacher acceptance and training. Before computers can significantly affect learning, there must be effective software. Before computers can enhance students' skills and knowledge, there must be successful integration of hardware, software for students, and software for teachers. The Johns Hopkins Center for Social Organization of Schools (Becker, 1986a) found that between the spring of 1983 and the spring of 1985

- the number of school computers quadrupled from 250,000 to over one million,
- three-quarters of those schools that had not previously used computers began to do so,
- the proportion of secondary schools with 15 or more computers jumped from 10 percent to 56 percent,
- the proportion of elementary schools with five or more computers went from seven percent to 54 percent, and
- about 500,000 teachers used computers with 15 million students during the 1984-85 school year in American instructional programs.

Using data collected from more than 10,000 teachers in a probability sample of more than 2,300 U.S. elementary and secondary schools during the spring of 1985, Becker (1986a) discovered a ratio of roughly one computer for every 40 students.

In addition to the Johns Hopkins database, we shall examine two other major national surveys of science teachers. One was a study by Iris R. Weiss (1987), who directed the 1985-86 National Survey of Science and Mathematics Education for the National Science Foundation. This study used probability sampling in two stages to select 6,156 teachers (75 percent return) from grades K-12 in all 50 states. Weiss divided the teachers into domains by subject and grade level, and gathered data on availability of resources, inservice education, and use of calculators or computers.

The National Science Teachers' Association (1987) assembled the third database and used 8,539 secondary science teachers. In August of 1985, the NSTA mailed 48,427 survey forms to all science teachers whose names were in the NSTA register. The study drew a stratified random sample of 8,539 teachers from 2,211 high schools from the 26,000 usable surveys the teachers returned. Stratification was by school size, grade range within the school, and whether the school was public or non-public. The science teachers indicated on the survey whether or not they used computers. The data do not indicate how many sections or even in which subjects the teachers use computers regularly. For example, if a physics teacher teaches three sections of physics and indicated that a computer was used during the classes, there is no way to know if the teacher uses computers mainly in other subjects taught or even in all three physics sections. Thus the NSTA data reflect "potential" computer use.

In examining these sources, we shall learn that science teachers are not the heaviest users of computers in the schools. We shall examine science teachers' uses of computers by subject taught, type and size of school, and their perception of the adequacy of their computer training. From these and other surveys, we may infer some of the barriers to more widespread and effective uses of microcomputers and other technical tools by science teachers.

If computers are to enrich the learning environment, schools must equip them with effective software and place them in the hands of teachers who recognize the limitations of computers as well as their potential. Preservice and inservice training has not kept pace with the development of technology for teaching. Consequently, new teachers are entering classrooms without a working knowledge of the potential of microcomputers in that environment. As the quality of software continues to improve, teacher training must include positive experiences with good science software that developers have integrated effectively into the scope and sequence of the classroom learning environments (Gleason, 1987).

This chapter will explore the status of use of microcomputers in science teaching. To do this, we must take a look at the previous decade and examine where we were when calculators and microcomputers became available for use in science classrooms and laboratories. We shall then look at current patterns of use as reflected by national surveys. Finally, we shall attempt to extrapolate current trends and make projections of future use.

ERIC

THE WAY WE WERE: USE PRIOR TO 1982

To appreciate the current status of computer technology in education, it helps to look back. We don't have to look very far back, however, for microprocessors have moved across the 1970s and 1980s like a meteor. In their book *Fire in the Valley,* Paul Freiberger and Michael Swaine (1984) describe the progression of microcomputers from the garages and hobbyist playrooms of California to the boardrooms of Fortune 500 companies. The book tells the story of young men, who were not model students, creating a revolution in education. Figure 1 (Frieberger and Swaine, 1984) is a timeline of key events in the history of computers. Note that only about 12 years have elapsed since the first appearance of microcomputers in pre-college classrooms. It is unlikely that hardware design, software development, teacher training, and other critical parameters of technology have reached equilibrium in such a short time.

Hardware

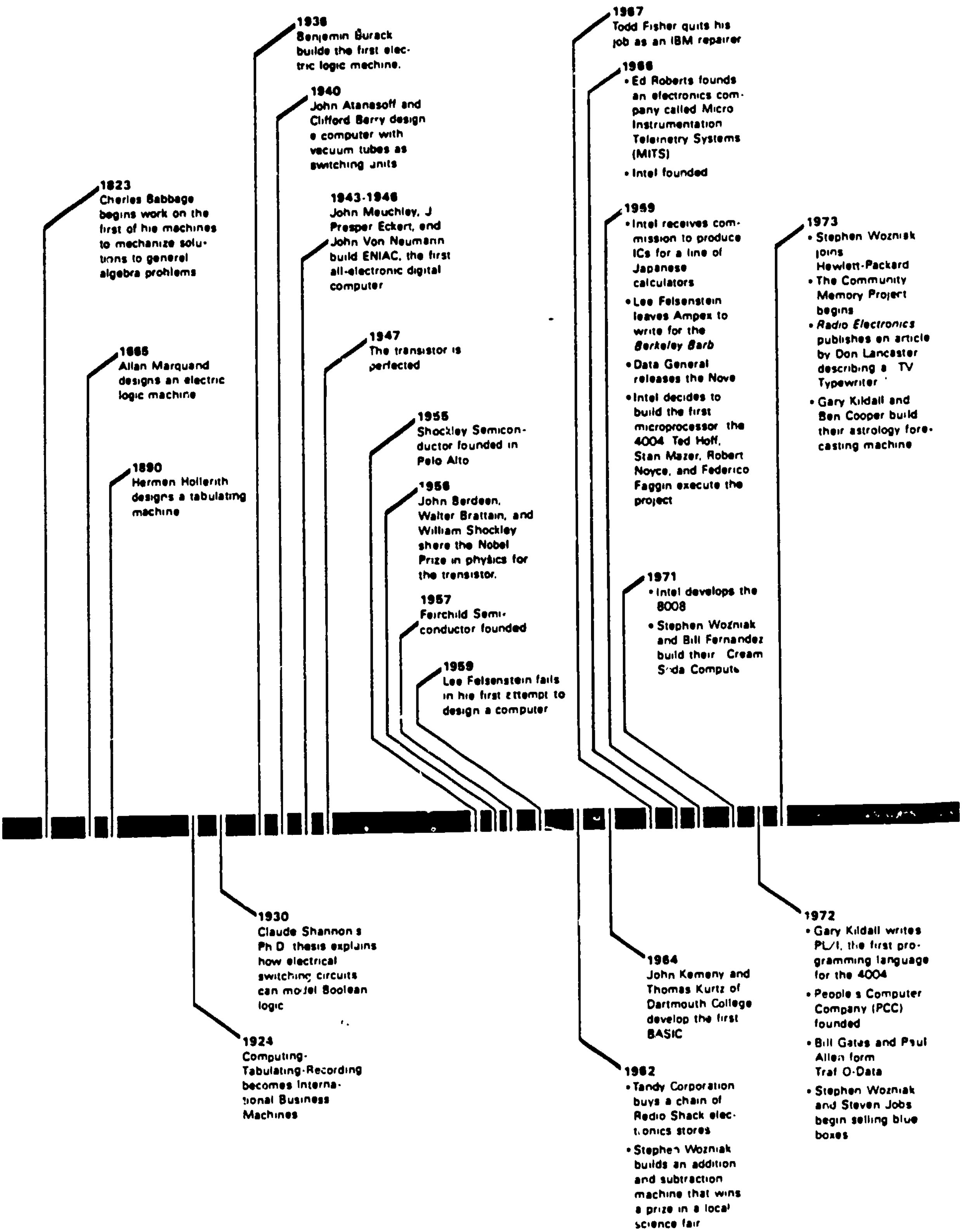
During the early 1970s, access to computing in pre-college classrooms was rare and available only through time-sharing on mainframe machines. Prior to the appearance of microcomputers in the late 1970s, most pre-college science teachers had never heard of classroom computers. A few electronic tinkerers made limited use of the tiny microprocessors and built computers from kits. Typically, these were limited to four or eight kilobytes (K) of random-access memory (RAM). The programs consumed most of the memory, leaving little room for data.

The first "microcomputer" was sold by John Torode and Gary Kildall in 1974. It was a single-purpose machine that printed horoscopes. Four years later Steven Jobs and Steve Wozniak began shipping the Apple II. On August 12, 1981, IBM announced their personal computer. Less than three years later—in January 1984—Apple introduced the Macintosh. In between, there were many other companies and computers, some of which made brief appearances in scattered science classrooms.

The costs of classroom computing prior to 1978 were too high to foster widespread use. Early versions of the Digital Equipment Corporation's (DEC) PDP-8 minicomputer cost more than $20,000 and were sold mainly to colleges and universities. DEC's $6,000 PDP-8F arrived in 1974 and allowed for loading of programs via paper tape written in BASIC language. The MITS Altair and Commodore PET computers, which appeared in 1976, cost less than $500. They came, however, without reliable storage media. They were mainly hobbyist machines, requiring heroic patience and significant programming skills to operate.

Perhaps because of its early start, Apple has the largest installed base of microcomputers in science classrooms (Jarvis, 1983; Gleason, 1987; Weiss, 1987). Apple was the first inexpensive microcomputer to offer a color monitor, reliable disk drives, and expansion slots for adding memory and peripheral devices. It came carefully assembled and tested, and sold in 1979 for less than $1,500 for a complete work station (monitor, CPU, keyboard, and disk drive). While this price exceeded that of comparable microcomputers, the expansion slots and rapidly growing software base contributed to its becoming the computer of choice among schools.

Timeline



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1974
- Ted Nelson's *Computer Lib* published
- Intel invents the 8080
- Xerox releases the Alto
- John Torode and Gary Kildall begin selling a microcomputer and disk operating system
- *Radio Electronics* publishes an article calling the Mark 8 "your personal minicomputer"

1975
- MicroSoft (formerly Traf-O Data) writes the first BASIC for the Altair.
- *Popular Electronics* publishes an article describing the MITS Altair
- Bob Marsh and Lee Felsenstein rent garage space in Berkeley.
- Cromemco founded
- Homebrew Computer Club holds its first meeting
- Amateur Computer Group of New Jersey founded.
- Processor Technology formed.
- Southern California Computer Society holds its first meeting
- Dick Heiser opens the first retail personal computer outlet, The Computer Store, in Los Angeles
- First issue of *Byte* magazine published
- Paul Terrell opens the first Byte Shop in Mountain View, California

1976
- Ed Faber joins IMSAI as director of sales IMSAI begins shipping its first computers.
- Bill Gates's "Open Letter to Hobbyists" lamenting software piracy published
- George Morrow's MicroStuf founded
- The first issue of *Dr Dobbs* published
- Data Domain founded
- World Altair Computer Conference held
- Gary Kildall founds Intergalactic Digital Research (later Digital Research)
- Trenton (New Jersey) Computer Festival held
- Kentucky Fried Computers founded
- Midwest Area Computer Club conference held
- Steve Leininger and Don French begin work on Radio Shack's first microcomputer
- Processor Technology's Sol appears on the cover of *Popular Electronics*
- Stephen Wozniak demonstrates the Apple I at Homebrew Computer Club
- Personal Computing Festival held in Atlantic City
- S100 bus named
- ComputerLand incorporates
- Mike Markkula visits Steven Jobs's garage
- The first sale of CP/M
- Michael Shrayer creates Electric Pencil

1977
- Jonathan Rotenberg founds Boston Computer Society
- David Bunnell begins publishing *Personal Computing*
- Seymour Rubinstein joins IMSAI as software product marketing manager
- The first ComputerLand franchise store opens in Morristown, New Jersey under the name ComputerShack
- Apple Computer opens its first offices in Cupertino
- Community Memory incorporates
- The first West Coast Computer Faire is held
- Apple introduces the Apple II
- Commodore introduces the PET computer
- Ed Roberts sells MITS to Pertec
- Tandy/Radio Shack announces its first TRS-80 microcomputer
- Adventure International founded

1978
- Apple introduces and begins shipping disk drives for the Apple II
- "Black Wednesday" firings at IMSAI
- Apple initiates Lisa research and development project

1979
- IMSAI files for bankruptcy
- Steven Jobs visits Xerox PARC
- Processor Technology closes
- Tandy/Radio Shack announces the TRS-80 Model II
- MicroPro releases WordStar
- IMSAI closes its doors
- Personal Software introduces VisiCalc

1980
- Hewlett Packard releases the HP 85
- The Apple III is announced
- Microsoft signs a consulting agreement with IBM to produce an operating system

1981
- Osborne Computer Corporation incorporates and a short time later introduces the Osborne 1, the first portable computer
- Steve Wozniak suffers a plane crash
- Xerox releases the 8010 Star and the 820 computers
- IBM announces its Personal Computer

1982
- Apple Computer announces Lisa
- DEC announces a line of personal computers

1983
- IBM announces the PCjr
- Osborne Computer Corporation files Chapter 11

1984
- Apple Computer announces the Macintosh

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Software

Software for microcomputers prior to 1982 was sparse and generally considered of poor quality. The National Science Foundation funded some early software development in science and math. For example, the *Huntington I* and *II* Projects, under the direction of Ludwig Braun at SUNY-Stony Brook, provided a few science programs that the microcomputers could run in their tiny memories. These early science programs were mostly simulations. Students could enter the programs into computer memory from the keyboard or from paper tape. *POLUT* simulated the impact of point-source pollution on stream aquatic life. *POP* provided graphical results of the exponential growth of human population. The programs limited output to the ASCII character set. Graphics consisted of asterisks. Color video graphics arrived with the Apple II. Gradually, teachers began to have more and better software, but the disk operating systems restricted the software to one brand of computer (Doyle and Lunetta, 1982). Magazines carried listings of complete programs in BASIC, such as a nuclear power plant simulation (Frimpter, and others, 1983). Teachers or students could type these into microcomputers and customize them. Within a year, there were at least eleven software titles for teaching about nuclear energy (Saltinski, 1984).

With the appearance of expanded memory and reliable disk storage, teachers did not have to enter their own programs. Companies could sell good software through catalogs like other classroom media. Thus, by 1982 teachers did not have to be programmers to use microcomputers effectively.

After the *Huntington I* and *II* software projects, the Minnesota Educational Computing Consortium (MECC) began offering teachers quality software at low prices. Like the *Huntington Project*, the National Science Foundation funded MECC to provide quality science and math applications for the new microcomputers. Simulations and drill were the predominant types of software for science classrooms (Elron, 1983). New applications, however, were visible on the horizon.

By the beginning of the 1980s, developers linked classroom microcomputers to more than keyboards and display screens. Peripheral devices opened up science learning to physically handicapped students (Tinker, 1983). A program that used microcomputers to help blind and partially disabled students collect chemistry lab data became available to secondary schools (Lunney and Morrison, 1982).

Peripheral devices grew from a need for analog input while playing games. The Apple II included a gameport for use with a pair of such devices, called "game paddles." Game players used these paddles (soon to become a "joystick") for aiming and firing at screen targets. Programmers soon realized, however, that the same input port could accept and display any attenuated signal that varied as a function of resistance. This opened the way to connect thermistors, light detectors, and even graphics tablets to the computer. Such peripherals put the human learner in intimate contact with data collection and display.

THE WAY WE ARE: USE DURING 1982-1987

By 1984, the use of computers for drill and practice had come under fire (Rossman, 1984). Programming the computer as a way of teaching science was in decline. Physics students, however, continued to use programming to learn problem-solving algorithms (Porter and Lehman, 1984). Papers began to be published calling for better design of science software (Lehman, 1983; Ballou, and others, 1984). A new cadre of science teachers who had no programming skills began using computers as classroom tools and offering help to other novices (Neal and Kellogg, 1984). The number of microcomputers available to teachers continued to grow exponentially.

Who Uses Computers?

There are about 95,000 persons teaching about 369,000 sections of science in American schools in grades K-12 (NSTA, 1987). These teachers are responsible for 8.3 million students. In addition to science, they also teach 23,000 sections of non-science and 33,000 sections of mathematics. Figure 2 displays the number of high school science teachers by subject and the number of science teachers who use computers. About one-fourth of all secondary science teachers reported that they used computers in 1985-86. The number of biology, chemistry, and physics teachers who reported using computers is approximately the same. Proportionately more physics teachers, however, use computers than chemistry teachers, and more chemistry teachers than biology teachers. More public school chemistry and physics teachers use computers than those in non-public schools. Male and female science teachers make equal use of computers.

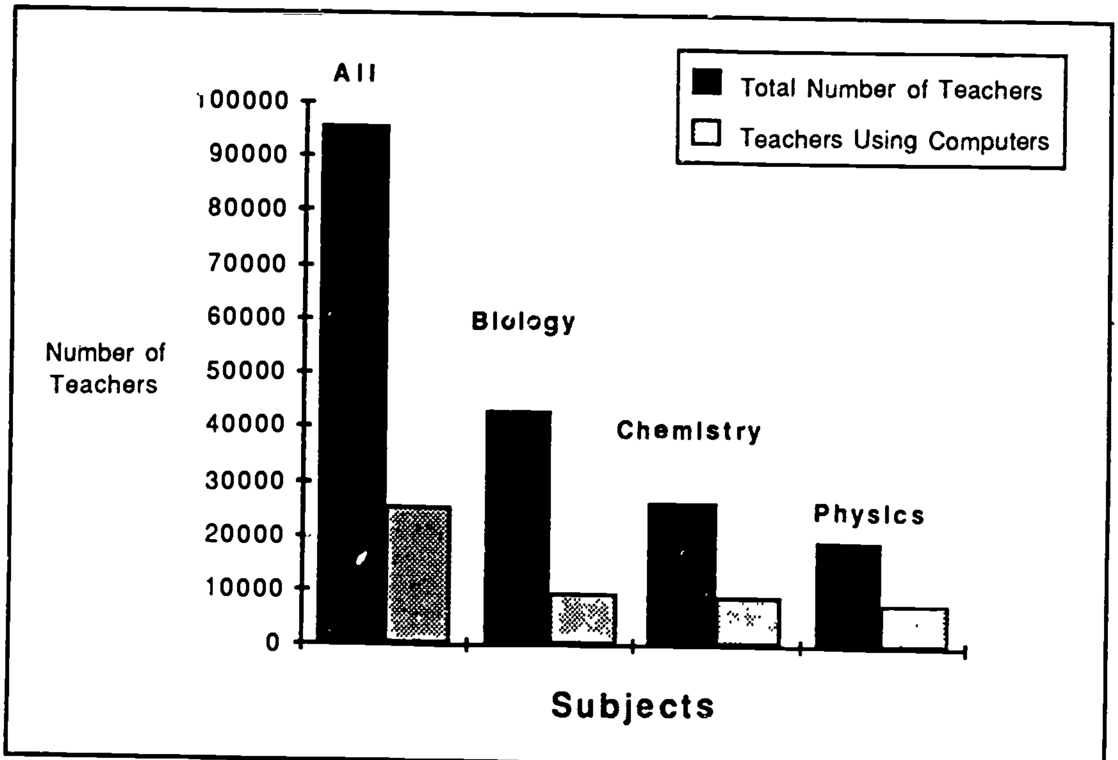

Figure 2: Total secondary science teachers (1985)

These data are consistent with the findings of Lehman (1985), who obtained surveys from science departments in 193 schools. These schools were about equally distributed over each of the four national assessment regions of the U.S., and represented a 57 percent return of surveys he mailed during April 1984. Lehman found that 77 percent of the 1,470 science teachers in the schools that responded did not use microcomputers in their classes. Only six percent used computers regularly, while 17 percent used them occasionally. In 41 percent of the schools, not a single science teacher used microcomputers in class. Suburban schools with six to ten science faculty were most likely to be using computers, while rural schools with one to five science faculty were least likely to make use of microcomputers for teaching. Lehman's data indicate a fairly even distribution of computer-using teachers throughout the different science content areas. Approximately 90 percent of computer users reported one hour or less per week per class in microcomputer-related instruction. He concluded that "very few science teachers are using microcomputers regularly in their science classes." (p. 583)

In the Johns Hopkins survey, Becker (1987a) reported this same pattern of low microcomputer use among science teachers. That study weighted the data by the frequency of computer use in each class or subject and by the number of classes or subjects for which the teacher used computers. Thus, this report yields more conservative estimates of computer use than others that count any frequency of use by a teacher as indicative of use in all subjects. The study classified teachers as users if they had (a) used the computer during the previous three days, (b) used a computer at least once during most weeks, or (c) used a computer at least three days in ten.

Using these criteria, Becker estimated that about one-sixth of American middle and secondary science teachers (20,000) used computers in their teaching during the 1984-85 school year. During the same period, about one-third of the math teachers (56,000) used computers for teaching math. Among secondary teachers who reported some computer use, science and math teachers used computers less frequently than teachers of other subjects. Less than one-fifth of middle school science classes used computers at least three days out of ten. In computer literacy and programming classes, 70 to 90 percent of the teachers reported hands-on computer use for at least three days out of ten.

The Johns Hopkins data indicate that computer use in science classes occupies only about six percent of the total instructional time on computers in high school, about three percent in the middle grades, and about one percent in elementary grades. The greatest use of computers during science classes (nine percent) occurs in grades nine and ten.

How are Computers and Calculators Used?

The same Johns Hopkins survey (Becker, 1987a) asked science teachers to indicate characteristics of the most recent occasion of computer use. As indicated by Figure 3, drill and practice still constitute the heaviest use of computers among science teachers, with biology teachers using this mode twice as much as chemistry and physics teachers. Nearly one-fourth of all computer use in secondary science classes is for programming. About one-third of all science teachers report using programming and word processing. (Since multiple uses were possible, the percentages do not add to 100.) Often the science teachers in a school are called upon to teach programming in addition to science subjects for which they are

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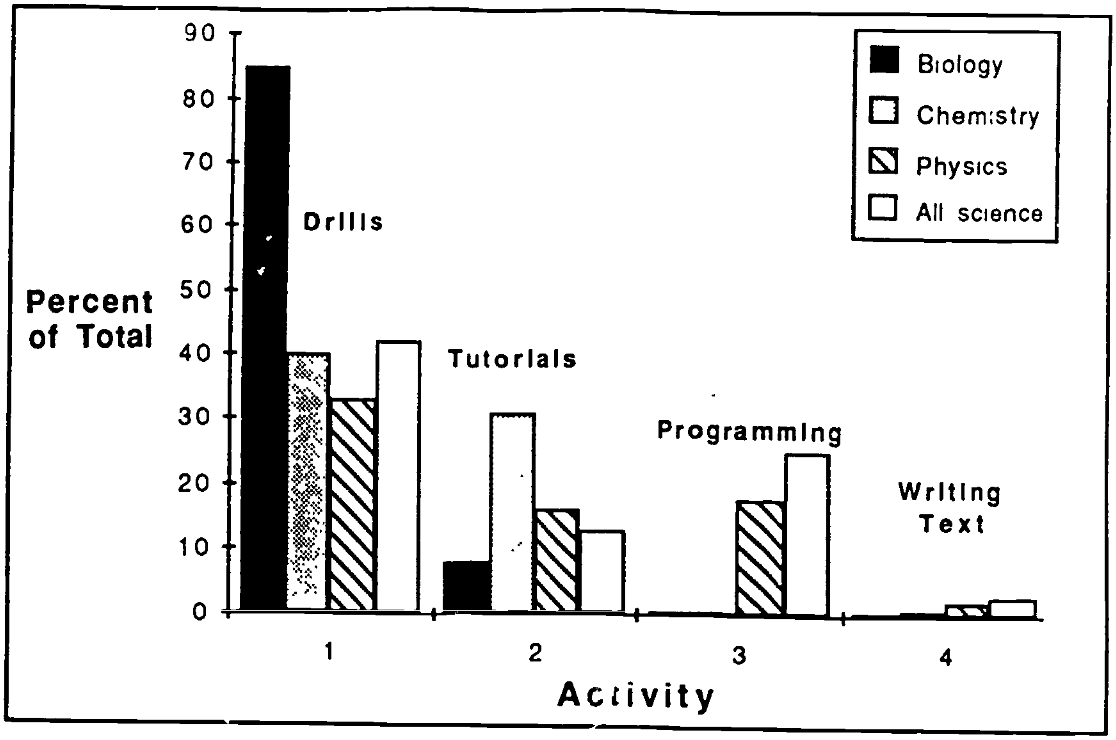

Figure 3: Type of computer activities (1985)

trained and certified. This may explain the high frequency of programming among the computer uses of all science teachers.

During drill and practice, the computer provides rehearsal of factual knowledge. Tutorials present new knowledge or skills. Students, however, maintain a somewhat passive role during drill-and-practice work and tutorials. Programming and text generation require that students play a more active role with computers. Furthermore, cognitive rehearsal is necessary. The students, consequently, must often use higher level skills.

Elementary, middle, and high school teachers make similar uses of computers in the classroom. Weiss (1987) asked science teachers to describe how they used computers in the most recent week and on a particular day of the week. Figure 4 indicates that teachers of science in grades 7-12 make heavier use of the computer as a laboratory tool and for simulations than do teachers in grades K-6. The study found few differences among grade levels in programming or problem-solving uses. Elementary teachers, however, seem to prefer games and drills. Given the expanded scale of Figure 4 (maximum use in any category is 17 percent), none of the indicated differences seem particularly significant. Weiss (1987) asked science teachers whether or not they used calculators in a randomly selected class. The data reflect use by 1,050 teachers of grades 10-12 and 658 teachers of grades 7-9 Results in Figure 5 indicate that high school teachers and their students use calculators in the classroom more than twice as much as middle school teachers. The percentage of teachers who use (and permit use of) calculators in the classroom is about twice as high as the fraction of teachers using computers (Figure 2). Level of use may simply reflect availability. It is interesting, however, to speculate on

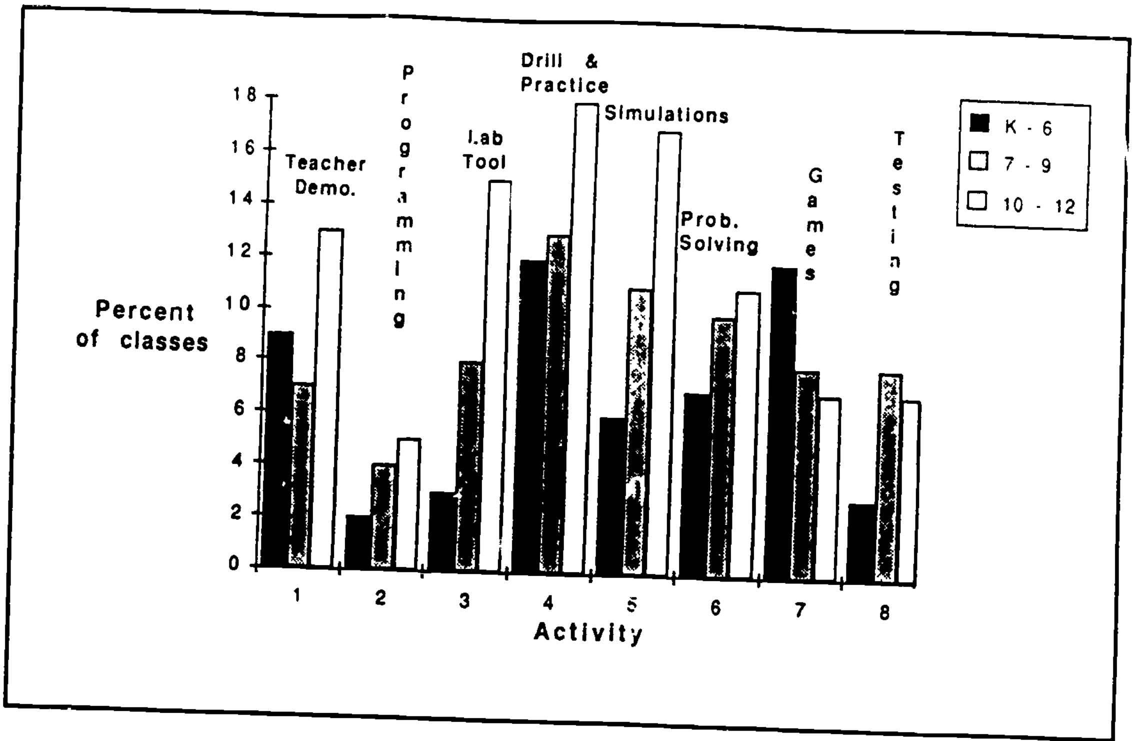

Figure 4: Computer uses by grade level (1985)

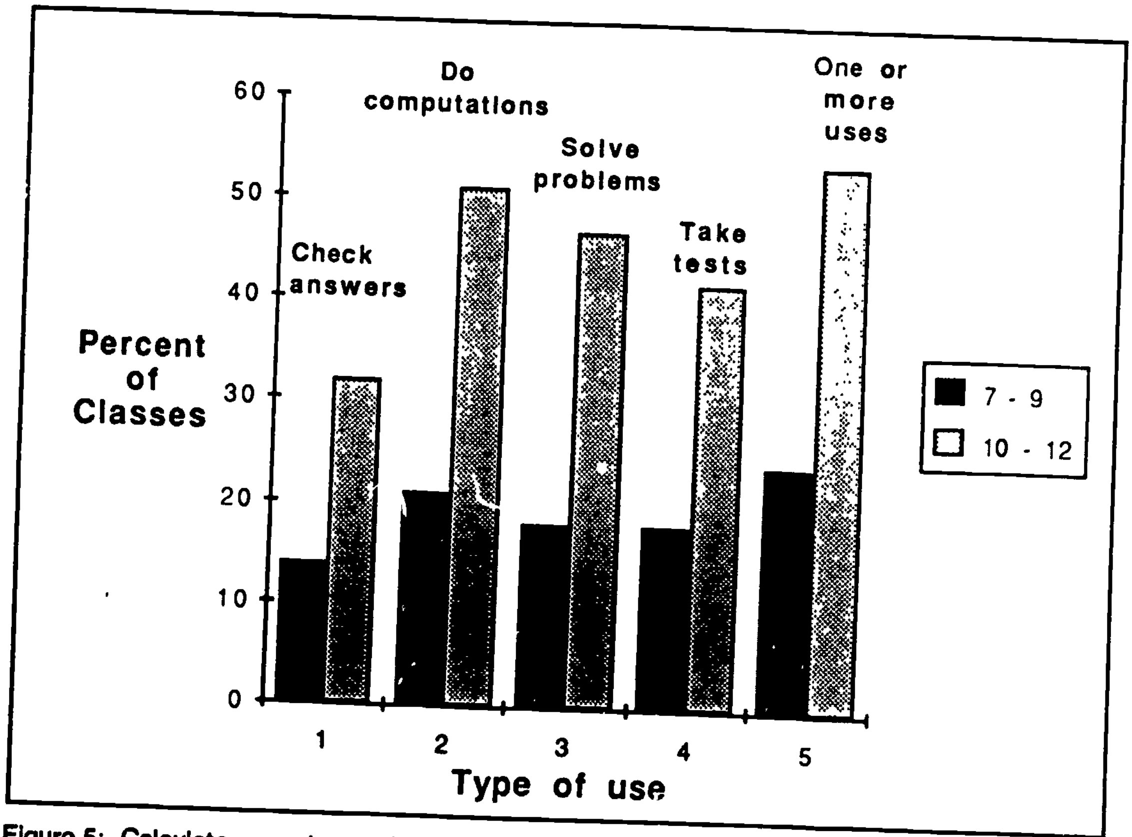

Figure 5: Calculator uses by grade level (1985)

the effect of the "learning curve" on teachers' computer use. Calculators preceded computers in common classroom use by about a decade. Perhaps we have not yet reached a saturation point in use of computers.

THE WAY WE ARE HEADING: USE FROM 1988

Teachers use computers in many different ways. Gerhold (1985) established seven categories of use of microcomputers in secondary science teaching. His application categories are (1) calculators, (2) black-box devices, (3) objects of instruction, (4) chalkboard substitutes, (5) instructional delivery systems (computer-assisted instruction), (6) simulation tools, and (7) process-control devices. Moore (1986) described innovative ways to teach concepts in chemistry, with courseware and equipment requirements. Besides their traditional use for drill, simulation, programming, tutorials, and data analysis, there are at least three additional ways that science teachers used computers in 1988. These are (a) microcomputer-based laboratories (MBL), (b) management and teacher utilities, and (c) telecommunications.

New Ways of Using Microcomputers

Microcomputer-Based Laboratories. Tinker's work with peripherals for handicapped learners and his concern for the preservation of laboratory options in science teaching (Tinker, 1984) led naturally to the creation of the microcomputer-based laboratory (MBL) (Technical Education Research Centers, 1984; Tinker, 1985). With MBL, science becomes truly interactive. The computer collects data in real time as the student watches an experiment in progress. The computer displays temperatures graphically as a substance absorbs or releases heat. The students can monitor distances, light intensities, pH, and other variables in pre-college labs in the same way researchers observe them in university laboratories. Science becomes more realistic. Learning becomes more concrete and intimately connected to observable phenomena (Ulerick, Bybee, and Ellis, 1988). Teaching science as process skills becomes easier for teachers (Dyrli, 1984).

Tinker and the Technical Education Research Centers in Cambridge are not alone in having described microcomputer-based laboratories as vehicles for bridging the gap between textbook and laboratory (Krieger, 1986). Walton (1985) and Lam (1985) discussed some of the ways in which microcomputers connect with laboratory experiments. Zeisler (1985) reviewed a chemistry experiment in which the microcomputer assisted with the generation of data tables, monitored calculation errors, facilitated the students' conclusions, and provided information for grading the students' reports. Horst and Dowden (1986) described an experiment in which the game port collected data and plotted a graph of oxygen generation.

Management and Teacher Utilities. Increasingly, teachers are using microcomputers as management tools. Grade book management was an early application of microcomputers. Some recent applications expand on this function. For example, Lagueux and Amols (1986) discuss how they use the microcomputer to manage judging and posting results of science fairs. Heikkinen and Dunkleberger (1985) describe microcomputer record-keeping to augment mastery learning. Teachers are using spreadsheets and databases to ease the tedium of maintaining inventory lists of equipment and supplies. Like other school staff, science teachers have discovered the advantages of word processing for maintaining and updating correspondence, tests, handouts, overhead transparencies, and other routine text documents.

Teachers use computer graphics in computer-generated newsletters. Where large-screen display is available, teachers may use the video output as a "dynamic chalkboard" to enhance lectures and demonstrations. In addition, science teachers are using classroom computers as devices to replace science equipment such as interval timers (McInerney and Burgess, 1985).

Telecommunications. One of the most interesting new uses of microcomputers is telecommunications, which expands the traditional boundaries of the classroom. With telecommunications, information from students and data sources outside of the classroom are accessible. Using a computer and modem at each end of a phone link, students and teachers may share programs and information in a two-way exchange. Where satellites are used, the entire world may be open to the students (Edwards, 1984). Using this method, teachers may search an enormous database for good science test questions (Dawson, 1987). International projects, such as the collection of data on acid rainfall, share data from remote sites monitored by students of many states and nations. Rakovic (1987) has even reported on the development of a "telecommunications high school" in Brooklyn, New York with goals, curriculum, student body and technology that departs sharply from tradition.

Hardware Location and Type

What brands of computers do science teachers use most often? This question is critical to software developers and teacher training institutions, as operating systems greatly restrict both the portability of software and transfer of learned skills. In February, 1987, Project SERAPHIM surveyed its 7,000 newsletter recipients—most of whom are active chemistry teachers at the secondary and college level. The survey asked readers to indicate the microcomputer hardware they used. Figure 6 presents the results by secondary school, college, university, and total. Of the 6,753 microcomputers, 2,070 (30.6 percent) were in secondary schools,

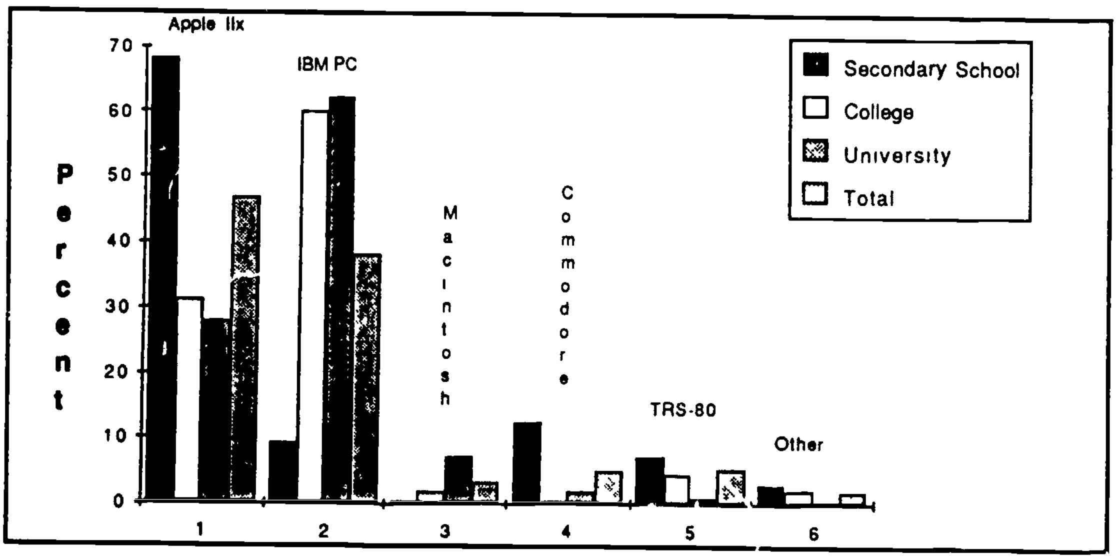

Figure 6: Predominant chemistry microcomputers

1,705 (25.2 percent) in colleges, and 1,583 (23.4 percent) in universities. The Apple II series microcomputer is the predominant choice among secondary chemistry teachers, while the IBM PC and its clones are more common among college and university chemistry departments. These results are consistent with those found by Duhrkopf (1987) for a national sample of biology teachers.

Where are computers located within schools? Figure 7 displays the location of the microcomputers from the Project SERAPHIM survey. In 1987, classrooms were the location for microcomputers that chemistry teachers at all levels preferred. While universities have twice as many microcomputers in labs (17.8 percent) as high schools (7.9 percent), this fraction is still small compared to the 60 to 75 percent in classrooms. Becker (1987a) also found that middle and high school science teachers used computers primarily in classrooms. Because most classrooms have only one or two computers, the student-to-computer ratio restrains their use whenever science teachers do not also use (or have access to) computer laboratories. Although Wainwright and Gennaro (1984) have suggested a variety of ways to use a single computer in science classrooms, there are distinct limitations on visibility and access during demonstrations and labs.

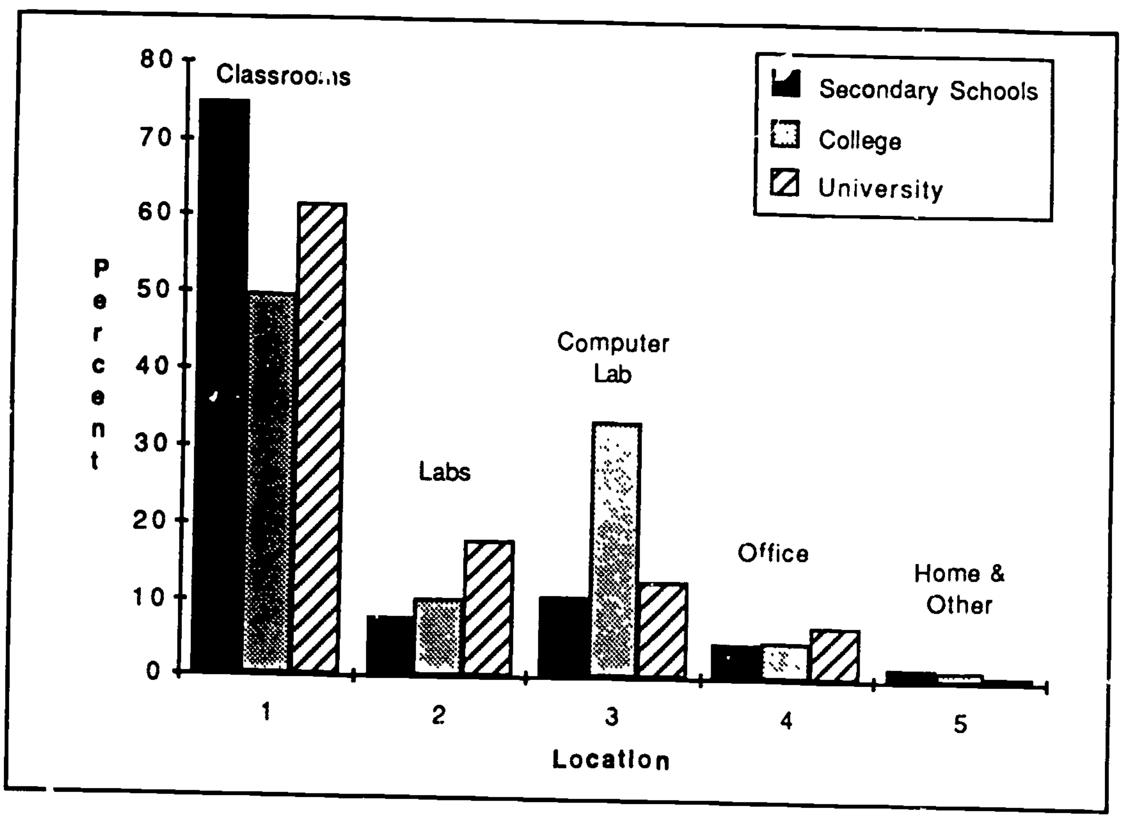

Figure 7: Location of computer reported

Becker's data (June, 1987) indicate that paired and group use of computers is common among middle and high school science classes. In 30 percent of science classes at that level, students used computers in groups of three or more. In addition to the obvious advantage of more efficient access, researchers have found group use of computers to facilitate problem solving and to enhance the development of process skills more than individuals working alone at computers (Fazio and Berenty, 1983).

What factors influence the selection of hardware and software available to science teachers? What determines location of available equipment and actual classroom uses? Both the availability of hardware and the machine specificity of science software may influence classroom uses by science teachers in each subject area. It is also quite likely that the prior experiences and training of teachers are critical variables in the frequency and category of uses.

Teacher Training for Computer Use

Weiss (1987, p. 84) found that roughly one in five mathematics teachers and one in four science teachers have had *no* training in the instructional use of computers. The training usually consisted of inservice workshops of less than three days total duration. When the survey asked teachers about their perception of their own preparation for using computers as an instructional tool, two-thirds indicated that they feel either "totally or somewhat unprepared" (Weiss). Less than 18 percent felt "well or very well prepared" (see Figure 8). There is little difference among teachers by grade level.

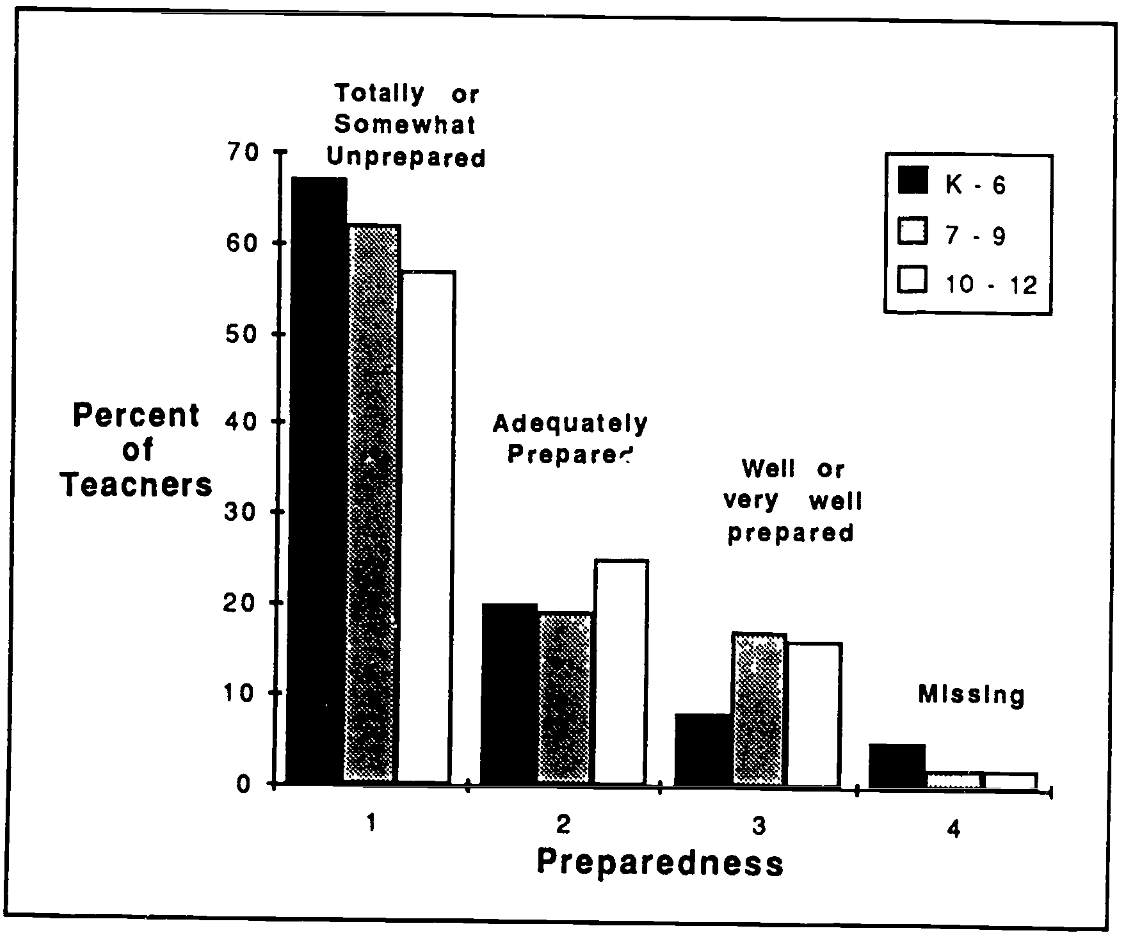

Figure 8: Teacher preceptions of preparedness (1985)

Lehman (1985) found that about 75 percent of those science teachers who use computers had at least the equivalent of a three-semester-hour course involving microcomputers, usually through inservice programs or a local college. The most common training was learning on one's own.

National Models

Given the diversity of software, novelty of hardware, lack of adequate teacher training, and low-use patterns among science teachers, what sort of intervention might succeed in making good use of available resources to enrich science instruction? Innovation has always been slow in making its way into educational practice, and the microcomputer is no exception. Successful implementation models, however, can demonstrate the true potential of microcomputers for classroom and laboratory use. To succeed on a national level, such models require

a) involvement of practicing classroom teachers in the design and implementation;
b) design contributions by programmers, cognitive scientists and teacher trainers;
c) major funding of design and implementation; at least over a five year period;
d) grass-roots communication among design team and teacher practitioners;
e) low-cost product readily available to teachers on the most common hardware.

Given a few such successful models and easy access of science teachers to the results, uses of microcomputers might increase and become more effective.

Project SERAPHIM. One such national model is *Project SERAPHIM* (Moore, and others, 1983). This project was funded by NSF in 1982 as a clearinghouse for information on the instructional uses of microcomputers in chemistry. Since then, its 30 workshop presenters have directed over 225 training sessions for thousands of teachers in the use of microcomputers in science instruction. Over 600 science programs are available on over 175 disks. These programs are provided at cost—about $5 per disk—through a free catalog to a mailing list that exceeds 7,000 names. New software is constantly being developed by chemistry teachers during summers and academic-year leaves as *SERAPHIM* Fellows.

In addition to its catalog and workshop offerings, since 1984, Project *SERAPHIM* has maintained an information network of active chemistry teachers, workshop presenters, and software developers through *CHYM:NET.* This electronic bulletin board resides in a mainframe computer in Ann Arbor, Michigan. It offers teachers and teacher trainers a 24-hour roundtable of current information through items and mail messages. Participants with information to share or questions to ask submit a paragraph or two as an item. The system informs other participants that the new item exists, and they may read it and elect to respond. The system appends all responses to the original item for everyone to read. Typical items include questions about the safety of chemistry demonstrations, the operation of new hardware and computer peripherals, the changes needed in *SERAPHIM* software, and who plans to attend NSTA conventions.

Items accrue to *CHYM:NET* at the rate of about two per week. Currently, there are approximately 80 participants.

The use of microcomputers to facilitate peer support and to provide quick solutions to problems points to future applications outside the traditional domain of microcomputers. Having other teachers within easy reach may improve teacher morale and reduce the sense of isolation many beginning teachers feel. Freedom from the constraints of distance and time heightens the value of *CHYM:NET*.

SERAPHIM Software and Peripheral Devices. Typical software simulations in the *SERAPHIM* collection place the students in roles such as (a) a scientist designing experiments to explore the scattering of alpha particles by thin metal foils, (b) an environmental scientist seeking the cause of fish kills in a lake, or (c) the operator of a sewage treatment plant who must apply appropriate chemicals to avoid polluting a river without exceeding a fixed budget. Simulation of a $30,000, high-performance, liquid chromatograph offers students opportunities that are otherwise unavailable in most labs. This simulation uses the computer as a tool to introduce students to the operation of a complex instrument.

Teachers also assemble inexpensive peripheral devices in *SERAPHIM* workshops. Teachers take the MBL devices back to classrooms for use in data collection and analysis. One of these devices uses the game port to measure light intensity as a function of the progression of a chemical reaction. Others measure temperature or pH through the same microcomputer game port. Each device is inexpensive to construct, and provides almost the same accuracy as the standard laboratory equipment it replaces.

PROJECTIONS FOR THE FUTURE: THE NEXT DECADE

The Educational Technology Center of Harvard University (1988) has produced a position paper on the future role of technology in science, mathematics and computer education. The authors describe how three research groups have examined the impact of technology-enhanced teaching units in five Massachusetts high schools during 1987. The goal of the units was to teach for understanding—to help students learn how knowledge is constructed in each subject area. Their three-fold approach was to (1) use the computer as a tool, not the main focus of attention, (2) choose targets of difficulty—those recognized as critical to further learning and yet difficult to teach—, and (3) involve active teachers in all phases of design and execution.

The researchers found that computers can serve as a stimulus to learning when teachers use them to present dynamic visual images of intellectually powerful ideas in a variety of symbolic representations. The group worked with middle school students on concepts of heat and temperature, mass and density, and the nature of scientific inquiry. Computers served as the vehicle for presentation and response where the researchers deemed them appropriate. Effective human teachers, however, are critical to the success of each unit.

The Office of Technology Assessment (1982) predicted that by 1994 schools will have over four million microcomputers. These machines have the potential for changing the way science is taught. Schools may not realize this potential, however, unless (a) we train teachers to use computers for what they do well; (b) schools provide support for the purchase of quality courseware and peripheral devices necessary to fully utilize the microcomputer's potential, and (c) we continue research in ways that computers benefit science learning. It is now time to examine some ways that teachers might use microcomputers and new storage devices in the science classrooms of the next decade.

Computers perform only as well as they are programmed. Thus, maximizing their potential requires good software. Klopfer (1986) calls for a new generation of tutoring software that will use the microcomputer's full potential. The creation of this software will take the cooperative efforts of effective science teachers (Shavelson, and others, 1984), cognitive scientists, and software engineers.

The best software must be available to institutions that train preservice and inservice teachers if we are to encourage improved uses of instructional computing. Frequent bibliographies and reviews of this software (Smith, 1983a; Smith, 1983b) must be available in journals accessible to teachers. Directories such as the "Science Curriculum Software Guide (K-12)" (Apple Computer, Inc., 1987) provide a convenient means to locate software for specific textbooks and school programs. Objective reviews of science software by active teachers can assist in the process of selecting the best. Previews such as the "1987 Educational Software Preview Guide" help schools to make software decisions.

New technologies, such as interactive videodisc and CD-ROM, invite speculation about their potential impact in science classrooms. Some (THE Journal, 1986) of those new technologies are slowly making their way into science classrooms. New applications, such as dynamic modeling of multivariate systems (Robson and Wong, 1985) have the potential to make microcomputers "intelligence amplifiers" for science and math students.

How teachers perceive themselves and the potential of technical tools for enhancing teaching will largely determine the future uses of technology in science classrooms. There is no such thing as a "teacher-proof curriculum." The National Technical Information Service (1987) reported on ways that teachers used computers in federally funded programs from 1981 through 1986. From this and Gleason's (1987) longitudinal study of the uses of microcomputers by Wisconsin teachers, it is clear that many teachers will *never* make use of computers, while others are quickly attracted to them. Attempts to increase the uses of computers in science classrooms must confront the "saturation point." This is the point at which all teachers understand their potential and the "early innovators" are already using them. Beyond this point, progress may be quite slow. Despite high-quality software, better inservice training, more accessible microcomputers, and curricular integration, there are personal barriers to more effective uses of technology in teaching. These human limits may be the true challenge of the next decade.

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The Effects of Using Computing Technologies in Science Instruction: A Synthesis of Classroom-Based Research

Kevin C. Wise

INTRODUCTION

Interest in the use of computing technologies in education is at an all-time high. During the 1981-82 academic year, about 18 percent of public school districts were using microcomputers, by 1986-87 this figure had risen to over 95 percent (Market Data Retrieval, 1987). Computer use in teaching is more evident at all grade levels now than at any time in the past. Analysis of recent figures indicates that of the total number of computers available, the percentage found in elementary schools is only slightly less than the percentage found in senior high schools (Hannafin and Peck, 1988). Microcomputers are becoming as much a part of school as blackboards and chalk, and now are as likely to be found in the first grade room as in the physics laboratory.

Further evidence for this interest in educational computing is also found in the funding that state governments have provided. In 1986, the amount of money spent for hardware and software was nearly $700 million dollars. Furthermore, most states have anticipated the need for even greater expenditures (Reinhold, 1986). Such massive investments carry with them implicit, and in some cases, explicit, expectations that the computing resources will enhance educational experiences throughout the curriculum.

Many earlier efforts to use microcomputers in schools involved special "computer" courses. Students studied topics such as the history of computing, the electronic theory behind computing hardware, and introductory BASIC programming. Schools are orienting recent efforts toward using computing technologies in the various subject areas; eleven states now require schools to integrate computers

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into the regular curricula. In Wisconsin, for example, the state requires its schools to use technology wherever appropriate in language arts, social studies, and science at all grade levels (Reinhold, 1986).

There are many questions to address if schools are to use microcomputers to their best advantage. Although the general public may believe that educators have a well-developed base of knowledge with regard to both overall and specific effects of using computers in instruction, the evidence suggests this knowledge base may be lacking. Through mid-1982, a research base on the use of microcomputers in science was virtually non-existent (Wise and Okey, 1983). As recently as four years ago, Okey (1984) described the integration of computing into science instruction as being uncommon. A mere half-dozen years ago student involvement with simple programming exercises, drill and practice, or computer tutorials defined the extent of computing technology use in many schools. This picture is rapidly changing, however, and researchers are reporting investigations on the effects of using computing technologies in science instruction more frequently. Classroom computing technologies now bring to the minds of science teachers and science education researchers instructional applications, such as microcomputer-based laboratories, simulations of laboratory investigations or other phenomena, videodisc-based lessons, telecommunications activities, and computer-based testing. Recent advances in educational computing are nowhere more evident than in science classrooms and curricula. Because of the increased use and study of microcomputers in science instruction, researchers should now systematically gather and synthesize the findings of these studies. Such analyses will help science teachers use microcomputers effectively.

PURPOSE

It is the purpose of this chapter to synthesize recent research on the effects using computers in science instruction. I used meta-analysis as the primary strategy for integrating the research. In addition, I shall present a narrative review of select studies to elaborate on the meta-analysis.

The meta-analysis will address the following questions:

1. In an overall sense, to what extent is student achievement either positively or negatively affected when teachers use computer-based instruction to teach science as compared to when they use traditional instructional approaches?
2. Are some kinds of computer-based instruction more effective than others?
3. Is computer-based instruction more effective in certain science curricular areas than in others?
4. Is computer-based instruction more effective for certain grade levels of students than for others?
5. Do the effects of computer-based instruction differ depending upon the design features of the research investigations in which the effects occurred?

A brief narrative review of studies that are representative of those the meta-analysis used will follow the presentation and discussion of the meta-analysis findings.

Methodology

The synthesis began by defining the population of studies from which I would select the research reports. I used studies dealing with classroom situations wherein teachers used microcomputers in some way to deliver science instruction or to facilitate the learning of science. I considered approaches that used videodiscs to deliver instruction as being microcomputing technology for the purposes of this synthesis. Furthermore, the investigations I selected had to compare the computer-based approaches with a traditional instructional approach. Finally, the researchers had to formally measure student achievement and report it in a form from which I could calculate effect sizes I defined achievement broadly to include cognitive, affective, and psychomotor behaviors. Student scores on paper-and-pencil tests and quizzes, responses on attitude scales, and actual performance of certain tasks were among the achievement measures I deemed appropriate.

I located appropriate studies by searching the databases of the Educational Resources Information Center (ERIC)--Resources in Education (RIE) and Current Index to Journals in Education (CIJE). I used a set of relevant key words to guide the search of reports from 1982-1988. I examined abstracts of investigations from the annual meetings of the National Association for Research in Science Teaching over the past six years to cross-check for studies not in the ERIC and CIJE databases.

Once I identified and actually obtained the investigations, I synthesized them using meta-analysis procedures (Glass,1977; Hedges, Shymansky, and Woodworth, 1986). To do this, I developed a coding form so that I could uniformly record the features and findings of each study. Coding schemes researchers used in earlier related efforts served as models for my form (Kulik, Bangert, and Williams, 1983; Wise and Okey, 1983; Wise, 1986). The study features that I documented characterized the design of the study itself, the context in which it took place, and the nature of the instructional treatments the researchers used. Documentation of study findings involved conversion of the student outcomes, however the researcher measured it, into units of standard effect sizes. I coded each investigation on two or more separate occasions to establish the reliability of the final set of data.

FINDINGS

I identified, obtained, and coded 26 studies that met the selection criteria. Researchers reported more than half of these studies during 1987 or 1988. A total of nearly 4,200 students, ranging from second grade through college level, participated in this group of studies. The studies dealt primarily with instruction on topics in the biological and physical sciences or the development of process skills.

The investigations in the sample yielded a total of 51 effect sizes (about two per study). These effect sizes ranged in magnitude from -.62 to +1.21. For question number one, the overall mean of the effect sizes is +.34 with a standard error of .06 (Table 1). This implies that across all measures, students who experienced computer-based instruction in science courses exhibited achievement superior to that of students who received traditional instruction by one-third standard deviation.

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Table 1
Summary of Mean Effect-Size Calculations for the Impact of Various Computing Technology Associated Instructional Approaches in Science

Instructional Approach	ES	SE	Number of Measures
Microcomputer-based laboratories	.76	.14	6
Microcomputer-based tutorials	.45	.18	7
Microcomputer-based diagnostic testing	.28	.05	3
Microcomputer-based simulations	.18	.08	24
Video-disc based lessons	.40	.12	11
Overall Effect	.34	.06	51

Questions two through five carry the initial analysis a step further by seeking to determine if the impact of computer-based instruction differs by type of approach or contexts in which the effects occurred. Table 1 also presents the analysis related to question two—the mean effect size, standard error, and number of student achievement measures for each of five categories of computer-based instruction. The highest numerical mean is for the microcomputer-based laboratory, followed by microcomputer-based tutorials, videodisc-based lessons, microcomputer-based testing, and microcomputer-based simulation. Each mean for effect sizes is positive and significantly different from zero. To determine if "real" differences are likely to exist between the means for effect size of the various approaches, I made pair-wise comparisons of .90 confidence intervals. Based on these comparisons, the highest mean, that of the microcomputer-based laboratory, differed only from that of the two lowest means, those of microcomputer-based testing and microcomputer-based simulation. I based the mean for simulation on four times as many effect sizes as the mean for microcomputer-based laboratories.

To answer question three, Table 2 presents the effects of computer-based instruction for science curricular areas. Physical science includes physics and chemistry; multiple science includes studies wherein the treatment covered several

Table 2
Summary of Mean Effect-Size Calcualtions for the Impact of Computing Technology Associated Instructional Approaches by Science Curricular Area

Curricular Area	ES	SE	Number of Measures
Biological science	.22	.06	16
Physical science	.45	.13	16
Science process skills	.33	.13	14
Science/technology/society	.42	---	1
Multiple science areas	.36	.15	4

Table 3
Summary of Mean Effect-Size Calculations for the Impact of Computing Technology Associated Instructional Approaches by Student Grade Levels

Grade Level	ES	SE	Number of Measures
K-4	.12	.21	4
5-8	.39	.09	20
9-12	.40	.13	16
College	.24	.08	11

different science topics or skills. I located no appropriate studies involving earth science. I observed the highest mean for effect size in studies involving physical science, while the lowest mean is for studies involving biological science. Comparisons of the .90 confidence intervals of the means for effect size revealed overlaps in all cases. While the measures were nearly evenly divided among the biological science, physical science, and process skill areas, only one measure was in the science/technology/society area.

In response to question four, Table 3 presents the effect of computer-based instruction in science at various ranges of grade levels. The two highest means for effect size are for students in the grades nine through twelve and five through eight. More than 70 percent of the measures I included in this analysis were for students at these levels. I found the third highest mean for effect size with college-level students. The lowest mean was for students in the kindergarten through fourth grades; however, this mean was for four measures and has a relatively large standard error. Pair-wise comparison of the .90 confidence intervals around the means for effect size for the various grade level range did not reveal significant differences.

Table 4 presents the means for effect sizes according to design features of the investigations (question five). The highest means for effect size occurred when researchers randomly assigned students to treatments, when the treatments were one week or less in duration, when the software was developed externally, when the treatment employed only one piece of software, when the researchers used the software to supplement instructional strategies that weren't computer-based, or when the researchers did not report the validity and reliability of the outcome measure. Despite the variations, which appear to be due to differences in study design features, only one of the six features reported here yields a real difference in the means for effect size. Significantly higher means for effect size occurred in studies in which researchers did not report the validity and reliability of the outcome measures, as is the case for nearly half of the measures in the data set.

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Table 4
Summary of Mean Effect-Size Calculations for the Impact of Computing Technology Associated Instructional Approaches by Study Design Features

Study Feature	ES	SE	Number of Measures
Students assignment to treatment groups			
Random	.42	.09	23
Non-random	.27	.08	28
Treatment duration			
1 week or less	.47	.10	16
2 - 4 weeks	.21	.11	17
5 - 8 weeks	.23	.14	6
Over 8 weeks	.40	.12	12
Source of software			
Researcher developed	.31	.08	27
Externally developed	.36	.09	24
Number of pieces of software employed in treatment			
1	.41	.09	18
2 or more	.30	.08	33
Software role in instruction			
Replaces other strategies	.26	.08	23
Supplements other strategies	.41	.08	28
Outcome measure validity, and reliability reported			
Yes	.21	.07	26
No	.52	.07	25

DISCUSSION

This meta-analysis of research on the effects of computer-based instruction in science leads to a number of observations, inferences, and recommendations. Subsequent sections will discuss and consider these in context of related works.

Production and Nature of the Studies. During 1986-1988, many researchers studied the application of computing technologies to science instruction. The number of investigations, however, seems relatively small considering the widespread availability and potential impact of microcomputing technologies in schools. We need to learn much more about how we may best apply the new technologies to instruction. The results may become obsolete rather quickly as the variety and sophistication of computer-based instruction continues to increase. As we have seen since the introduction of microcomputers to schools, both the innovative and the routine applications will be found in science classrooms; therefore, this is where researchers should direct their efforts.

In attempting to gather research reports, a number of studies I initially selected on the basis of promising titles were inappropriate for collecting the types of evaluation or outcome data I needed to compute effect sizes. Ulerick, Bybee, and Ellis (1988) also found that the nature and methodologies of research on microcomputer-based education have diversified from a focus on student achievement, which was most evident during the period when mainframes were the only computers available. They cite the case study as an approach to describing actual classroom transactions and a variety of learning outcomes. We need research based on a mix of methodological approaches to determine the effects (both transactional and outcome) of computer-based instruction, the contexts in which the effects occur, and the reasons these effects occur.

Overall Effect Observed in Outcome Studies. This study found nearly the same results for computer-based instruction in science as Kulik, Bangert, and Williams (1983) found in an earlier study of secondary schools across all subject areas. They calculated an overall effect size of +.32 with a standard error of .06 from 48 studies, as compared to an effect size of +.34 with a standard error of .06 for this study. The meta-analysis conducted by Kulik and others included studies in science as well as other subject areas, but included only investigations of students in grades six through twelve. While the present analysis included only studies covering science content, the majority of them were of students in grades five through twelve. Other meta-analyses of the effects of computer-based instruction across a variety of grade levels also have yielded positive outcomes (Burns and Bozeman, 1981; Kulik, Kulik, and Bangert-Drowns, 1985; Niemiec and Walberg, 1985; Willett, Yamashita, and Anderson, 1983). The present meta-analysis is unique with regard to two attributes in that it deals with just science topics or skills, and includes only "microcomputer era" technologies. Based on both past and recent experiences I infer that existing evidence supports computer-based instruction as effective in promoting learning in science.

Effects Observed for Various Instructional Approaches. Based on a limited number of studies, the microcomputer-based laboratory yields a higher effect size than that of microcomputer-based simulation, or microcomputer-based testing. Microcomputer-based tutorials and video-disc lessons lie in the middle, nearer the overall mean for effect size for all approaches to computer-based instruction. Comparisons of the present findings with those of analyses by Kulik and others (1983) and Niemiec and Walberg (1985) that also address the relative effects of different approaches reveals little in the way of a pattern. The analyses differ somewhat in the category labels the researchers used for instructional approaches and thus possibly as to how they assigned studies to categories. For example, what one analysis called diagnostic testing another analysis might have classified as computer-managed instruction. The same might have occurred with the programming and problem-solving categories. Furthermore, previous analyses have not included microcomputer-based laboratory and videodisc-based lesson categories. Both the amount and kind of evidence gathered to date does not yield a substantive picture of the relative effect of various approaches to computer-based instruction. Recent findings suggest, however, that some of the newer of these strategies, including microcomputer-based laboratories and videodisc-based lessons, are among the most promising.

Microcomputer-based tutorials are the only approach to computer-based instruction in which a consistent level of effect occurred throughout analyses. The computer-based tutorial category was the second most effective approach in each analysis. Mean effect sizes for this category were .45 in the present analysis, .36 in the Kulik and others' report (1983), and .34 in the Niemiec and Walberg analysis (1985). As with all the approaches, researchers should study the tutorial approach further to verify its impact and to explain reasons for its effectiveness.

Effects Observed in Various Study Contexts. The current study found only one significant variation in effect sizes for study contexts. Study contexts include the science subject, the grade level of the students, the method of assignment of students to treatment groups, and whether or not the study reported the validity and reliability of the outcome measures.

Although the highest mean occurred when teachers used computer-based instruction in teaching topics on physical science, this did not differ significantly from the lowest mean for using computer-based instruction in teaching topics in the biological sciences. When teachers taught process skills with computer-based instruction the resulting effect size was near the average of the mean of +.34. I made a similar observation in an early analysis that is parallel to the present one (Wise,1987).

While a number of studies included some instruction in science process skills, only one dealt with a science/technology/society topic. I found no studies in which a teacher used computing technologies to influence a student's awareness of science careers or on science as it relates to personal needs. Researchers have conducted virtually all studies of computer-based instruction in the more traditional areas of science curricula. Thus, the role of computers in developing the broader construct of "scientific literacy" is still unclear, suggesting a new direction for future research.

Differences in grade level did not associate with significantly different means for effect size. An average to slightly above average mean of effect size for junior high and high school level students, however, seems to be a consistent finding in most analyses. The effects of microcomputer-based instruction is uncertain in the kindergarten through fourth grades due to the small number of studies. Niemiec and Walberg (1985), however, found a large effect in the kindergarten through third grades, but their analysis primarily involved experiments using mainframe computers. We have a great need for more studies examining the effects of computer-based approaches to instruction on the achievement of students in primary grades.

The only study context resulting in significant differences was the reporting of measures of validity and reliability. For those studies tnat reported validity and reliability, a lower overall effect size occurred. More than half of the total number of studies were of this type. Because these indices provide information about the quality of measurement instruments, this group of studies is preferable for estimating the overall effect size.

Effects Observed in various Treatment Contexts. I found no significant variations in effect size due to treatment contexts. Treatment contexts include the duration of treatment in weeks, the source and number of pieces of software for the treatment, and the role of the software in instruction. These studies suggest variables that may be worth examining in the future. One additional feature for which there were few details, was the role of the teacher during treatments. A full description of the treatment, its purpose, and the role of the teacher in the treatment need explication in future research.

The largest difference between means for treatment contexts was between treatment durations of one week or less and those of two to four. This difference, though not significant, amounted to .26 effect size units, in favor of the shorter duration. Kulik and others (1983) also found greater effects in shorter duration studies.

Another relatively large, though not significant, difference was between measures taken on treatments in which software replaced other instructional strategies and those in which software supplemented other forms of instruction. This difference amounted to an effect size of .15 in favor of the treatments in which software was a supplement. Other reviews and analyses of research suggest this "integrated" type of instructional approach is preferable (Hasselbring, 1984; Kulik, 1983; Wise, 1987).

NARRATIVE REVIEW OF SELECTED STUDIES

This section presents a narrative review of select studies and provides additional perspectives to the meta-analysis findings. To keep this review brief and reflective of recent research, I shall not attempt a comprehensive review of all studies. Instead, the following sections describe works in the categories of microcomputer-based laboratories and videodisc-based lessons, which are two promising areas of research.

Microcomputer-Based Laboratories (MBL)

Brasell (1987) conducted an investigation of an MBL motion unit that helps students learn about how velocity-time and distance-time graphs change depending on the speed and direction of motion. The researchers divided the high school physics students among four treatment groups. Two groups received variations on the MBL approach, a control group received a paper-pencil activity parallel to the MBL, and a second control group received no motion graphing activities. The MBL variations allowed one group to immediately view computer-based graphics of the motion "in progress" (real time MBL) while another group could only view computer-base graphics of the motion about 20 seconds after they observed it (delayed time MBL). On a 24-item posttest of the ability of students to interpret graphs of distance and velocity, the scores from the group using real-time MBL were significantly higher than those of the other groups. The scores for the group using delayed time MBL did not differ from those observed for the control group. Analysis of the test items indicated that the superior performance of the group using real-time MBL was due primarily to a reduction in the number of graphing-convention errors the students made. The investigator suggested that the delayed presentations of the graphs required students to retain information and events that they could not or did not know how to retain. Furthermore, the delayed MBL treatment appeared less motivating to the students. They seemed to be less eager, active, and involved than those provided with the real-time MBL. Overall, the standard MBL (real time) was most effective.

In a recent study, involving a semester-long physical science course, Linn, Layman, and Nachmias (1987) sought to identify the order or chain of cognitive accomplishments necessary for proper graphing performance. The researchers wanted to determine how far eighth graders of average ability might move along this chain as a result of numerous MBL activities. Based on a pretest and posttest comparison, the investigators determined that although students started the course with good knowledge regarding the features of graphs, the MBL activities in which they participated enhanced their ability to recognize trends and derive meaning from graphically presented information. Furthermore, the investigators found that students improved in developing mental templates of heating and cooling curves as a result of the many occasions they viewed these kinds of graphs on the computer screen during MBL activities. The authors inferred that MBL may provide both "memory support" and concept templates that facilitate learning.

Mokros and Tinker (1987) conducted a three-phase investigation of how a student learns to use graphs with MBL experiences. The first phase of this investigation involved conducting clinical interviews with middle school students to determine both the graphing skill and the misconceptions typical at this age level. The investigators observed that students tended to equate a graph with a picture, and that students frequently confused slope and height. The second phase of the investigation involved classroom observations of sixth grade students as they worked on an MBL unit that dealt with motion graphing. The investigators observed consistent patterns in the way that groups worked and found evidence that the students were developing the appropriate graphing skills as a result of their work. The final phase of the investigation was an effort to evaluate the effectiveness of numerous MBL activities in physical science, spread over three months, in developing the graphing abilities of middle school students. The researchers used an achievement test of graphing skills and an interview during an experiment to gather data on the students. A pretest and posttest comparison of achievement test scores showed a significant positive change in the students' ability to use and interpret graphs. Further analysis showed that the graph as a picture misconception and the slope/height misconception were corrected by the MBL treatment and that these may not have been misconception at all. In summary, the researchers suggested that the multiple modalities and the linking of real events with their abstract representations are among the features that make MBL activities particularly effective for teaching graphing skills.

Videodisc-Based Lessons

Branch, Ledford, Robertson, and Robinson (1987) evaluated the effectiveness of an interactive computer program that used a videodisc to teach first year veterinary students to analyze canine heart sounds and murmurs. The students in the experimental and control treatments received direct instruction on the theory and examples of various conditions from actual clinical cases, including the amplified heart sounds and oscilloscope waveform patterns. Additional audio examples were available to all students on tapes. The treatment conditions differed in that while the control group continued to get exposure to audio recordings of heart sound, the experimental group interacted with the videodisc lessons that included the heart audios, visual waveforms, and pertinent still pictures such as diagrams or necropsy slides. The videodisc program had a "toggle" feature that allowed students to switch between recordings of different patterns for comparison purposes. At the conclusion of the unit the students were given a recognition test on heart sound. Although the experimental group scored slightly higher, the difference in group means was not significant. The authors concluded that the interactive videodisc was effective, and for practical reasons desirable, as an alternative to traditional training methods. The students were enthusiastic about the method. Furthermore, it provided the students practice with observing and discriminating skills, which is not always possible with actual clinical cases.

Leonard (1987) conducted a study to determine if interactive videodisc lessons could be effective substitutes for or extensions of conventional activities in the biology laboratory. Interactive videodisc versions of two commonly performed laboratory activities were the treatment in this investigation. One of these activities involved studying the effects of temperature on seedling respiration rates. In the regular laboratory setting, the students in the control group conducted an actual experiment that involved indirectly measuring oxygen consumption, which was the dependent variable. Those students who were using the interactive videodisc, the experimental group, watched an actor perform the experimental manipulations. They gathered information via audio or visual cues from the monitor or by keyboard interaction with the program. A second laboratory activity dealing with climate and its effect on the distribution of worldwide life followed the same general pattern. The students in both groups had three hours to complete each activity. Mean scores on quizzes and laboratory reports for each of the activities did not differ between groups. The investigator suggested that interactive videodisc lessons may be viable as an alternative to certain standard laboratory activities, especially in light of the practical advantages they afford.

Waugh (1987) examined the influence of interactive videodisc programs on the achievement of first-year college chemistry students, when the programs are a supplement to or substitute for regular laboratory activities. The treatment groups consisted of those who completed a traditional laboratory on chemical equilibrium, those who completed an interactive videodisc simulation of this laboratory, and those who completed both of these activities. Grades from laboratory reports and scores from an equilibrium quiz were the achievement measures. The students who worked with the interactive videodisc simulations, either as a substitute or supplement, out-scored students in the traditional laboratory group on both measures. The author concluded that the interactive videodisc simulation was superior to the traditional laboratory experience in helping the students to acquire chemical equilibrium concepts and that interactive videodisc simulations merit consideration for use as a supplement to or substitute for traditional laboratory investigations. The author noted he did not measure manipulative skills that students develop during actual laboratory experiences as part of the investigation.

OVERALL SUMMARY

Only recently have researchers reported enough studies of microcomputers in science education for meta-analysis procedures to be useful in synthesizing the results. At present, I conclude that microcomputer-based instruction is linked with improved student performance relative to traditional instruction. This finding is similar to that of instructional applications of mainframe computers involving several decades worth of research. The present findings are even more encouraging, considering the varied applications, conditions, and groups of students that this current meta-analysis included. As more powerful hardware and software becomes available and as educators gain experience with its use, microcomputing technologies will play an increasingly diverse and widespread role in instruction. Researchers should direct their investigations at both evaluating the effects of "state-of-the-art" applications and explaining why these effects occur.

Although some categories of computer-based approaches to instruction look particularly promising, it is far too early to make any declarative statements in this regard. We require more studies using variations of MBL, interactive videodisc, tutorial, simulation, and testing programs to lend stability to the tentative findings of this analysis. We also need additional work to provide insight into the contexts in which the effects of computer-based instruction occur. For example we presently know very little, based on published research, about the effects these approaches have on elementary school science.

In addition to achievement outcomes, almost every study made reference to two other kinds of changes. First, the researchers noted some change in the "instructional time factor." Interestingly, in some studies, the students who used computers finished their lessons faster, while in others they lingered longer. In either case, the amount of time for the computer-assisted treatment differed from that required for the control. Future studies might endeavor to formally document and explain this potentially important variable. A second kind of change noted in most studies was the increased motivation and interest that the students displayed. The investigators found striking differences in this variable. We need future research studies to examine this variable, especially as it pertains to the quality and level of student engagement during treatments that use computer-assisted instruction.

Beyond the kinds of findings this meta-analysis generated there is an important place for research that looks beyond outcomes. The research studies on microcomputer-based laboratories, in particular, include research designs and strategies for gathering information useful for explaining effects and for linking the approaches with learning theories. We need more investigations of computer-based instruction that get at "why they work." An information base of studies that use a variety of methodological approaches will be a critical key to advancing our understanding of the use of computers in instruction.

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8

Science Education and the Challenge of Technology [1]

Marcia C. Linn

INTRODUCTION

In this chapter, I analyze the relationship between science education and informational technology over the last 15 years, identify promising trends, and recommend policies for the future. I focus on (a) lessons learned from research on learning and instruction, (b) the relationship between the teacher and technology, and (c) the influence of technological advance on educational practice. Fortunately, the potential impact of technology on science education comes at a time when students, teachers, policy makers, and numerous comparative assessments suggest that science education in America requires a major overhaul.

Why might technological advance catalyze improvement in science education? First, scientists use constantly advancing technology to help them solve complex problems. These tools of experts might also help students. Second, recent technologies have already invaded schools. Currently, precollege students have access to over 1.4 million computers at school and more at home (for example, Becker, 1986). Third, the information explosion changes the skills students need, and electronic databases will make this information available in schools. Fourth, technology has transformed the workplace by taking over manufacturing and other functions. As a result, those students currently in school will probably change jobs several times during their careers and therefore need skills for learning new

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information. Fifth, educators use rapidly advancing technological tools. Such tools can help teachers simplify tedious record-keeping and secretarial tasks, gain access to colleagues and information, and enhance instruction. Sixth, recent research on learning clarifies how scientists solve complex problems. These findings suggest how teachers could use technological tools to teach problem-solving skills to students. Thus, technological advances can improve science education, and science educators have the opportunity to respond to current shortcomings of science instruction by harnessing technology.

THE CURRENT STATE OF SCIENCE EDUCATION

At present, there is widespread agreement that science education is not effectively teaching American students. A recent study revealed that both average and the very best American students performed well below their counterparts from most other industrialized countries on test items reflective of the current science curriculum (see Figures 1 and 2, National Science Foundation [NSF], 1987). This survey reinforces findings from many other national and international assessments

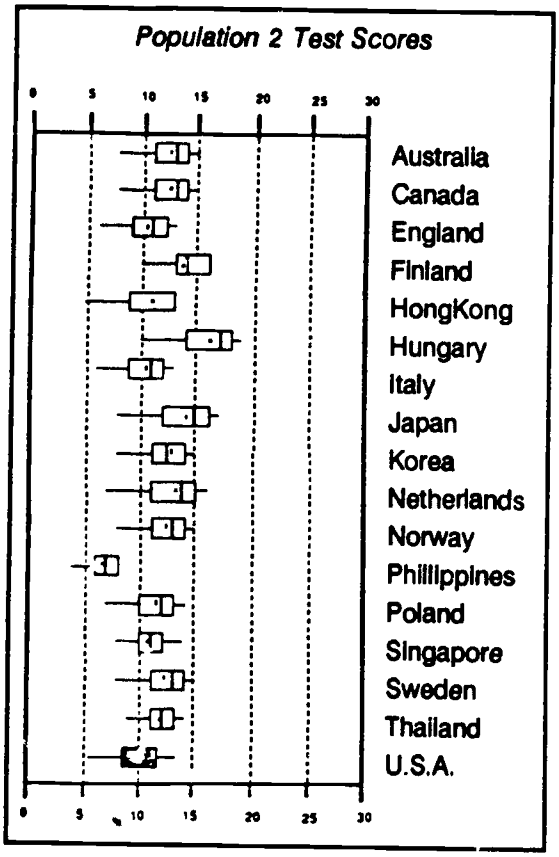

Figure 1: Core test scores for seventeen countries

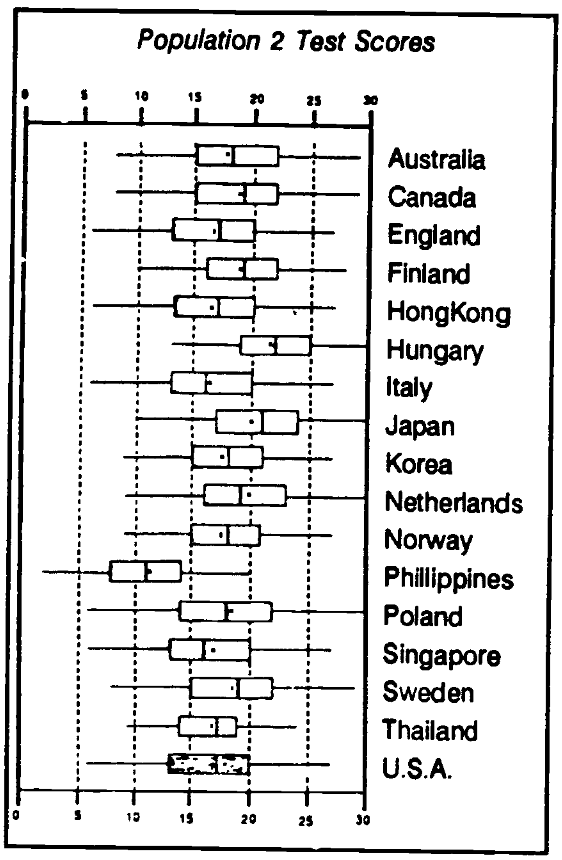

Figure 2: Core test science scores of the bottom 25 percent of those in school at population 2 level

Source: International Association for the Evaluation of Educational Achievement (IEA), Science achievement in the seventeen countries: A preliminary report.

(International Association for the Evaluation of Educational Achievement, 1988; National Assessment of Educational Progress, 1978; National Commission on Excellence in Education, 1983). Furthermore, the percentage of foreign students enrolled in graduate science programs in American universities has increased from 21 percent in 1980 to 28 percent in 1986 (NSF, 1987), and the number of American students has stabilized. Other indicators also suggest that Americans are not maintaining their past standards. For example, a comparison between the quality of patented ideas in the United States and Japan reported a tentative trend toward an increase in the number of high-quality, patented ideas in Japan compared to the United States (Broad, 1988; NSF, 1987). In summary, performance on national standardized tests, enrollment in advanced scientific programs of study, and analysis of the quality of patented ideas all suggest that the United States is losing its edge in scientific accomplishment. America needs a new, improved approach to science education.

Although standardized test scores indicate serious problems with American science education, they do not dictate a solution. Indeed, they often trigger increasing drill and practice, which probably contributes to poor performance, because information that is not cohesively integrated is rapidly forgotten (Linn, 1987a). The response of increasing drill is reinforced by science textbooks that (a) emphasize science information rather than scientific reasoning and (b) cover topics so quickly that students cannot integrate information or apply what they learn to new problems. Emphasis on memorization deters students from integrating and understanding scientific phenomena and detracts from problem solving and self-monitoring. Instead, given rapid technological advances and the information explosion, students need skills for solving new problems, not skills for memorizing scientific information, which can be readily accessed in electronic databases or which will be outdated by the time the student graduates.

To achieve a robust, cohesive understanding of science, students need a realistic and philosophically sound view of science. Rather than memorizing and absorbing information, students should expect to analyze and question information, to synthesize and integrate their knowledge, and to cooperatively solve problems that require understanding of scientific principles. Students must be expected to apply information learned in one situation to similar problems in other situations. With these skills. students will perform better on standardized tests as well as on indicators of problem-solving skills. Furthermore, students will understand that the business of science is discovering new information.

A minority of science programs do emphasize a philosophically sound view of science that uses "discovery learning," "hands-on" experimentation, or scientific problem solving to illustrate the process of science. Although promising, these approaches rarely go far enough. Often, discovery learning experiences are unguided, so the students have no idea how to proceed; or, discovery learning is conducted without the details that the students need to draw conclusions. Unless programs provide integrated and systematic experiences, the students end up with fragmented and incomplete understanding. To be effective, discovery learning takes instructional time and teacher expertise. The students will not integrate their knowledge if, just when they get started on a really interesting problem, they need to stop because the fifty-minute class period has elapsed or the week devoted to thermodynamics is over. Students learn complex problem-solving skills when individually guided by knowledgeable teachers. In support of this claim, Bloom (1984) concludes that tutoring might be two standard deviations more effective than traditional instruction. Yet those who currently teach science often lack the science knowledge and pedagogical skills required to tutor students on complex problems (National Science Board, 1988).

In summary, although teachers have difficulty implementing a philosophically sound view of science education, drill on science information is not the alternative. Many believe technological advances can help implement discovery activities, can free teachers to spend more time tutoring individuals and small groups of students, and can help prepare teachers to provide a philosophically sound view of science. Several projects, which I shall discuss, that use technology in innovative science programs point the way.

In this paper, I argue that we can achieve the kind of science education American students deserve by: (a) combining recent technological developments with recent advances in understanding how students learn and what makes instruction successful; (b) establishing collaborations between curriculum developers, educational researchers, teachers, and policy makers; and (c) refining preliminary approaches through trials in realistic settings.

INTEGRATING TECHNOLOGY INTO SCIENCE EDUCATION

While implementing technology, science education has passed through three discernible stages. In this developmental process, those involved are jointly constructing an understanding of how technology and science education can complement each other. Factors influenced by the process include the goals of science education, the role of the teacher, and the nature of technology.

Stage I: Technology in the Service of Established Goals

At first, developers targeted technological innovations to the established goals of science education, rather than seeking creative uses for these technological innovations. Developers were often isolated, unaware of the efforts of others, unaware of educational research that might influence their efforts, and optimistic about the ease with which technological tools could improve science education. For example, precollege science teachers and their students wrote multiple-choice quizzes and created question-and-answer type software. Even these traditional goals were difficult to achieve because developers lacked tools for including graphics or building interfaces between the computer and the student, and therefore often failed to use technology effectively, as the following examples illustrate.

Imitating Textbooks. Early science software imitated textbooks by placing paragraphs on the computer screen and interspersing questions. As a result, most of the disadvantages of texts, but few of the advantages, were achieved. In particular, (a) students and teachers have skills for browsing through textbooks that do not apply to browsing through screen-presented text, (b) comprehension falls when text appears on a computer screen, and (c) access to computer-presented text is, of necessity, constrained by the availability of the hardware, which limits access to school hours.

Drill and Practice. Many developers used computers for drill and practice, which was consistent with the goal of memorizing scientific information. This approach draws on principles from Skinner's learning theory, on user interfaces designed for electronic games, and on motivating students by keeping score. For example, a chemistry program designed to help students memorize how compounds interact involves (a) skill in directing the cursor around a computer-presented maze while being chased, (b) rapid decisions on which compounds will interact with other compounds, and (c) strategic thinking about the game-like scoring system. The emphasis on eye-hand coordination excites the students, but may overwhelm the scientific content. In addition, this software emphasizes absorption of isolated pieces of information to get a higher score, rather than encouraging the students to understand the material.

Simulating Science Experiments. Teachers often omit experiments from the curriculum for lack of equipment, lack of space in the classroom, lack of instructional time, potential for danger, or potential for disrupting learning. As a result, software developers have made experiments available on computers. Developers designed these computer-presented experiments to (a) provide access to experiments; (b) emphasize some of the problems that arise in the lab, such as selecting the correct instrument, zeroing the balance scale, placing samples properly, or interpreting results; or (c) extend experimentation to problems not appropriate for classroom instruction.

Bork (1980) created computer-presented experiments to replace classroom experiments. In one example, the students connected batteries and bulbs with wires and simulated electrical-circuit experimentation. Bork argued that this approach freed the teacher from worrying about whether the batteries were charged and the bulbs were working, and allowed the students to focus on observing differences in the intensity of the bulb, depending on the number of batteries connected. Many science teachers disagreed, pointing out that experiments with batteries and bulbs were (a) cheap and easy to conduct in classrooms, and (b) one of a small set of experiments appropriate for classroom instruction. The simulation was not fully tested because the hardware never achieved widespread use.

Tribbles (Von Blum and Hursh, 1987) provided access to previously unavailable experiments by simulating genetics experiments with fruit flies. The program allows the students to analyze either the phenotypes or genotypes of the resulting population. The students can predict characteristics of offspring, set up experiments, and analyze the outcomes. Since the first version, more powerful hardware and software have permitted development of effective graphics and refinement of the interface. The revised program is a popular software tool today.

Widely used software for science education was developed for a mainframe computer by the *PLATO* project at the University of Illinois (Smith and Sherwood, 1976). With the advent of microcomputers, those developers used their considerable experience to develop microcomputer-based approaches to science experiments. The chemistry simulations developed by Stan Smith and Loretta Jones at the University of Illinois are one example. Using the IBM Info Windows touch screen, combined with a videodisc, this approach allows the students to participate in completely simulated experiments. The students experience many of the same problems that might arise in a laboratory, such as selecting the correct instrument for their experiment, placing sample material in the instrument correctly, setting the background appropriately, and interpreting the result. The software features simulated experiments that would be difficult for students to conduct on their own, due to the requirement of collecting data in remote locations, the need to use expensive equipment, or the need to use dangerous chemicals. The students make decisions as if they were experimenting on their own, such as where to place a collector to sample air quality, and how to display and analyze the data. The advantage of the simulated experiments is that the program directs the students' attention to the main decisions that need to be made. On balance, the students may become immersed in the details of conducting the experiment and lose track of the implications of their findings, just as they do when conducting experiments in real laboratories. The developers are analyzing the advantages of (a) using simulations by themselves, (b) using simulations for pre-lab instruction, and (c) using simulations for post-lab review.

Efforts to simulate science experiments, therefore, offer promise for science education. Successful programs have benefitted from trial and revision. Furthermore, many excellent efforts have been thwarted by changes or limitations in the hardware and software environments.

The Teacher Dialogue. A valued component of science instruction is the dialogue between teacher and student. Often, teachers conduct dialogues with the class or with individuals and communicate important scientific concepts. The dialogues of Socrates or Rousseau's (1892) teaching of Emile serve as models for this approach.

Arons, Bork, Franklin, Kurtz, and Collea (1981) and others have taken the teacher dialogue as a model for the development of science software. They observe teachers using dialogues in classrooms and attempt to implement the practices of teachers in a computer program for students. Rather than using classroom apparatus, the program features illustrations and dynamic diagrams of scientific phenomena. Although some dialogues achieve what appears to be interactive discussion, these dialogues are limited by the ability of the computer to process natural language (for example, Bork, 1981). Therefore, if the students fail to use key words, the program acts more like a lecturer than an interactive companion. These dialogues have the property of encouraging the students to reflect on problems and generate solutions. Difficulties arise when the students come up with answers the computer cannot recognize. The process then resembles an adventure game, where the user seeks words the game will accept. Furthermore, human tutors motivate their students to continue to think about complex tasks by providing encouragement and empathy not possible with most dialogues (Lepper and Chabay, 1985). As a result, the cognitive outcomes of computer dialogues are likely to differ from those achieved by teachers.

Demonstrations Using Technology. Science classes often feature demonstrations. Teachers demonstrate experiments, illustrate relationships, and graph results. Many demonstrations can be presented by computer. For example, developers have created a simulation of the periodic table that allows teachers to dynamically illustrate the heating of the universe from absolute zero to a point where virtually every element is vaporized. In another example, the teachers can use Rocky's Boots, a dynamic simulation that employs "and," "or," and "not" gates to construct "machines," to illustrate how these gates perform. The simulation provides a dynamic trace of the activation pattern for the constructed circuit, going beyond what would be possible without technology (Stein and Linn, 1985).

Thus, software can help teachers demonstrate scientific phenomena in ways that would be difficult or impossible without technology. On balance, demonstrations, like lectures, often reach only a small proportion of the audience and may emphasize isolated phenomena, not integrated understanding.

Writing and Computation Aided by Technology. Most science classes involve writing and computation that students could perform using standard software for word processing and data analysis. Early experiences with these tools in the classroom suggest that they have some important advantages. Students now regularly learn to use scientific calculators with numerous functions and, as a result, focus more on problem interpretation than on tedious calculations.

How can word processing facilitate scientific report writing? Striley (1988) compared students who wrote collaborative reports using paper and pencil with those who wrote reports on the word processor. With paper and pencil, the students often divided responsibility, saying, "You think and I'll write." In contrast, in the word processing option, the students jointly constructed sentences and revised their reports. Using the word processor, the students could refine their ideas and still produce neat reports. They were reluctant to erase and refine their ideas when using paper and pencil. Thus, an unanticipated consequence of using word processing was an increase in collaboration among students.

Summary. In summary, many software developers initially sought ways to use technology to implement practices already common in science classrooms, rather than move toward more philosophically sound practices. Programs emphasizing drill and practice on science information, however, reinforced an already questionable goal for science instruction; further, demonstrations of scientific phenomena tended to perpetuate the lecture. In contrast, efforts to use technology for simulating experiments and word processors for writing reports revealed potential advantages of technology in science education. At this stage, the limitations of hardware and software caused real problems. Graphical representation of scientific phenomena required extensive programming. Manufacturers abandoned hardware installed in schools. Developers could not implement many ideas given the power of school computers.

Efforts to use technological tools for existing goals in Stage I revealed uncertainty about the interaction between technology and the teacher. Some, such as the teacher dialogues, took over major functions performed by the teacher. Others, such as drill and practice or simulated experiments, took over functions previously performed by books or apparatus, freeing the teacher to focus on integrating and synthesizing the information. These efforts paved the way for teachers and schools to rethink the role of the teacher in the classroom of the future.

Stage II: Adapting Science Education to Technological Innovation

In the history of science, technological innovation has shaped the direction of scientific advance on the one hand, and individuals have harnessed technological tools to redirect scientific investigation on the other. In the second stage of the relationship between technology and science education, technological tools reshaped science education and science educators stimulated technological innovation. Instead of using technology for existing goals, developers focused these tools on problem-solving and complex reasoning skills. Two factors predominated. First, developers made technological tools that expert scientists use available to students, arguing that tools that help experts solve problems could teach problem solving to students, rather than sustain questionable practices currently in use in classrooms. Second, developers collaborated with cognitive researchers and combined advances in understanding learning and instruction with technological advance to teach a more philosophically sound view of science teaching.

As the examples below illustrate, since science students are not experts, the tools of experts did not automatically impart the problem-solving skills of experts. Rather, these tools provided an opportunity for teachers, researchers, and curriculum developers to focus on roles and materials that would help students to develop complex reasoning skills.

As science educators incorporated these tools, they benefitted from more powerful software development environments that made revision easier. In addition, schools supported hardware developments that offered upwardly compatible advances, because the new hardware did not make the established software obsolete.

Programming. Programming was the first expert use of technology that schools implemented for students. Many scientists solve problems by writing their own computer programs to analyze data and to display information collected in their laboratories. As a result, some argued that students in science classes would learn problem solving from instruction in programming.

Perhaps the most well-known argument for programming is found in Papert's Mindstorms (1980). Inspired by the developmental theory of Piaget, Papert argued that students who use powerful programming environments would have "wonderful ideas" about science. He developed Logo, to allow students to explore scientific phenomenon by writing programs. For example, using turtle graphics, students can give direction to either a screen turtle or a robot-like floor turtle and examine the response to these instructions.

Papert and others report exciting insights gained by students who use Logo and turtle graphics. Papert describes students who examine the consequences of having the turtle move both east and north simultaneously and discover that the turtle moves along the resultant vector (Lawler, 1986; Hughes and Macleod, 1986; Turkle, 1984). Lawler (1986) reports designing Logo programs that result in powerful insights into mathematics and science for his young children. Investigations by many researchers, however, reveal that Logo's success is largely determined by the efforts of sensitive teachers.

Investigations in realistic settings reveal that Logo does not, by itself, inspire students to develop wonderful ideas about science. Proficiency in Logo takes considerable time and students rarely build tools to help with other problems (Pea and Sheingold, 1987). Students are not experts and do not automatically think like experts. Just as other discovery-learning environments rarely succeed, so Logo used without expert direction rarely yields effective learning (Pea and Kurland, 1987).

Yet, environments such as Logo make it easier to build tools targeted to specific goals of instruction. Creative uses of Logo did result from the development of teaching tools. Lawler (1986) developed tutorials for his children rather than having his children learn Logo. Logo heralded an important trend. It became an effective courseware authoring tool, allowing developers to create exploratory environments and provide guided discovery on important concepts.

Findings for Logo are consistent with investigations of other programming languages, such as BASIC and Pascal. Many researchers conclude that students have difficulty learning programming, that much time elapses before they get to serious problem solving, and that they need instruction in the problem-solving skills of experts, not free exploration of a programming language. In particular, experts engage in design, draw on a repertoire of algorithms or templates, and reflect on the flaws in their reasoning. These skills are rarely taught (Linn, 1985; Mandinach and Linn, 1987; Sloane and Linn, in press).

Recently, programming environments have been refined to make the debugging tools of experts more available. For example, Macintosh Pascal, shown in Figure 3, offers many of the debugging tools experts use. Experts often debug programs by tracing the values of variables while running a program. Macintosh

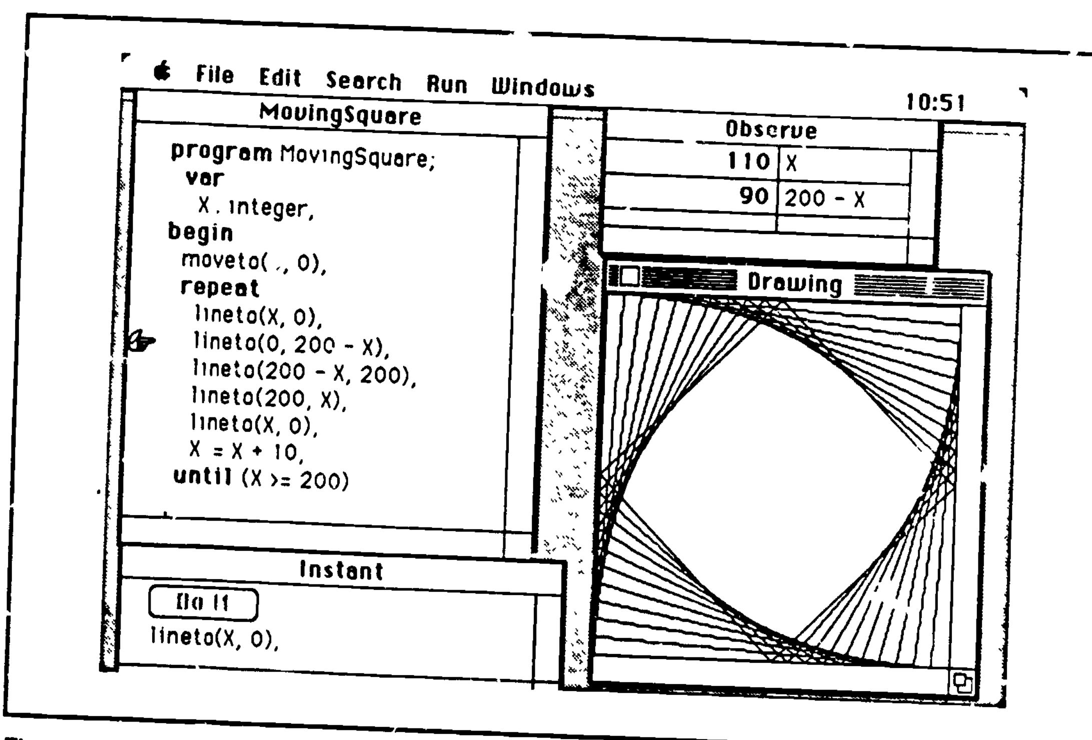

Figure 3: A screen display from Macintosh Pascal demonstrating some programming tools and the juxtaposition of the program and its output

Pascal allows the student to do a trace by requesting it from a menu. A moving finger indicates which line of the program is being evaluated, an observe window indicates the values of the variables at the time that line is being executed, and an output window indicates the state of the output, which in this case is graphic, at the same time. Paralleling findings for Logo, much research reveals that simply having this tool available does not help students develop the reasoning skills required for using it (Nachmias, Friedler, and Linn, 1988).

Thus, precollege programming courses rarely require the knowledge level that activates use of problem-solving skills. Furthermore, even if students learn the syntax, they need instruction in the thinking skills that experts use.

Microworlds. To encourage students to use the thinking skills that experts use to investigate scientific problems, developers have created environments called "microworlds" that provide feedback about some scientific phenomena. Microworlds allow students to develop hypotheses about complex scientific phenomena, to design experiments to test these ideas, and to use the feedback to reflect on their conception of the phenomena, just as experts develop models and simulations to test their ideas. Although the microworlds generally require much less learning of syntax than programming, they share with programming a need for instruction in generating ideas and using feedback from experiments to succeed.

For example, the dynaturtle (Di Sessa, 1979, 1986) allows the students to explore Newton's laws of motion but does not teach the students how to use the information they acquire. Before coming to a science class, the students construct views about motion from experiences in the natural world that in many ways contradict Newton's laws. They conclude that objects in motion tend to slow down. They argue that when you push an object it moves in the direction that you push it, rather than assuming that a new force adds to previous forces that have acted on an object. Furthermore, some students invent forces to explain the behavior of objects (Reif, 1987; Clement, 1987). These conceptions of the natural world become robust and cohesive by the time the students encounter physics instruction and tend to persist even after the students have learned Newton's laws. Frequently, the students will conclude that physics learned in a science class applies to problems encountered in a science class, but not to objects in the natural world.

Developers hypothesized that microworlds could provide robust and cohesive alternatives to the students' misconceptions. A question, however, is whether the students would integrate their microworld experiences with their other experiences or assume that the physics applied using microworlds does not apply in the natural world.

Further exploration with the dynaturtle microworld by White (1981, 1984) revealed that the students had difficulty linking experiences with the dynaturtle to experiences with the natural world. As a result, White and Frederiksen (1987) have expanded the notion of a microworld into a progression of microworlds, each coming closer to experiences the students encounter in the natural world. They used what they call the *ThinkerTools* environment to create a series of microworlds (White and Horwitz, 1987). This series provides greater control over discovery than is possible with a single microworld. Using a sequence of microworlds, teachers can guide their students to slowly add variables and concepts to their view of the natural world, until they incorporate both their prior experiences and their classroom experiences into a cohesive, unified model.

The White and Frederiksen (1987) approach also involves instruction in the thinking skills students need to analyze feedback from the microworld. These researchers constructed a curriculum that successfully taught sixth graders more about force and motion than is typically learned by high school students. The curriculum included (a) a motivational phase that exposed the students' misconceptions and inconsistencies in thinking; (b) opportunities to explore key principles governing the behavior of objects; (c) modeling of techniques for making abstract ideas concrete, observable, and qualitative for the students; and (d) gradual increases in complexity that allowed the students to build on accurate prior knowledge. As the students constructed accurate understanding of these scientific phenomena, the program introduced Newton's laws of motion to explain the observations. The developers reasoned that, ultimately, the students needed a philosophically sound view of the scientific enterprise, including understanding of the laws of motion that scientists use. Thus, White and Horwitz focused on imparting the thinking skills of experts as well as on devising a model similar to models that experts use. They have yet to explore how students make the transition from microworlds to naturally occurring problems.

White and Frederiksen's (1987) implementation of microworlds for instruction incorporates recent research on how students learn and how teaching can become effective. The sequence of microworlds encourages the students to combine difficult representations of the same concepts, and thereby gain better understanding of them. The guided discovery limits the information that the students must process at any one time, thereby increasing the likelihood that the students will understand. Furthermore, the *ThinkerTools* environment has the advantage that one can easily reformulate it to illustrate a different set of principles. Both students and teachers might modify the *ThinkerTools* environment to set up new microworlds for the students to explore. As the students become more sophisticated, they can add features to the microworld that they wish to explore, and teachers can do the same.

In summary, students can use microworlds to develop expert problem-solving skills. A sequence of microworlds is not sufficient to teach the students to think like experts; however, such a sequence offers an opportunity to do so. Furthermore, unlike programming, microworlds can address specific scientific phenomena.

Real-Time Data Collection. Microworlds allow the students to explore phenomena not readily accessible to experimentation. In contrast, real-time data collection facilitates and simplifies experiments that the students conduct. Using real-time data collection, the students can collect, analyze and display information just as expert scientists do. Science teachers can spend less time ensuring that the students collect accurate data, and concentrate on expert thinking skills, such as analyzing and interpreting data.

Several effective real-time data collection environments exist. All use probes connected to microcomputers and provide graphic output (see Figure 4). Laws (1986) created opportunities for students to gather information from experiments involving temperature and sound. The Bank Street College of Education included

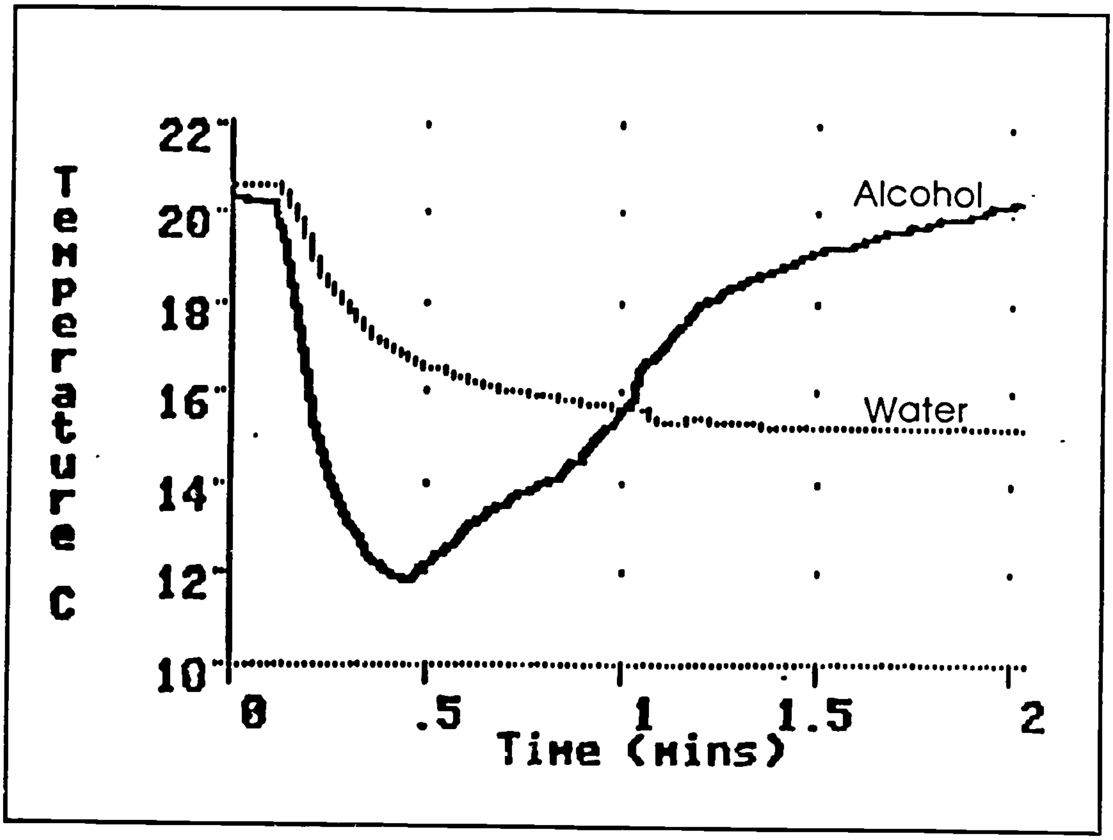

Figure 4: Evaporation graph of alcohol and water

real-time data collection among the activities offered in the *Voyage of the Mimi* curriculum (Pea and Sheingold, 1987), and Tinker (1987) at Technical Education Research Centers has devised a vast array of real-time collection techniques for temperature, light, sound, motion, and other scientific phenomena.

As was the case for microworlds, the availability of real-time data collection is far from sufficient for effective science instruction. Curriculum materials that emphasize the problem-solving skills that students need make this approach effective. For example, the *Computer as Laboratory Partner (CLP)* project has implemented a real-time data collection curriculum for thermodynamics in a local middle school and refined the curriculum using principles from learning and instruction (Linn and Songer, 1988; Linn, Layman, and Nachmias, 1987; Nachmias and Linn, 1987; Friedler, Nachmias, and Linn, 1987; Striley, 1988; Songer and Linn, 1988).

One unanticipated consequence of real-time collection was that the students were far more effective at interpreting graphs presented on the computer screen than at interpreting graphs they constructed by hand (Linn, Layman, and Nachmias, 1987; Brasell, 1987; Mokros and Tinker, 1987). Essentially, the dynamic presentation of information in graphic form reinforces for students the idea that a graph represents a relationship rather than a picture. Thus, the students can link the temperature graph in Figure 4 to the evaporation of water and alcohol by watching the computer screen while waving their temperature probes. Without MBL experience, students commonly interpret motion graphs as pictures, assuming that when the graph goes up, the object being graphed is going up a hill. In the *CLP* project, Linn, Layman, and Nachmias (1987) found that the students could transfer their understanding of temperature graphs to motion graphs representing the speed of a bicycle over time.

To impart the distinction between heat energy and temperature, the *CLP* project staff devised a curriculum, identified a realistic setting. tested four versions of the curriculum, and reformulated the curriculum in light of student performance after each trial. As they reformulated the curriculum, the researchers changed the cognitive demands placed on the students, but not the activities. Enhancements to the cognitive demands resulted in a fourfold increase in learning outcomes (Linn and Songer, 1988), which demonstrated the importance of the process of curriculum reformulation. Several principles governed reformulation. First, staff on the *CLP* project sought an appropriate qualitative model for thermodynamics, consistent with a variety of research studies that had concluded that students need mental models or robust representations of scientific phenomena to understand them effectively (see Gentner and Stevens, 1983; Smith and Goodman, 1984). Many textbooks emphasize the computation of gains or losses in calories or degrees centigrade to represent heat and temperature. The *CLP* Project found that this quantitative representation of thermodynamics throws a veil of numbers over the distinction between heat energy and temperature. Ultimately, the researchers chose a qualitative model that focused on heat flow and that represented heat as a massless entity.

Second, the researchers emphasized the thinking skills of experts, including self-monitoring and self-regulation in reformulating the curriculum. Eventually, the students need to learn to direct their own learning and to be responsible for integrating their own understanding. The *CLP* curriculum transferred responsibility for complex problem-solving procedures from the teacher to the students. The *CLP* project emphasized having the teacher model self-monitoring skills and then support students as they imitated the skills (Linn & Songer, 1988); this follows research results which were reported by Brown and Palinscar (1987).

The third principle governing reformulation was motivation. Students who are motivated to study science learn more and work more independently. *CLP* students reported great excitement about scientific investigation (Kirkpatrick, 1987). The students liked working with technology, because the technology responded to them (Lepper, 1985). They reported feeling that science is important because they work with computers. The students also recognized that they were responsible for their own learning. One female student, when asked by a reporter to comment on the *CLP* curriculum, remarked, "For the first time I feel like I can find something out for myself in science"

The *CLP* curriculum allocates 12 weeks to thermodynamics rather than the usual single week to instill robust understanding. Allocating extensive instructional time to thermodynamics helped 13-year-olds gain a deeper understanding of heat energy and temperature than is typically achieved by 17-year-olds (Songer and Linn, 1988). Furthermore, although students in the *Computer as Lab Partner* curriculum spent 12 weeks on thermodynamics, they did as well as, or better than, their peers on standardized tests, no doubt in part because they were more proficient at interpreting graphs than students in traditional programs.

In summary, real-time data collection is a tool used by experts to solve complicated scientific problems. Curriculum reformulation yielded a curriculum that provided robust models of scientific phenomena, encouraged self-monitoring skills, and motivated the students to participate in science. When combined with an effective curriculum, in this case developed over numerous trials and refinements, it is possible for real-time data collection to greatly enhance the students' understanding of complex phenomena and their ability to solve new scientific problems. An additional consequence of real-time data collection is that the students gain expert skills for interpreting graphs and can transfer this understanding to new problems. As the result of experience with real-time data collection, the students are likely to perform well on graphing items on standardized tests. Thus, this tool of experts does, at minimum, impart graphing skills needed by science students, in contrast to other expert tools, such as programming.

Modeling of Scientific Phenomenon. Experts frequently use technological tools to model scientific phenomenon, such as the lifecycle of stars, the interactions of the heart and lung system, and the spread of disease. Scientists create models based on their theoretical ideas and then test them against experimental data. Recently developed software makes this tool available to students. The *STELLA (Structural Thinking, Experimental Learning, Laboratory with Animation;* High-Performance Systems, Inc., 1985) software allows students to define and test complex models without understanding the underlying mathematics.

Mandinach (1987, 1988) and her colleagues at the Educational Testing Service have taught high school biology, chemistry, physics, physical science, and history teachers to use *STELLA* and then helped them design activities to take advantage of the software in their classes. They found that their students designed complicated models and refined their models in light of empirical data, used models that other students had designed to gain understanding of scientific principles, and learned the value of computer modeling (Mandinach and Thorpe, 1987a,b).

As for other tools of experts, a curriculum to accompany *STELLA* is needed to teach the skills experts use to model scientific phenomena. To design a model, experts design a problem solution, specify the factors likely to influence the outcome, select appropriate values and ranges for these factors, and then indicate how these factors might interact in the experimental situation. Once a model has been designed and analyzed, experts test the effectiveness of the model and reformulate the model when tests reveal deficiencies. Thus, engaging in the modeling of scientific phenomena and the refinement of the model in light of empirical data offers opportunities for development of important thinking skills. Mandinach (1988) is working with instructors to develop teacher roles and curriculum materials that impart these skills.

Intelligent Tutoring. The success of expert systems for well-defined tasks, such as configuration of a computer system or analysis of a geological sample from a drill hole, has motivated developers to determine whether students could learn an expert's techniques through the use of intelligent tutors. Just as in some tasks expert scientists have been replaced by expert systems, the argument is that expert teachers might be replaced by intelligent tutors for some domains.

Emulating the behavior of expert scientists on narrow problems, however, is considerably easier than emulating the behavior of expert teachers. In addition, those designing intelligent tutors have looked to learning theory more than to the behavior of expert teachers when implementing designs. Anderson and his colleagues (Anderson, Boyle, and Reiser, 1985) have designed intelligent tutors governed by the ACT theory of learning (Anderson, 1976). These tutors teach domains with a small set of rules governing performance, such as algebra symbol manipulation, geometry proof construction, and Lisp computer programming. These tutors address the traditional goals for instruction found in textbooks. Thus, the geometry tutor teaches the rules of geometry. In algebra, the tutor teaches students to manipulate algebraic symbols, and the Lisp tutor teaches students to write Lisp functions.

Based on ACT theory, intelligent tutors developed by Anderson and his group at Carnegie-Mellon University create a model of how the student solves problems, provide feedback to guide the student to imitate the correct model, and select appropriate problems based on prior performance of the student. The tutor has difficulty interpreting responses when the student strays from an expected solution path. Tutors quickly correct students if they appear to be heading down a blind alley, but accept many valid solutions to problems.

Evaluation suggests that Anderson's intelligent tutors are reasonably successful in imparting the information they are designed to teacn, but they do not emphasize the problem-solving skills of experts. Thus, the algebra tutor has been successful in teaching algebraic manipulation, but less successful when the emphasis is on designing problem solutions. The geometry tutor is not always consistent with classroom goals because some teachers place little emphasis on proofs and others resist the representation of the geometry proof the tutor used. Although the representation offered by the geometry tutor is at least as effective as the traditional two-column proof, when students are required to produce two-column proofs, instruction using a different method requires that the students recognize the similarities and reformulate their experiences in the two-column proof format.

Other evaluations suggest that the students learn the strategies the tutor teaches but are not convinced that these strategies constitute an exhaustive set (Reiser, 1988). Thus, the students comment that although they finally solved the problem the way the tutor insisted, they believe their solution to the problem would also succeed. Providing a tutor with sufficient information to explain why alternative solutions are unsuccessful would seem to be an interesting goal for future intelligent tutors.

Thus, current intelligent tutors focus on the content goals of science or mathematics textbooks rather than on the thinking skills of experts. Furthermore, these tutors are limited to rule-governed domains. Finally, it seems clear that expert teachers perform functions not represented in theories governing current intelligent tutors, including empathizing with the student, selectively providing feedback and rarely indicating that the students are incorrect (Lepper and Chabay, 1985). The technology used for the design of expert systems provides direct feedback to learners but does not provide the thinking skills emphasized by expert teachers, including (a) encouraging the students to proceed until they recognize their own errors or (b) teaching the students to recognize when they need feedback. Nevertheless, intelligent tutors provide an ideal laboratory for investigating the effectiveness of the instructional theories used to design them. Tutors can be programmed to contrast one instructional approach with another and can reliably implement alternative instructional approaches.

Databases. Another technological tool experts use is the electronic database. Visionaries suggest that electronic databases will replace almanacs, taxonomies, and textbooks as a source of up-to-date information about a vast array of things. Hypermedia environments that allow pictures, graphs, text, and other information to be linked in non-linear patterns offer considerable promise (Goodman, 1987; Nelson, 1987). The availability of HyperCard (Atkinson, 1987) and similar products may increase effective use of databases for precollege instruction. As with other technological tools that experts use, techniques for searching, accessing, and utilizing database information remain to be clearly delineated or effectively taught.

For example, databases are particularly important in medical school instruction (Olivieri, 1987). Medical school instructors are converting complex lectures to hypermedia stacks. Thus, a lecture on pneumonia might include videodisc-presented slides of viruses and bacteria that cause pneumonia, as well as videodisc-presented images of x-rays of individuals suffering from various forms of pneumonia. All this information could be linked to a core set of principles about pneumonia, and the principles could also point to information about appropriate treatments, including different forms of antibiotics, as well as medical histories of particular patients with puzzling symptoms. Ultimately, the instructors might present such databases in the context of instruction in medical school, sold to the student as a study guide, and updated regularly. The students would then use this database throughout their medical careers to look up information when presented with complex diagnostic problems. Current databases available for precollege science instruction are less complex and modifiable than the medical school materials.

Databases thus have the possibility of encouraging students to integrate information and engage in self-monitoring. For example, databases may provide students with models of appropriate relationships between information. Whereas textbooks, by presenting information in a linear, sequential form, may discourage students from integrating it, databases can illustrate the rich relationships among information as well as systematic patterns of relationships. Hypermedia environments can go further to provide examples of the networking of ideas. Databases also provide feedback to students when they investigate hypotheses. For example, if students had a database with information about animals, they could investigate such hypotheses as the relationship between heart rate and animal size. To make these tools effective, teachers and curriculum developers need to provide models of integrated information and feedback on student progress.

Summary. In summary, the tools of experts used in science classes in Stage II provide the opportunity to use complex problem-solving skills, but are not sufficient to elicit or impart the problem-solving strategies that experts use. In fact, as programming instruction has illustrated, using the tools of experts might require novices to engage in memorizing syntax rather than solving problems. To make effective use of the tools of experts, teachers and curriculum developers have looked to research on learning and instruction for guidance and have begun to identify ways to impart the problem-solving skills that experts use.

Trial and Refinement. Finding effective ways to use principles from learning and instruction in conjunction with the tools of experts requires collaborative trial and refinement because so many complex factors interact in the classroom. All the projects incorporating the tools of experts have benefitted from trying the materials in somewhat realistic settings that involve teachers, researchers, administrators, and policy makers; analyzing the effectiveness of the materials in realistic settings; and refining the curriculum materials to make the instruction more effective. The most dramatic evidence for curriculum reformulation was found for the *CLP* curriculum, where changing the cognitive demands of the curriculum, but not the activities used in the curriculum, resulted in a fourfold increase in the students' understanding of principles of thermodynamics.

Teaching Thinking. Introducing the tools of experts into the science curriculum leads to changes in the goals of science instruction and the roles of science teachers. As knowledge proliferates, students and citizens alike will need the problem-solving and self-monitoring skills that scientists use. For example, with the availability of modeling tools, the students will have the opportunity to create and test ideas about complex phenomena, whereas lacking problem-solving and self-monitoring skills, these same students will be unable to use modeling software effectively. Thus, expert tools facilitate modification of the goals of science curricula and the roles of science teachers, moving away from emphasis on absorbing scientific knowledge and towards emphasis on designing, predicting, analyzing, and interpreting scientific events.

As discussed above, to engage in problem solving and self-regulation, students must pursue a single topic for more instructional time than is required to memorize information. Fleeting coverage often introduces more vocabulary words in each week of science instruction than are introduced in foreign language classes at the same school. To teach reasoning, it will be impossible to cover as many topics as are traditionally included in precollege science courses. Nevertheless, students need to know about the subject matter in order to design problem solutions and monitor their own problem-solving strategies. They need teachers to model problem solving, guide student behavior, and encourage self-monitoring.

Technology. In Stage II, more powerful hardware and software allowed developers to use graphics, real-time data collection, and large databases. It was possible, using workstations, to build intelligent tutors. In addition, the installed base of technology in education expanded. Nevertheless, the school market remained marginal—few schools budgeted for maintenance, much less software. As a result, most technological developments devised for schools were supported by government grants. Using the tools of experts was often the only software alternative and even for programming, few curriculum materials existed.

During this stage, Logo emerged as a possible courseware authoring environment, several computer operating systems were enhanced to include "tool boxes" that made development easier, and software designers began to realize the potential advantages of creating specialized tools for those using technology in instruction.

Stage III: Integrating Technology and Learning

At the onset, we argued that technology shapes instruction, that educators shape the development of new technological tools, and that ultimately, curriculum developers, hardware and software developers, researchers, and those involved in realistic settings will interact synergistically to achieve reformulated goals of science education.

Attempts to achieve this third stage of understanding are constrained by currently available educational settings. Many have proposed reformulations of instructional delivery to incorporate technological advance (Shanker, 1987a,b; Futrell, 1986, 1987; Linn, 1987a,b). These reformulations, however, involve political, economic, and sociological forces that are beyond the scope of this paper.

The other major issues in Stage III concern (a) synergistic combination of technological innovation with increased understanding of learning and instruction, and (b) the development of flexible, reformulatable technological tools better suited to the process of curriculum reformulation than the tools of experts that were characteristic of Stage II.

Technology and Research on Learning and Instruction

Many opportunities for synergistically combining technological advance with principles from learning and instruction are becoming apparent. Examples for cooperative problem solving, expert knowledge representation, and instructional flexibility illustrate this trend.

Cooperative Problem Solving. One example concerns teaching students collaborative problem solving. It is clear that complex scientific problems require a community of scholars and that joint problem-solving skills are needed by effective researchers. Combining technological advance with analysis of how collaborative problem solving might be taught could lead to effective ways to teach collaborative problem solving in science classes.

Some preliminary insights come from the *CLP* classroom where the instructor encouraged students to collaborate. Striley (1988) noted that the 16 monitors present in the classroom facilitated collaboration. When anomalous results appeared on a monitor, groups of students would join those conducting the experiment and attempt to jointly resolve the anomaly. Thus, the presence of feedback encouraged the students to resolve discrepancies, facilitated joint interest in scientific problems, and encouraged discussion.

Other insights came from efforts to teach students to solve complex, naturally occurring problems. Often science curricula ignore large problems that cannot be addressed by individual students, even though these problems could be effective for teaching complex problem-solving skills. Students working jointly can divide larger, more complex problems into components, work on their own piece of the problem, and then report back to the group. This model, characteristic of scientific research groups, seems equally amenable to science instruction. Technological tools can help groups of students integrate their efforts at problem solving through electronic mail and feedback on partial solutions. For example, in Pascal programming, groups can work on large, complex problems that they could not solve individually. All groups can evaluate their part of the solution individually before the pieces are combined. This innovation has the desired additional advantage that it forces the students to proceduralize their code so the code of others will not interact with it.

Kids Network, discussed elsewhere in this volume, is another example of the advantages of collaborative problem solving with technology (Tinker, 1987). Using electronic mail, students across the country can create databases of the results from research investigating the same question and review these systematically. Linn and Clancy (1988) have found another way to help students learn about large complex problems. They have students practice collaborative skills by modifying programs written by experts. Thus, the students are asked to reformulate a portion of a solution to a complex problem, to debug a program, or test a solution. The technological environment provides the students with an opportunity to analyze solutions to problems they could not generate themselves and to generate a solution that they could contribute to but not individually devise. Furthermore, these researchers provide expert commentary that imparts the thinking skills needed for the task.

To make these efforts effective, teachers model cooperative problem solving and support the students when they use the techniques. Furthermore, the curriculum emphasizes and rewards group problem-solving skills rather than only individual processes. Progress will require that curriculum developers, teachers, and software developers work together to create materials such as these.

Expert Knowledge Organization. Another opportunity for combining technology and curriculum development is imparting the knowledge organization that experts use. Expert problem solvers learn generalizable algorithms, templates, or plans that they can apply to many similar problems. These algorithms or templates are often not apparent from inspecting the expert's solution, and are often not emphasized in technological tools that experts use, although they may be implicit. As Soloway (1988) suggests, the templates that experts use can be stored in a database and made more explicit by providing shortcuts for applying common templates in model-building programming. Effectiveness is increased by providing solutions that illustrate how experts use these templates and by having teachers model the use of the templates. Thus, by reformulating technological tools as well as curriculum materials, it is possible to help students gain an understanding of templates or algorithms for problem solutions, and recognize the advantages of looking for reusable chunks of information rather than learning isolated pieces of information. Such an emphasis allows teachers to encourage their students to reflect on their own problem-solving approaches and become better at self-monitoring.

Instructional Flexibility. A third opportunity arising from a synergy between technological advance, curriculum innovation, and increased understanding of the learner is instructional flexibility. With on-line curriculum materials, large databases of software, images and catalogs, and electronic mail, teachers could tailor their instruction to their own needs and interests and those of their students. For example, a teacher could choose to provide deep coverage of motion one year and of magnetism the next. In each case, the teacher could select appropriate written materials from the database and print it for the students, order appropriate software electronically, and request appropriate activities from a database of materials in the central storage area. Rather than relying on rapidly outmoded textbooks, the teachers would draw on recently written materials. Rather than omitting images, software, and experiments because they are difficult to locate, the teachers could retrieve these from CD-ROM storage, databases of experiments or simulations, and centrally stored equipment. Finally, in this futuristic environment, the "standardized" test items for students would reflect the topics the teacher covered and the computer would interactively administer the test. These resources would not, by themselves, impart the thinking skills and collaborative learning skills students need, but they would permit teachers to focus on complex problem solving and permit students to explore interesting and timely topics. Eventually, the students could use such curricular resources to design personalized curricula or conduct sustained investigations of scientific phenomena.

Technological Tools of the Future

Each of the suggestions for combining advances in technology with advances in learning and instruction suggest reformulation of the technological environment the student uses. One of the drawbacks of implementing the tools of experts in the classroom is that often those tools are quite unmodifiable and not designed for instruction. Clearly, greater progress in Stage III development would result if those developing the materials could rapidly modify the technological environment as well as the curriculum.

Recently, authoring environments of several sorts have emerged to alleviate this situation. First, more powerful courseware authoring environments are now available. *CT*, developed by Sherwood and Sherwood (1986) at Carnegie-Mellon University, allows non-professional programmers to devise curriculum materials. Languages such as True Basic and Lightspeed Pascal access the Macintosh toolbox and permit much more rapid development of instructional materials than was possible in the past. Using the HyperCard environment, it is possible to launch other applications, such as *Lightspeed Pascal* or *STELLA*, thereby permitting developers to design an interface between the student and the application, rather than attempting to augment the application. Another new authoring system, *Course of Action* (Authorware, 1987), also integrates well with the tools that experts use, allowing developers to incorporate more pedagogical principles into technological materials. In addition, authoring environments such as Course of Action and HyperCard, combined with expert tools such as *Light Speed Pascal* or *STELLA*, allow easy reformulation of the instructional component of the curriculum, yet incorporate a complex, expert tool that would be beyond the development capabilities of most curriculum developers.

CONCLUSIONS

A great deal of progress has been made in combining technological advances with insights into science learning and science instruction to improve science education. At first, developers used technological tools to achieve the established goals of science education. In the second stage, the tools of experts formed a good starting point for effective use of technology in science classrooms, and made it possible to focus on the thinking skills experts use. The third stage forms the beginning of efforts to target science education to the complex needs of

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society. This process involves redefinition of the roles of teachers, technology, textbooks, experiments, and other influences to evolve the science programs that will restore our nation to prominence in education. To accomplish this, priorities include:

1. Develop courseware authoring environments that facilitate reformulation of educational software to improve science instruction. Such environments make it possible to tailor curriculum materials to teachers and students and greatly reduce the cost of development.
2. Take full advantage of the talents of teachers in modeling scientific processes, encouraging students to learn, and helping learners gain coherent understanding to improve science education. To do so requires improved teacher preparation, enhanced teacher status, and a reconceptualization of school organization, as well as better understanding of how teachers can use technology.
3. Provide substantial trial and refinement of innovations in realistic settings to create materials that reach their full potential. This process has succeeded in the *CLP* project, the *ThinkerTools* project, and others discussed above. In the past, the *Science Curriculum Improvement Study* (Karplus, 1975) and the *Health Activities Program* both benefitted from trial and refinement. In the area of reading instruction, the *KEEP Program* in Hawaii benefitted from this process (Vogt, Jordan, and Tharp, 1987; Tharp, and others, 1984), as did efforts to design reciprocal teaching (Brown and Palincsar, 1987).
4. Reformulate the goals and emphasis of science education to impart the thinking and reasoning skills that students need in the information age. Technological advances, such as the availability of on-line tailorable science curricula, reduce reliance on textbooks and facilitate changes in the goals. Simulations, microworlds, and on-line feedback make emphasis on the process of science more practical.
5. Encourage true collaboration among curriculum developers, precollege teachers, educational researchers, school administrators, and state and national policy makers to foster effective technological innovation in science education. These individuals must work with motivated students and supportive parents in order to fully achieve the science instruction needed in our schools. These collaborations are necessary to guide the trial and refinement that leads to effective instruction. As a result, many national groups have called for funding of Centers for Collaboration in Science Education or similar entities (for example, Linn, 1987b; Pea and Soloway, 1988).

Let us jointly address these important problems and move to impart more cohesive, self-regulated understanding of science. A philosophically sound view of science can arise if students spend time engaged in guided discovery, emulating the problem-solving skills of the teacher and using feedback from the technological environment.

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9

A Technology-Oriented Elementary School Science and Health Program: Implications for Teacher Education

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Several contemporary reports have highlighted the importance of information technologies in future education programs (Boyer, 1984; National Science Board, 1983; Linn, 1986). In 1987, therefore, it was time to take a next step in the reform of American education and design a technology-oriented science program for elementary schools—a program that uses information technologies to improve the learning and teaching of science. During 1987 and 1988, International Business Machines (IBM) and the Biological Sciences Curriculum Study (BSCS) collaborated on a study to complete such a design.

This chapter reports the results of the IBM/BSCS design study. After a brief overview and the resulting curriculum framework, the chapter includes a general description of courseware requirements, of a proposed technology-oriented classroom, and of a design for implementing a technology-oriented program. Implications for teacher education conclude the chapter.

The purpose of the chapter is to describe a technology-oriented science program. This program is not yet a reality, but it could be. After reading the chapter, the reader will probably join the authors in their conclusion that indeed, such a program is possible and that it certainly does have implications for the education of teachers of science.

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THE DESIGN STUDY

The project, a study of science and health education in the elementary school, had three major goals. The first goal was to design a framework for an elementary school science and health program consistent with current trends and needs as identified by the education and scientific communities. The second goal was to determine the appropriate uses of information technologies in elementary science and health programs. The final goal of this study was to produce a plan for implementing an exemplary elementary school science and health program that makes effective use of information technologies in learning and teaching. To achieve these goals, the study was based on, and the recommendations supported by, a thorough examination of the following: available research on teaching and learning; national reports; extant curricula; state and local requirements; and the perceptions, programs, and practices of elementary school teachers and administrators (Robertson, Ellis, and Muscella, 1988; Powell, Kuerbis, Bybee, and Malone, 1988).

During the design study, the BSCS staff gathered information from a variety of sources. This study used panels of experts who synthesized the information into a manageable form that both maintained the accuracy and integrity of the information and contributed to the construction of a framework for a K-6 curriculum that is oriented toward technology.

A FRAMEWORK FOR CURRICULUM AND INSTRUCTION

The following passage presents the goals of this curriculum in a single statement.

Children should learn about science, technology, and health as they need to understand and use them in their daily lives and as future citizens. Education in the elementary years should sustain children's natural curiosity, allow children to explore their environments, improve the children's explanations of their world, help the children to develop an understanding and use of technology, and contribute to the informed choices children must make in their personal and social lives.

- A curriculum framework should provide a view of the characteristics of the instructional materials and activities. Some characteristics of the proposed technology-oriented elementary school science and health program are as follows:
- The curriculum is based on the developmental stages and tasks of students.
- Activities within the curriculum focus on the students' lives and their world.
- A student's personal and social context is used to promote healthy behaviors and to develop scientific, technologic, and health concepts and processes.
- Activities within the curriculum contribute to learning the basics of reading, writing, and mathematics.
- Students and teachers use information technologies to enhance the learning of science.

The title for the proposed K-6 science and health curriculum is: *Science for Life and Living: Integrating Science, Technology, and Health*.

The word *Science* is prominent in the title. This is, after all, primarily a science program and ought to be recognizable as such. The program's orientation is pro-active, subsequently the preposition *for*. The program is not primarily *about* life and living, nor science *in* life and living, but it is *for* life and living. Furthermore, the design study supported an orientation toward personal and social goals. The words *Life and Living* represent the personal (life) and social (living) goals of the program.

The curriculum integrates the disciplines of science, technology, and health. In this chapter, we focus on using information technologies that enhance the teaching and learning of science. Technology as a discipline, however, is a theme of the proposed curriculum. In this program, students not only learn *with* information technologies, but they also learn *about* technology.

Scope and Sequence

A scope and sequence describes the structure of a curriculum for every grade level. Scope refers to the concepts and topics included in the curriculum. Sequence specifies when the students study a certain content area. Table 1 displays the scope and sequence for the proposed program.

Science for Life and Living:
Integrating Science, Technology, and Health

K	Awareness of Myself & Others	Awareness of My World	Awareness of Space	Awareness of Time	Awareness of Movement	Awareness of Technology

<table>
<tr><th></th><th>Organizing Concepts & Skills</th><th></th><th>Science</th><th>Technology</th><th>Health</th><th></th></tr>
<tr><td>1</td><td>Order & Organization</td><td rowspan="6">INTRODUCTION</td><td>Objects & Properties</td><td>Materials & Structures</td><td>Safety & Security</td><td rowspan="6">INTEGRATION</td></tr>
<tr><td>2</td><td>Change & Measurement</td><td>Events & Evidence</td><td>Tools & Machines</td><td>Wellness & Personal Care</td></tr>
<tr><td>3</td><td>Patterns & Prediction</td><td>Cycles & Symmetry</td><td>Construction & Testing</td><td>Decisions & Nutrition</td></tr>
<tr><td>4</td><td>Systems & Analysis</td><td>Physical Systems & Living Systems</td><td>Transportation & Communication</td><td>Self & Substances</td></tr>
<tr><td>5</td><td>Transformations & Investigation</td><td>Energy Chains & Food Chains</td><td>Design & Efficiency</td><td>Fitness & Protection</td></tr>
<tr><td>6</td><td>Balance & Decisions</td><td>Ecosystems & Resources</td><td>Constraints & Trade-Offs</td><td>Self & Others</td></tr>
</table>

Each grade level has three types of units: introductory, core, and integrated. The purpose of the introductory units is to engage students in the year's study. If the introductory units engage the students, then the students will direct their interest, enthusiasm, and motivation toward the study of science, technology, and health.

The concepts, processes, and skills of the introductory units are those of the core units, and as such, introductory units serve as advance organizers for the core units, as a preliminary integration of the concepts. Introductory units also establish such classroom routines as cooperative learning, use of equipment, and procedures for hands-on activities.

The three core units at each grade level are in science, technology, and health. Each unit has a conceptual orientation, such as these from the first grade program: order and variation (science), materials and structures (technology), and safety and security (health). Connections among science, technology, and health are made within units and among units. Each unit has a dominant emphasis, for example, science; and each unit incorporates other areas, for example, technology and health, as appropriate. This is the first level of integration. Although integration is a goal, the primary aim is to have each unit represent a concentrated study in the respective area. Each core unit is 6-8 weeks in length.

Each year's study culminates with an integrated unit. Such major topics as plants, animals, oceanography, aviation, and space are the integrating subjects for these units. The concepts, processes, and skills of introductory and core units are applied to the topics in these integrated units.

Instructional Model

An instructional model provides educational means to achieve designated goals through teaching strategies within the scope and sequence. The instructional model for the proposed curriculum has five phases: engagement, exploration, explanation, elaboration, and evaluation. Each phase has a specific function and is intended to contribute to the learning process. The instructional model is applicable to the design of print and hands-on materials and electronic courseware.

We based our proposed instructional model on a constructivist view. Constructivism is a dynamic and interactive conception of human learning. Students redefine, reorganize, elaborate, and change their initial concepts through interaction between their own selves and their environment. The learner "interprets" objects and phenomena and internalizes the interpretation in terms of current concepts that are similar to the experience presented or encountered. Changing and improving conceptions, therefore, often requires challenging the students' current conceptions and showing them that their conceptions are inadequate. The instructional and psychological problem is to avoid leaving the students with a sense of inadequacy. If a current conception is challenged, there must be opportunity, in the form of time and experiences, to reconstruct a conception more adequate than the original. In sum, the teacher can assist the students' construction of knowledge by using sequences of lessons that challenge the student's current conceptions and by providing time and opportunities for reconstruction.

The basis of the instructional model for this program is the original learning cycle used in the Science Curriculum Improvement Study (SCIS) program. We have modified and extended this learning cycle and drawn on research in the cognitive sciences—research that deals primarily with student misconceptions. Four factors justify this instructional model: (1) research from the cognitive sciences, (2) concordance of the model with the scientific process, (3) utility to curriculum and software developers, and (4) practicality for classroom teachers.

RECOMMENDATIONS FOR INFORMATION TECHNOLOGIES

The new information technologies are a significant factor in the current reform of education in general, and of science education in particular. A major goal of this design study was to determine the appropriate uses of information technologies in elementary school science and health programs. In this section, we shall discuss general recommendations for information technologies. We divided the information technologies into microcomputer courseware and video courseware. The following sections present our recommendations for microcomputer courseware. Following the recommendations for microcomputer courseware, we present recommendations for video courseware.

Microcomputer Courseware

We have catalogued microcomputer courseware according to its instructional purpose. Grouping courseware according to instructional purpose simplifies the discussion of design recommendations and focuses our attention on instructional issues. For the following discussion, we divide microcomputer courseware into eight types: information processing, microcomputer-based laboratories (MBL), telecommunications, systems modeling, programming, simulations, tutorials, and practice. The following subsections provide brief descriptions of the microcomputer courseware. We do not intend to give detailed specifications of the courseware, rather, we aim to provide the reader with a glimpse of specific courseware and to present an overview of a technology-oriented program.

Information Processing. Information processing includes using the microcomputer to enter, store, revise, and print hard copy of text, including graphics and alpha-numeric characters. The information processor will have the extended abilities to process and present both tabular (numeric and alpha), graphic, and audio information; to insert figures, charts, pictures, graphs, text, and audio into a computer program; and to accept text, data, graphics, and audio from other utilities (for example, optical scanner, videodisc, compact audio disc, telecommunications, and MBL).

A text editor is the core of the information processor. The user can enter text using the keyboard, retrieve it from a storage medium, such as a disc or CD ROM, and edit the text easily. The microcomputer can display the text in a variety of font sizes, styles, and colors. The text editor will include desktop publishing capabilities with which the user can integrate text and graphics into a single document. The user can edit the text using the keyboard and a pointing device, such as a touch-screen or a mouse.

The information processor will include the capabilities of a graphics editor. The user can enter, edit, store, and retrieve high-resolution color graphics, create animated graphics, and insert and relocate those graphics within text and computer programs. The user can retrieve graphics as pictures from computer storage media or as video stills or motion segments from a videodisc. The user can use pointing devices—such as a touch screen or a mouse—to draw, animate, and move graphics. The microcomputer will store a collection of commonly used graphics for retrieval, editing, and placement in text or computer programs.

The information processor will include the capabilities of an audio editor. The user can enter, edit, store, and retrieve high fidelity audio, create sounds and music, and insert and relocate those sounds within computer programs. The user can retrieve sound and music from videodiscs, records, tape players, microphones, music synthesizers, and compact audio discs. The user can store collections of commonly used sounds and music for retrieval, editing, and placement in computer programs.

The information processor will include the functions typically found in spreadsheet, database, statistical analysis, and graphing programs. The user can enter alpha-numeric data into the database, perform calculations with and manipulations of the data, and display the results as text, as tabular data, or as pie, line, or bar graphs. Calculation capabilities will include descriptive and simple inferential statistics, scientific-mathematic functions, and searching and sorting routines.

With the database, the students will have the ability to obtain access to information, to enter new information, to modify existing information, and to save the modification. This database will use two sets of data. One set will be data that the developers provide with the curriculum; this set will contain thousands of items used in the instructional units. The second set of data will be the information the students gather and enter to answer specific questions. The database will store information as text, numbers, graphs, pictures, or video or audio segments.

When creating a document and when running instructional software, the user will have available all components of the information processor. Instructional programs will use the information processor to create and manipulate text, data, and graphics. The text editor, graphics editor, audio editor, database, and data analysis programs will all share information and will integrate the information into one document or program.

Microcomputer-Based Laboratory. In the microcomputer-based laboratory (MBL), the students will use the microcomputer to gather, store, display, manipulate, and analyze data. MBL software and hardware packages will process data collected through probes and sensors. Data types will include measurements of temperature, sound, light, pressure, distance, resistance, voltage, heart rate, blood pressure, and electro-dermal activity. The program will take input from an internal or external clock, keyboard, pointing device, systems modeler, and graphics pad.

The database (in the information processor) will store and display all data gathered from probes and sensors. MBL data display will take many forms: a line graph over time, pie graph, bar graph, meter, data table, graphic design, voice print, sound waves, and histogram. Options will exist for automatic and manual scaling and re-scaling of graphs, *hearing* the graph, mathematical and algebraic manipulation of the data, hard-copy printing of all data displays, saving of data and graphic displays to disc, and movement among the display formats without the loss of data.

Data gathered by the MBL package will control the operation of the systems modeler, interactive videodisc, and simulation programs described elsewhere in these specifications. The system must have a provision for controlling the operation of other systems while gathering real-time data or retrieving data stored in the database.

Telecommunications. With telecommunications, students will interact with large science and health databases, such as data on diseases or research, and they will share information about their investigations with students and scientists. Telecommunications will allow students to share information about science and health, and thus participate in the social enterprise of doing science and practicing health, which is essential in developing a proper understanding of the nature of science and health.

Telecommunications involves transferring information from one site to another using microcomputers linked via cables, telephone lines, satellite communication systems, or a combination of the three. The telecommunications package required for science and health education includes the ability to search databases and information networks (for example, CompuServe), to share data with remote personal computers, to interact with networks that specialize in conferences, and to send and receive electronic mail. The information processor will be used to enter, edit, manipulate, and store the information gathered through the telecommunications package. The transfer of information with the package will be a simple process that an upper elementary grade student or teacher can follow.

Systems Modeler. A systems modeler will be available to enable students, teachers, and developers of the curriculum to express their thoughts about how systems work. With the systems modeler, the user can construct a structural diagram of the components of a simple system and define the interrelationships among the components. The systems modeler will be a tool that reduces the need to simultaneously think about the components, variables, values of variables, and the equations defining the relationships among the variables. The systems modeler also will allow the user to define relationships in several qualitative and quantitative ways, thus reducing the mathematical abilities required of the user. The systems modeler will give students and teachers who lack skills in sophisticated mathematics the opportunity to think about complex scientific phenomena in a concrete and direct manner.

Input for the systems modeler will be in the form of data from experiments (entered via keyboard or MBL), equations, qualitative relationships among variables, and graphs. The student will construct the diagram of a system by using the information processor to enter and edit graphics, data, or text. The student can then manipulate the graphics, data, and text by using a pointing device, such as a touch-screen or a mouse. The microcomputer will have a collection of systems for retrieval and analysis by the student. Also, instructional programs will use the systems modeler to construct simulations and to provide the user the opportunity to study those systems. Output will be in the form of icons, graphs, meters, data tables, or numbers.

Systems modelers will teach cause and effect relationships and the systems approach in modeling such phenomena as a food web, population growth, digestion, sexually-transmitted disease, drug abuse, pendula, plant growth, and soil erosion.

In simple cases, students will observe a system and then use the systems modeler to construct a diagram of the components of the system and to define the interrelationships among the components. In other cases, the program will present the students with a system or a simulation of the system and its model. By manipulating the inputs and the relationships among the components and by observing the resulting outputs, the students can explore the simple systems they create and the complex systems provided by the developers.

Programming. In districts that teach computer programming to children in the elementary school, the teachers can encourage the students to use their programming skills for solving problems in science and health. An optional component of the educational computing materials, the programming language will be a form of the LOGO language or a similar language. The language can be taught as a component of the computer literacy requirement and used as a tool when learning science and health.

Simulation. The microcomputer courseware also will include simulations for imitating imaginary or real phenomena. The student will have opportunities to provide input to the simulation. To involve the student in the simulation, the computer program will prompt the student to make choices from a list of options or to manipulate objects that the program graphically represents on the screen; by doing this, the program enables the student to control the simulation. With simulations, the students can react to events, such as changes in digital value (temperature), audio tones, speed, or even graphic representations of the phenotype of offspring from a genetic cross. The input requested of the student will simulate, as realistically as possible, the activities that scientists do, and thereby will actively involve the students when they are learning science.

Tutorial. Microcomputer courseware for the program will incorporate an intelligent tutor. The tutor will be a component of the microcomputer-based laboratories, systems modelers, programming languages, information processors, telecommunications, simulations, and practice packages. It will be an unobtrusive feature of those programs and available when needed.

A good tutor can engage the student in learning activities by asking questions, giving directions, providing clues, and giving feedback. The questions can focus the student on the phenomena the student is studying and on procedures the student must follow. The directions can guide the student in the performance of the activity. The program can give clues that help the student make observations, inferences, and conclusions. The clues, however, should not provide the answer and the program uses them only when the student reaches an impasse. There can be feedback that indicates the state of completion of the task—successful, partial, incorrect, or incomplete.

Practice. Teachers will use the microcomputer to provide the students with practice that is not achievable by other methods, or to reinforce activities presented in other modes. In general, practice packages will use the strengths of the microcomputer to provide learning experiences that are interactive and appeal to the senses of sight, hearing, and touch. Practice packages will use microcomputer graphics, video, and MBL. Practice will not be limited to simple skills, but also will include complex thinking skills, such as controlling variables, forming hypotheses, and making decisions.

When used, practice will be part of an overall instructional package. For example, the computer acting as a tutor might introduce the concept of classification; then it might use a simulation to demonstrate classification; finally, the computer tutor might follow up by providing opportunities for the student to *practice* the skill. The computer tutor can oversee the practice session, and provide only positive and negative feedback when the student is making satisfactory progress; but if the student is having difficulty, the computer should interrupt and provide remediation.

Video Courseware

The technology-oriented program will include three types of video presentations: sequential, archival, and interactive instruction. All three types will be used extensively throughout the grade levels. Sequential video can present an uninterrupted flow of information. It will use motion segments, still frames, and time-lapse photography to engage the students and to present new information in a dynamic manner.

Interactive video will give students the chance to explore the concepts and information in great depth and will allow the user to control the learning experience. The curriculum will use two kinds of interactive video: an archive of still and motion images and an interactive package that uses motion and still images to instruct. These two types parallel the computer applications of database and computer-assisted instruction (tutor, practice, and simulation). With archival video, a student is in complete control and can explore the archive of images while seeking to understand a topic. Students will control interactive video by using the keyboard or a pointing device to respond to prompts from the microcomputer to answer questions and to seek more detailed information about the video. With interactive instruction, however, an intelligent tutor will control the interactions between the computer program and the student. The intelligent tutor will teach the student the major concepts and skills for the topic.

The video segments will be stored on laser-read discs—such as videodiscs and compact discs—that make retrieval of the information easy and prompt. When using interactive video, the microcomputer will overlay the video display with text and graphics and the user will point to objects on the video as a method of input. The microcomputer can capture still frames and sound from the videodisc and incorporate them into computer programs. In addition, the microcomputer can use the information processor to incorporate the still frames into printed text through its desktop publishing capabilities.

A TECHNOLOGY-ORIENTED CLASSROOM

In the last section, we described educational courseware. In this section, we focus on questions such as: How will students and teachers use the courseware? and What does the classroom look like? We answer these questions through a discussion of a technology-oriented learning environment and the characteristics of that environment. We shall recommend uses for educational technology hardware for elementary school science and health.

To accommodate varied learning styles and to maximize student learning, we recommended a variety of educational technologies, such as text, manipulative materials, video, and microcomputers. The learning environment will allow many opportunities to achieve mastery of the concepts, processes, or skills and thereby overcome weaknesses specific to the learner, the teacher, or the activity.

By providing several learning tasks that appeal to different senses and learning styles, we ensure that students will have repeated exposure to the same skills and concepts in different contexts. The following sections contain discussions of two components of the learning environment—classroom organization and educational technologies.

Classroom Organization

The classroom organization will both encourage the engagement of teachers and students in the learning activities, and be flexible enough to accommodate the varied activities. Some learning tasks the teacher will conduct with the whole class, and others, the teacher will conduct in small groups or individually. Some activities the teacher will conduct simultaneously, with all students working as a group or in small groups; other activities the teachers will conduct with individual students or small groups working on differing tasks in a multi-task environment.

Justification for the grouping of students is based on our understanding of how professionals conduct their scientific inquiries, how students learn, and how teachers manage classrooms. In general, science is an activity conducted by groups of scientists; in many situations, students learn best when interacting with their peers; and, teachers can manage classroom activities best when students are working in groups, thus reducing the numbers of student-teacher interactions and making those actions more meaningful.

Teachers can efficiently conduct whole-class activities, such as giving directions, demonstrations, and large-group discussions. But, learning is also an individual activity; therefore, evaluation of a student's learning will focus on the individual, and the teacher will be able to provide enrichment and remediation on an individual basis.

Figure 1 illustrates the organization of a model classroom that is a learning environment oriented toward technology. The central location of the teacher's work station signifies the central role of the teacher in the learning process. The work station will provide the teacher with tools to assist student learning and to conduct direct instruction with the whole class. The usual teaching technologies will still be available: a porcelain board (substitutes for the chalkboard), an overhead projector, a desk, and writing materials.

In addition, the teacher's work station will have a microcomputer with a large-screen monitor, a laser printer, and a modem. The teacher's microcomputer will be the central server for the students' microcomputers, and it will manage records of student learning. The teacher's microcomputer will connect to other computers within the school, within the school district, and outside the school system. With the large-screen monitor the teacher will conduct class activities that use the microcomputer and videodisc player. With the printer, the teacher will make hard copies of student work and reports of student progress and will prepare such instructional materials as worksheets. The modem will send to other sites information about the students and it will also gather information for instructional activities from other sources.

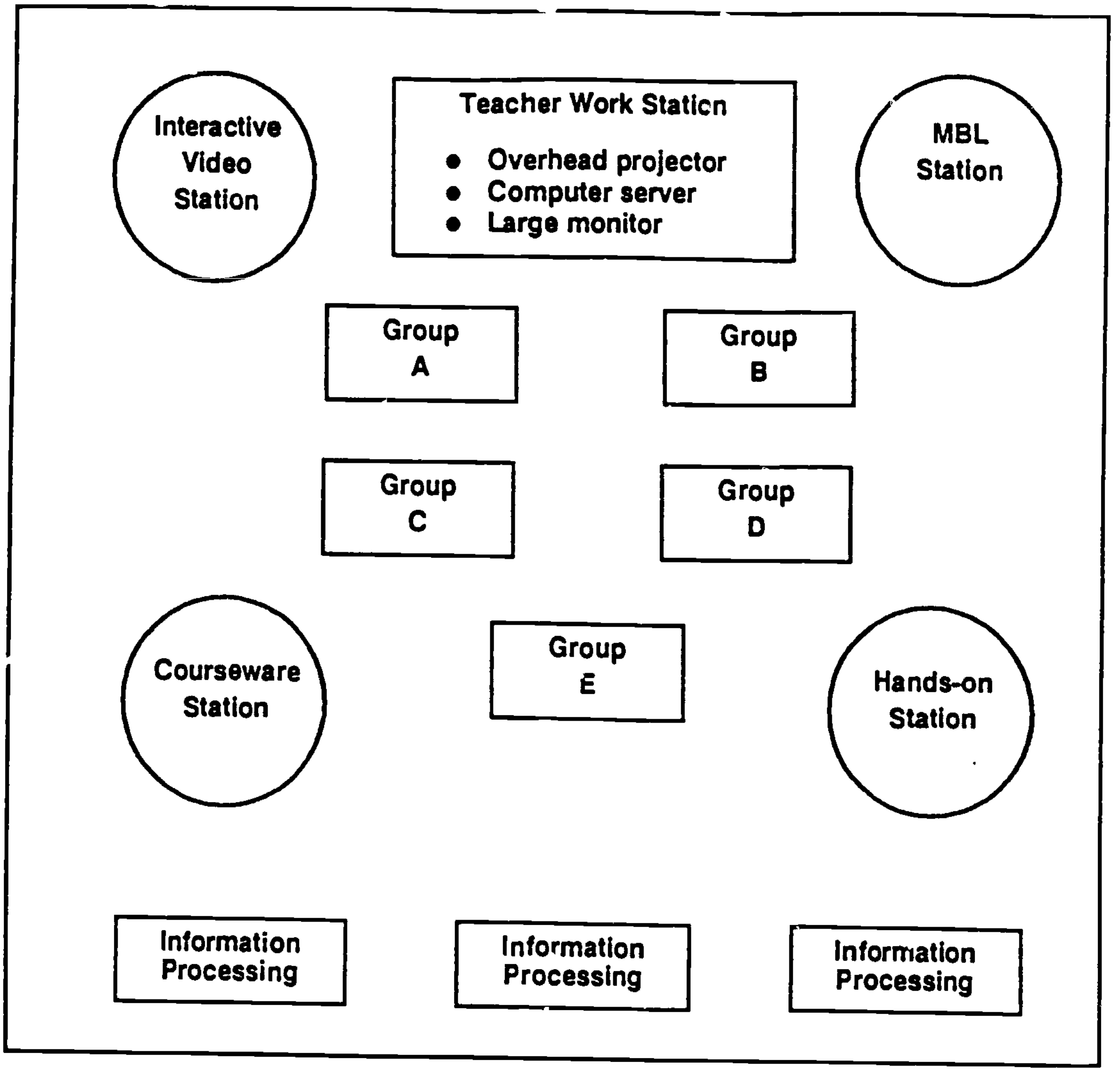

Figure 1: Organization of a model classroom

Students will work in cooperative-learning groups, so there will be a table for each group. The students will work at these tables independently, as a group, or during whole-class activities.

At various times during the units, the students will work at learning stations. Learning stations are justifiable because they provide a variety of activities cost-effectively. If a teacher conducts several activities simultaneously, then for a particular activity the teacher needs only enough equipment and materials to accommodate one group, rather than the class. We designed the following learning stations for the classroom: an interactive video station, an MBL station, a courseware station, a hands-on station, and information processing stations. Each station will be large enough to accommodate a group of five students. At each station, the students will conduct one set of activities.

The station for interactive video will present interactive video, sequential video, or audio without video. For large group presentation, the interactive video station and MBL station will connect with the large-screen monitor at the teacher's work station.

Educational Technology Hardware Requirements

Broadly defined, educational technologies are tools that help students to learn and teachers to teach. Educational technologies of particular value for elementary school science and health include printed materials (textbooks, teacher guides, science trade books, reference books, workbooks, worksheets, and laboratory manuals), living and nonliving objects and phenomena, learning aids (blocks, buttons, rulers, balances, pendula), computing systems, video systems, audio systems, and writing aids (paper, pencil, colored markers, dictionary). For this design study, we concentrated on analyzing the role of electronic media—microcomputers and video. This learning environment will require three microcomputer hardware configurations: (1) personal work stations for students to run courseware and to process information, (2) a microcomputer-based laboratory (MBL) station for the students to conduct activities, and (3) an interactive videodisc station for running videos and software.

Personal Work Station. A student, or small groups of two to five students, will require five personal work stations for educational courseware and information processing purposes. During the units of study, the students will regularly use the information processor to record personal observations and explanations of scientific phenomena. When they work in small groups and as individuals, the students will use courseware to refine the science concepts and skills that the teacher has introduced and elaborated upon either at other stations or through other activities. It is possible to have work stations dedicated to information processing. To maintain flexibility and to ensure maximum use, however, all personal work stations will have the following components:

- a screen capable of displaying color graphics
- a keyboard
- a minimum of 1 megabyte of Random Access Memory (RAM)
- a pointing device (touch screen and/or mouse)
- an adapter for network communication
- a connection to a laser printer
- a capability for high fidelity sound
- an ability to access a CD ROM player

The personal work station will support color graphics and smooth animation. The screen will display graphics in color and text in variable fonts. The work station will have a minimum of one megabyte of memory. The heavy dependency on color graphics and the critical need for animation dictates a memory size exceeding that commonly available on microcomputers.

The work station will support two kinds of pointing devices: a touch screen and a mouse. Children will use the touch screen heavily in the lower grades, and the mouse in the upper grades. Neither device is satisfactory for all software, although the touch screen is more suitable than the mouse for controlling the interactive video system. The mouse would be suitable for construction sets and text editors. The pointing device would enable selecting and moving graphic objects on the screen.

The system will have an adapter for network communication so that the operator can retrieve programs from file servers rather than from floppy discs.

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The network will have at least one laser printer that is capable of printing graphics as well as text of varied font styles and sizes.

Sound output will be of high enough quality to reproduce pleasing musical sounds and natural human speech. A sound synthesizer, capable of generating four independent voices simultaneously, will be available.

Several applications require information databases, so the system will have a CD ROM player to provide fast access to those data. The CD ROM player will be part of the teacher's work station.

Microcomputer-based Laboratory Station. One work station will be used for conducting (MBL) investigations. The teacher also will use this work station for demonstrating MBL investigations. At the MBL station, the microcomputer will connect to equipment that can provide input from investigations and output to control electronic devices.

The microcomputer component of MBL activities will serve a dual purpose. First, it will provide graphical and numerical representations of data, such as graphs, voice prints, wave forms, meters, and data tables. Second, it will guide the students as they perform laboratory experiments by providing tutorial assistance, help, and evaluation. To support these functions, the system will have the full capabilities of the personal work station, plus a variety of laboratory probes and interface devices. The components of the MBL station will include

- a screen capable of displaying color graphics
- a keyboard
- a pointing device
- a serial port and cables
- several laboratory probe devices
- a multi-purpose interface box
- an infrared communications link
- a motor controller

Laboratory probes will include

- dual thermometers
- a microphone/speaker
- an ultrasonic distance measuring device
- several photogate timers
- a pressure sensor
- an electromyogram probe
- an analog potentiometer
- a volt-ohmmeter
- a clock/calendar

Interactive Videodisc System. A classroom oriented toward technology must have both sequential video (not dependent upon student or teacher input during the presentation) and interactive video (accepting and processing input during the presentation). Although sequential video does not strictly require computer control, computer control is highly desirable because the teachers and students can use the interactive videodisc system (IVD) to prepare tailor-made presentations of the sequential video.

The station that runs the interactive video will have all of the capabilities of the personal work station plus a high-resolution color monitor, a high-quality sound system, an overlay graphics adapter, and a computer-controlled videodisc player.

The computer program will provide a graphical menu to select still frames and motion sequences from random locations on the disc; the program also will display the contents of the videodisc, will prompt for selections, and will prepare the presentation in the requested order.

The user will control interactive video by input from a touch screen or mouse as the laser disc presents the video material. The program will branch to other segments, or superimposes text or computer-animated graphics on the screen. Touch regions will activate and de-activate synchronous with the video material.

A DESIGN FOR IMPLEMENTING THE TECHNOLOGY-ORIENTED PROGRAM

We have learned much during the last two decades about how change occurs in schools. First, to fully integrate an innovation into a school's curriculum takes time—typically between three and five years. Second, to incorporate a new technology-oriented science and health program into the school curricula, the principal, teachers, and other staff must change their current practices. Third, when the principal sanctions an innovation and designs a strategy to implement it, change will likely occur. Fourth, principals more effectively foster change in their schools when they establish a team for facilitating the change. Finally, when teachers have collegial support and collaboration, their teaching practice will probably change. These principles underscore this discussion and are instructive in planning strategies for implementation.

Knowledge about change in schools and technology-oriented curricula suggests that the following recommendations are important components of an implementation plan for a technology-oriented curriculum

- Identify the important components of the innovation.
- Use the principal as the change facilitator for the innovation.
- Support and train a team for facilitating change. The team should include the building principal, an experienced teacher, district supervisors for science and computer education (if there are such staff), and outside consultants (from universities, the publisher, or the curriculum developer). During a three- to four-week workshop, members of the team should learn the principles of the content, technologic, and pedagogical aspects of the curriculum and how to use consultation and coaching skills with teachers.
- Assist the change-facilitation team in developing an action plan for implementation. An action plan includes a description of an ideally implemented curriculum, annual goals, and specific, measurable objectives.
- Foster collegial support and coaching among teachers. Team planning among teachers, visits to one another's classrooms, and informal conversation about the curriculum should become de rigueur in the school.
- Develop a multimedia approach for training in the technologic, content, and pedagogical aspects of the curriculum. The developers should provide multimedia training materials on interactive video, working

collaboratively in small groups, and working with MBL and microcomputer courseware. The teachers should participate in an initial training workshop, in follow-up seminars during the year, and in team meetings within their building.

- Ongoing support of the teachers should be provided until the curriculum is fully implemented.

Important aspects of ongoing support are

- A technical expert who can consult with the teachers on a weekly basis.
- A curriculum specialist or a supervisor from the district office should visit the school on a biweekly basis and monitor implementation progress.
- To monitor implementation, the change-facilitation team should work closely with both the computer consultant and the support person from the district office.
- Collegial support and coaching among teachers should become standard practice.

IMPLICATIONS FOR SCIENCE TEACHER EDUCATION

Some will no doubt criticize the program, courseware, and technologies we designed as too futuristic. The criticism is especially true if one only examines contemporary elementary classrooms. We think this is an incomplete and inadequate assessment. One must also examine social changes, trends in education, and the influence of private enterprise in the area of information technologies. This expanded view suggests that significant changes can be expected in education during the next decade. Furthermore, one important factor in the current reform is the addition of information technologies to the educational menu from which teachers pick and choose.

It seems to us that two points are clear. One is the need to construct a vision of what technology-oriented classrooms might be like. This was one purpose of the chapter. The second point is the need to think about the teacher education issues attendant to the implementation of information technologies in school science programs. The latter is the aim of this AETS yearbook, and this present discussion. Our recommendations for teacher education are brief because this was not the primary purpose of the chapter.

Traditional Education for Elementary School Science

Several demands of the program we designed are within the range of current teacher education. For example, there should be continued emphasis on "hands-on" approaches to science teaching. And, elementary teachers need a broad understanding of the life, earth, and physical sciences and a good understanding of technology—as a discipline. In addition, we recommend the integration of health into the elementary science program; elementary teachers, therefore, need training in health education.

There is also the need to develop some context for understanding the concepts of these disciplines. Here, the contemporary orientation termed "Science-Technology-Society" (Bybee, 1987) may be a real benefit to teacher education programs. Also, examination of new NSF-funded elementary science programs can provide an excellent orientation toward topics and concepts that elementary teachers will need to know and apply in the early 1990s. (See, e.g., Bybee and Landes, 1988; Foster, Julyan, and Mokros, 1988; and Sandler, Worth, and Matsumoto, 1988.)

Education in Information Technologies

Because there is limited time in the science education program for prospective (and practicing) elementary teachers, care and discretion must be exercised in designing the program. The general aim of the information technology program should be introduction, awareness, and *practical use* of courseware. We emphasize the practical use aspect of the statement. Elementary teachers do not need to know all the intricate electronics of a microcomputer or the complexities of programming in order to use courseware effectively. Teachers effectively use the overhead, television, movie projector, and other resources without a thorough knowledge of optics and electronics.

We have a second recommendation. Just as we have found that involving teachers in hands-on activities is an effective way to prepare them to use hands-on approaches of instruction, so too with information technologies. We suggest that elementary teachers actually use the various systems and types of courseware described as they learn in their education courses and content courses. For example, elementary teachers should have some experience with information processing, telecommunications, microcomputer-based laboratories, simulations, tutorials, and practice programs.

A third recommendation has to do with the technology-oriented classroom. To the degree possible, prospective and practicing elementary teachers should experience a classroom similar to the one we described in this chapter. They should get practice using the various student work stations (MBL, IVD, information processing) and the teacher's station.

The final set of recommendations has to do with teaching methods. Here we think two areas need emphasis. First, instructional issues need consideration. Most new elementary school science programs have a teaching model. Teachers need to understand these models at both the practical and theoretical level. Also, they should have some understanding of these models at the programmatic level. That is, how they are incorporated into the curriculum and what they can achieve. Another way of saying this, in the context of this chapter, is that courseware can be designed for a specific, important purpose (e.g., for practice, to introduce concepts, to collect data) or for nonproductive purposes (e.g., as something to do on Friday is to misuse the software and the instructional model).

Our second area of recommendations for teaching methods has to do with the social psychology of student groups. Many contemporary programs have incorporated cooperative learning models. This approach has a substantial base of research and a significant practical value in the elementary school science program that is oriented toward technology. We shall not review the research on cooperative learning. (Roger Johnson has done that in another chapter in this AETS Yearbook.) The practical value of cooperative learning has to do with the fact that students will work with information technologies in groups. (We also note that this situation also applies to traditional laboratory work in science programs.)

An awareness of, and experience with, cooperative groups is an important first step toward teachers using information technologies. Perceived classroom management issues can be alleviated through an introduction to and use of the social psychology of groups.

One final note on classroom management. The technology-oriented classroom *can* reduce many management issues. But, teachers must be familiar with the hardware and software. If they are not familiar with information technologies, or are required to develop a familiarity with them while teaching, then there is some likelihood that they may not become familiar enough with the technologies to use them effectively and efficiently. Resolving this problem suggests the need to incorporate an introduction to using microcomputers for classroom management into preservice and inservice programs.

CONCLUSION

This chapter presents a vision of a technology-oriented elementary school science program. The program is based on a design study supported by IBM and conducted by BSCS. While the view is somewhat visionary, it also reflects current trends in education. If future elementary classrooms are anything like the classroom presented here, science teacher education programs need revision.

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10

Cooperative Learning and the Computer

Roger T. Johnson
David W. Johnson

During the past 40 years, education has focused on curriculum: how students interact with material. There has been some interest in how teachers and students interact and a growing interest in how current and future technology will affect the classroom. What researchers have ignored almost completely is the interaction between students. How do students interact with each other as they learn? This is just as important as the curriculum and the interaction between the teacher and student and in some ways more powerful than these. When introducing appropriate use of computers into science classrooms, we cannot afford to continue to ignore the impact of the interaction between students and to make the same mistakes that "traditional" education has made.

When in the science classroom, the students can interact with each other in three basic ways:

- *Competitively,* in which the students try to do better than the other students in the classroom to be at the "top" of their class.
- *Individualistically,* in which each student works toward a set criteria without needing to worry about the efforts of other students.
- *Cooperatively,* in which the students work toward a mutual set of goals, and in which none has finished unless all members of the group have some understanding of the concepts and know that all members have learned and can explain the concepts.

Of the three patterns of interaction, competition is presently the most dominant in American education. A vast majority of students in the United States perceive school as a competitive enterprise in which it is important to do better than other students. This competitive interaction is widespread when students enter school, and it grows stronger as the students progress (Johnson and Johnson, 1983). This perception on the part of students is not hard to understand.

Teachers have been led to believe that a *good* class is one in which the students are separate, and quiet. "Save that for the hallway," and other admonishments clearly give the message that, in the classroom, the teacher does the talking. Many teachers and software designers have automatically shifted this "do your own work" expectation to the computer and assume they should structure computer-assisted instruction individualistically. Research on how people learn best, ironically, goes in exactly the opposite direction.

RESEARCH ON INTERACTION BETWEEN STUDENTS AND LEARNING

Researchers have conducted hundreds of studies, some dating back to the late 1800s, that compare students who were learning cooperatively, competitively, or individualistically. Reviews of this body of research (Johnson and Johnson, 1975, 1978, 1983; Johnson, Johnson and Maruyama, 1983; Johnson, Maruyama, Johnson, Nelson and Skon, 1981; Sharan, 1980; Slavin, 1983) indicate that cooperative interaction when compared to competitive and individualistic provides:

- Greater achievement and retention of material.
- Greater achievement motivation.
- More frequent use of higher level reasoning strategies.
- More positive attitudes toward school, subject area, and instructors.
- More positive attitudes toward classmates regardless of handicaps, gender, ethnic background, or level of ability.
- Greater self-esteem, psychological health and collaborative skills.

The research base is so broad and so extensive that it leaves little doubt that, while teachers have been taught to want individualistic, quiet classrooms, more learning occurs when students work together, talk through the material with each other, and support each other's work.

In a set of studies done in cooperation with Apple Corporation and schools in St. Louis Park, Minnesota, computer-assisted instruction with cooperation promoted higher daily achievement, more successful problem solving, and higher performance on factual recognition, application, and problem-solving test items than did computer-assisted instruction in competitive and individualistic conditions (Johnson, Johnson, and Stanne, 1985a, 1985b). We need to prepare teachers to structure their students' work at the computer on the basis of how people learn best, rather than on tradition.

ASSUMPTIONS FOR COOPERATIVE INTERACTION AT THE COMPUTER

Cooperation at the computer provides students with the opportunity to talk through, explain, and summarize the material. This oral explanation is part of the reason that achievement increases and students retain more material in the cooperative setting than in competitive and individualistic settings. There is something important in taking thoughts and putting them into words. Teachers, therefore, need to structure and encourage this cognitive translation when students are working with computers.

Social modeling is a powerful influence when heterogeneous groups of students work at the computer. Students who are enthusiastic and knowledgeable about the computer are role models for other students and are especially effective when the material is complex. Social modeling is powerful when comparing one's own cognitive strategies to others' strategies—not only picking up new strategies, but becoming more conscious of one's own.

Peer support and encouragement are much more potent than any computer screen that displays: "Nice job!" The social support of the cooperative setting not only is invaluable for persistence, but cooperative groups handle failure more constructively than do individuals. The warmth and approval of one's peers are especially important when tasks are difficult or frustrating. In addition, the feedback from peers is specific and relevant to the situation and therefore more likely to be acted upon.

The obvious benefit of the cooperative group at the computer is that the students need fewer computers. Because most schools cannot afford a computer for each student, this is an important role of cooperative groups. The research indicates, however, that even if the school could afford a computer for each student they should not want students to work individualistically on most computer tasks.

Finally, there is evidence that students prefer to work cooperatively at the computer (Hawkins, and others, 1982; Levin and Dareev, 1980; Muller and Perlmutter, 1985). Even when playing computer games in an arcade, the students will cluster around one computer and share the experience. It appears that the students are much more likely to seek each other out at the computer than they normally would for other class work. The computer may not only be a good place to cooperate, but may also be a good place to introduce cooperative learning groups in schools.

THE DIFFERENCES BETWEEN TRADITIONAL GROUP LEARNING AND COOPERATIVE LEARNING GROUPS

There is a vast difference between just a cluster of students at the computer and a group of students working cooperatively at the computer. Just putting students close to one another seldom produces cooperation. There are a set of basic elements in a cooperative relationship that teachers need to structure in the environment.

The most crucial aspect of a cooperative learning group is *positive interdependence*—starting with a mutual set of goals that tie the group together into a "sink or swim" relationship. Students need to know that they can not be successful on a cooperative task unless the other students with whom they are linked are also successful. It is important, therefore, for teachers to be adept at structuring clear "group goals" that leave no room to doubt the cooperative tie. One example would be a physics class in which the teacher has put students into heterogeneous groups of three to prepare each other for a quiz. The group goal is to make sure that each member of the group scores above the 70 percent level on the quiz. The teacher can further strengthen the group goal by giving five bonus points to each student if their group is successful (all above 70 percent).

In a computer setting, a teacher might ask a group to produce one product that each of them signs, signifying that each agrees with the answers and can explain them. Other ways to strengthen the positive interdependence are to assign complementary roles (for example, Keyboarder, Checker, and so forth) and to make sure they have only one set of materials (for example, one computer).

The leading complaint of older students about working in groups is the "hitchhiker" who does not work, but will sign anything. A cooperative learning group that functions well has *individual accountability*. Each student has to contribute to the learning, know the material, and be able to explain it. The reason for structuring cooperative learning groups is to produce stronger individuals—more students who know more material, feel good about themselves, and are accepted by their peers. The teacher needs to establish, as part of the goal for the group, the rule that *each* student needs to know the material. The teacher should then follow up by giving a test to all members of the group or by interrupting a group working at the computer and select one student at random to explain what is being learned. These oral exams give the message that it is dangerous to hitchhike or, more importantly, that it is dangerous to allow someone in your group to hitchhike.

There is no magic in structuring positive interdependence and individual accountability. It is the *promotive behaviors* that the group goal encourages and the responsibility for self and others that make the group powerful. It is important that students *talk* through the material, *check* to see that everyone understands and can explain, give one another *support and acceptance*, stay with the group (cognitively and physically), and *celebrate* successes as a group. It is important to keep the groups small (two to three members), so that each student gets a chance to talk through the material and feels in control of the situation. The groups need to be heterogeneous enough to have at least one good role model in each group if possible. Positive interdependence and individual accountability encourage promotive behaviors.

Even when students recognize the need to cooperate and want to, they are not always skillful at it. Years ago, when students came from large families and worked together as a family, it may have been the norm, but not now. Teachers will need to teach students collaborative skills so groups become more effective. Working cooperatively at the computer also offers a great opportunity to teach communication, trust, leadership, and skills for resolving conflicts. Teachers can introduce these behaviors as roles assigned to members of the group (for example, checking for understanding, encouraging all members to share ideas, and so forth). If teachers would teach students to listen to each other with more care and to give more support and acceptance for other students' ideas (even when they don't agree), it would be a great gift to students—certainly as important as any subject matter. Teachers teach and students learn communication, trust, leadership, and skills for resolving conflicts like any other skills.

In any classroom, if the students are working in small groups at the computer and the teacher is grading papers at the desk, planning for the next hour's class, or is anywhere except in the middle of the groups, a basic element of interaction between the teacher and students is missing from the instruction. We need to train teachers to *monitor the cooperative learning groups* not only for cognitive progress, but for the interpersonal and group skills as well. The only way to know if the lesson needs to be retaught tomorrow, or what specific behaviors need to be taught to make the groups even more effective, is to be there, gathering data. Teachers can systematically gather data at least three times (beginning, middle, and end of lesson) so that feedback is accurate and promotes growth.

Students need time to *evaluate how well their group is functioning* and what they need to do to be even better. Teachers need to know how to structure the students' evaluating of cooperative behaviors so that the evaluating behaviors become real and useful rather than superficial. Members of the group who instantly agree that they were a "great group" (and say they have finished evaluating their group) have not evaluated their group. Group evaluation is digging deep into what it was that made the group "great" and what specific behaviors they could add to make the group even greater. If there is specific feedback from the teacher as well, students will need time to process it. If students never focus and reflect on their group behaviors, the teacher can never expect the groups to improve.

Researchers have written much on the strategies teachers need to provide these basic cooperative elements to a learning situation (Johnson and Johnson, 1987; Johnson and others, 1986). Organizing a cooperative learning environment is a complex skill and not gained without practice. Examine the three models for the use of cooperation at the computer in the next section of the chapter and make sure you can find the basic elements of cooperation in each.

MODELS OF COOPERATIVE LEARNING AT THE COMPUTER

There are numerous ways of combining cooperative learning and computer-assisted instruction. Teachers may have students work in cooperative learning groups at the terminal itself or away from the computer to plan the material for input into the computer at a later time. Teachers may structure cooperatively almost any learning task students conduct at the computer. Although researchers have shown cooperative learning procedures to be effective on a wide range of tasks, including simple drill and practice, the effectiveness of the cooperation increases as tasks become more difficult, ambiguous, conceptual, or in need of divergent perspectives. Given below are examples of the use of cooperative learning with computer-assisted instruction for drill-and-practice, simulation, and word-processing learning tasks.

Example 1: Drill and Practice

Teachers may use any drill-and-practice program just as easily with a pair (or triad) as with a single individual. To structure a drill-and-practice program cooperatively, the teacher:

1. Assigns students to pairs with at least one member who is able to run the computer program and who is task oriented.
2. Instructs students to alternate the roles of keyboarder (who enters their answer once they agree) and explainer (who explains how to work the problem or the rule they need to answer the question correctly).
3. Provides the materials the students need and the computer.
4. Assigns the task of completing a specified number of drill-and-practice problems.

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5. Structures the positive goal-interdependence by requiring students to reach agreement on the answers before entering them into the computer and by requiring each member of the group to be ready to explain why the group answer is appropriate.
6. Tells students to begin and then monitors how effectively the pairs are working together and fulfilling their role assignments.
7. Intervenes to teach more effective collaborative skills. Because it is a drill and practice, interventions to teach the required operations and concepts may not be frequently necessary.
8. At the end of the lesson, asks pairs to list specific behaviors that helped them work together and to decide on a specific behavior they could engage in next time to promote each other's learning.

You may find a more complete discussion of the teacher's role in structuring such cooperative learning activities in Johnson and Johnson (1987) and in Johnson, and others (1986).

Example 2: Geology Search

We have used a computer simulation named *Geology Search* (Snyder, 1982) with many of the teachers we have trained. This simulation requires the students to search for oil using information gained through density scans, core samples, and seismic blasts. The basic task for the students is to find oil and make as much money from the sale of the oil as possible. To do this, the students have to learn basic information on how oil was formed, when it was formed, and the geological formations within which oil is trapped, as well as on the nature of and procedures required for density scans, core samples, and seismic blasts.

The basic role of the computer is to provide information and give feedback on the consequences of the actions the students take, thus serving as an adjunct to the students' decision making and problem solving and to the written technical materials. The basic role of the students is to master the relevant technical information and to apply their knowledge in deciding what actions to take to complete successfully the problem-solving task of finding the oil—utilizing the computer to record their decisions and to give feedback on the consequences.

The specific role of the teacher when using cooperative learning procedures with this simulation is as follows. Teachers create positive goal interdependence by instructing students to work as a group, to make all decisions by consensus, and to ensure that all members agree with the decisions and understand the geological information necessary to find oil. Teachers inform the students that (a) the students will complete daily worksheets and take a final test, (b) the teacher will base an individual's unit grade on the total of the group members' scores on the final test and on the daily worksheets of the individual member, and (c) the teacher will also award bonus points on the basis of how much money *the total class* makes from the sale of their oil. The role of the teacher is to structure each period's work and to monitor the learning groups to ensure that students are practicing appropriate collaborative and role behaviors. More specifically, the teacher's role consists of the following steps:

1. The teacher randomly assigns students to groups of three (the size of the group may vary according to the number of computers available).

Alternatively, the teacher may wish to assign one high-, one middle-, and one low-achieving student to each group.

2. The teacher arranges the room so that the groups can initially meet *away* from the computer.
3. The teacher may sometimes "jigsaw" the information that the students need to engage in the simulation by giving each group member a packet of information (basic facts about density scans, core sampling, seismic blasting) to read, master, and teach to the other members of the group. This establishes each member of the group as an expert on a body of technical information and creates positive resource interdependence among students. The students work individualistically to master the information and plan how to teach it best to the members of their group.
4. The teacher then gives time for each member to present their information to the group. The group then decides what tests to conduct in what order in what area of the continent they are exploring to reach a decision as to where to drill their first well. The students may make their first, second, and third choices as to potential drilling sites in this first meeting.
5. The teacher then assigns members of the group one of three roles (thereby creating positive role interdependence):
   a. *Keyboarder* enters the group decisions into the computer. The teacher allows no input into the computer until all members of the group agree on the action they will take.
   b. *Recorder* plans and supervises a division of labor so that all members of the group help in recording the information resulting from the tests they conducted.
   c. *Checker* requires group members to demonstrate comprehension of the information they are using to decide where to drill for oil and ensures that consensus has been reached on all decisions.

   The teacher rotates the roles periodically so that all students play each role.
6. Each group then makes its tests on their first, second, and third choice of potential drilling sites. The group drills wells if the test results seem promising. The computer gives the amount of oil found in each well (if any) and lists the current market price, giving the students the option of selling or stockpiling their oil.
7. The group then moves away from the computer to evaluate the results, reflects on how well their strategies are working, and chooses the fourth, fifth, and sixth potential drilling sites. This process is continued until the number of class periods allotted for the simulation are over.
8. Each group then records the amount of money they have made. Members discuss how well they functioned as a group and make plans for improving their collaborative skills in future groups.

Example 3: Writing Reports with Word Processors

A combined procedure for using cooperative learning procedures with individualistic work in using a word processor to write reports or other assignments is as follows:

1. The teacher assigns students to pairs with at least one good reader in each pair.
2. The teacher assigns the task of completing a report on a specified topic on the word processor. The students are to achieve this task by completing the following procedure:
    a. Student A describes to Student B what he or she is planning to write.
    b. Student B listens carefully, probes with a set of questions, and outlines Student A's report.
    c. This procedure is reversed with Student B describing what he or she is going to write and Student A listening and completing an outline of Student B's report.
    d. The students research individualistically the material they need to write their assignments, keeping an eye out for material useful to their partner.
    e. The two students, using the word processor, work together to write the first paragraph of each assignment to ensure that they both have a clear start on their compositions.
    f. The students then work individualistically to enter their reports on the word processor.
    g. When the students finish, they proofread a printout of each other's work, make corrections in capitalization, punctuation, spelling, language usage, topic sentence usage, and other aspects of writing that the teacher specified. The teacher also encourages the students to provide each other with suggestions for revision.
    h. The students revise their work on the word processor.
    i. The two students then reread each other's assignments, and sign their names (indicating that they guarantee that no errors exist).
3. The teacher structures positive goal interdependence by informing students that one of their scores for the material will be the total number of errors made by the pair (the number of errors in student A's report plus the number of errors in student B's report). The teacher may also give a score on the quality of each student's work.
4. The teacher tells the students to begin and then monitors the pairs, intervening where appropriate to help students master writing and collaborative skills.
5. When the group finishes the unit, the teacher has the students discuss how effectively they worked together (listing the specific actions they engaged in to help each other), plan what behaviors they are going to emphasize in the next writing pair, and thank each other for the help and assistance each other provided.

Teachers can use a modification of this procedure when a cooperative group is preparing a single lab report for the group.

SUMMARY

There are three basic ways students can interact with each other as they learn. They can *compete* to see who is "best;" they can work *individually* toward a goal, without paying attention to other students; or they can work *cooperatively* with a vested interest in each other's learning as well as their own. The students in cooperative learning situations (Johnson and Johnson, 1983)

- *Celebrate* each other's successes;
- *Encourage* each other to complete assignments;
- *Discuss* the learning material with each other;
- *Help* each other by
  - analyzing and diagnosing problems,
  - transforming information into other forms, such as their own words, a picture, or a diagram, and
  - relating material they are studying to previous learnings;
- Are *motivated* by the enjoyable experience of working together; and,
- *Learn* to work together regardless of individual differences.

In almost all schools the number of students far exceeds the number of computers, so it is inevitable that students will work with computers in small groups.

In a cooperative learning situation, teachers assign students to groups of two to four members and give the students an assignment to complete as a group, while ensuring that all group members master the material (no hitchhiking allowed) and interact skillfully.

When students work collaboratively, they can (Johnson and Johnson, 1983):

- Observe and imitate each other's use of the computer, which increases their speed in mastering hardware and software.
- Observe, imitate, and build upon each other's strategies, thereby increasing their mastery of higher level reasoning processes.
- Experience the encouragement, support, warmth, and approval of a number of classmates.
- Have their peers evaluate, diagnose, correct, and give feedback on their conceptual understanding and can orally summarize the material.
- Have their peers expose them to a greater diversity of ideas and procedures, more critical thinking, and more creative responses while completing the assignment.
- Have their peers encourage them to stay on task and to exert a concentrated effort.

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Integrating Information Technologies into Instruction: The Voyage of the Mimi [1]

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The Voyage of the Mimi and *The Second Voyage of the Mimi* are multimedia packages for upper elementary schools; both integrate technologies with learning and teaching in the areas of science and mathematics. These multimedia packages, funded by the Department of Education and the National Science Foundation, include two television series, microcomputer software, and printed materials for teachers and students. As part of developing these materials, project staff also experimented with an optical videodisc.

Schools have used *The Voyage of the Mimi* for four years. The Mathematics, Science and Technology Teacher Education Project (MASTTE)—a training program for teachers that is also supported by the National Science Foundation—trained teachers in 13 districts around the country to use *The Voyage of the Mimi*.

The Second Voyage of the Mimi was recently completed, and it will be available soon for use in schools. During design and production, project staff field tested *The Second Voyage* with teachers and students. Findings from a similar formative evaluation of the first voyage contributed to its revision and to the development of

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The Second Voyage. A research program accompanied the MASTTE project also, and offers insight into the process of incorporating this kind of material into schools. This chapter briefly describes the multimedia packages, and summarizes the MASTTE research program.

PRODUCING THE VOYAGE OF THE MIMI

The design of both *The Voyage of the Mimi* and *The Second Voyage of the Mimi* is based on proven approaches to effective learning and teaching, combined with ideas about how technology can enhance these approaches in schools. We wanted both projects to create not only a context for learning that is open-ended and appealing to students, but also a context that provides structure in various forms that will help students grasp the process of doing science. The materials are designed to promote in-depth interactive experiences with particular concepts and skills. They are structured to support inquiry learning by helping the teachers to create circumstances for exploration and problem solving and by involving the students in interesting and motivating problems and issues. The materials also involve the students in activities that will help them to understand mathematical and science concepts.

The Voyages are not complete curricula, but offer "hooks" into many topics and ideas in different areas of the curriculum. The Voyages provide an activity base that promotes hands-on exploration and independent investigation. Students and teachers can take different paths outward from a core of ideas and materials. The goal is to provide an integrated approach to science and mathematics learning that supplements standard curricula. To the degree we achieve this goal, mathematical and scientific ideas and procedures become interconnected tools for solving problems.

Choices of Technology

Each of the components of the multimedia package was carefully constructed to use print, television, or microcomputer software to its particular advantage and to distribute the pedagogical burden among these media. Together the media form an integrated package adaptable to different classrooms. We expect this strategy of orchestrating the multimodal qualities of several technologies to become an increasingly important approach for reorganizing the learning that can take place in classrooms.

The television series is the centerpiece of *The Voyage of the Mimi.* The format accommodates classroom use as well as open-circuit broadcast to homes. This powerful medium transports into the classroom parts of the world that are interesting but otherwise inaccessible. Television engages students in science by showing motivating circumstances in which scientists and their young assistants do interesting work. The television series presents non-stereotypic images of science and attractive and diverse models of scientists not otherwise readily available—especially to girls, minorities, and physically disabled students. It embeds science and mathematics in a real-world setting in which human values impinge on the scientific enterprise. The narrative format offers a context that gives reason and urgency to problem solving, and, therefore, real-life meaning. Through the television series, it is thus possible to bring the world into the classroom in an involving way.

In addition to enriching students' knowledge about science, the television series was designed to motivate the students to investigate, in-depth, a set of science and mathematics topics in associated "learning modules." Each learning module from *The Voyage of the Mimi* consists of a piece of microcomputer software and print materials.

The software programs take advantage of the interactive properties of computer technology and engage the students in working with particular concepts that the television series presented or included in its theme. For example, a simulation program helps the students to learn and use basic navigational skills and instruments. The software programs also embody ways that scientists actually use computers—for example, a microcomputer-based laboratory gathers physical data (temperature, light, sound) and displays it in dynamic graphs (see Tinker's chapter). Students can use the software independently or in small groups.

Print materials were produced to orient the teachers to the package, to provide background information, and to suggest different curriculum "hooks" or directions of which they could take advantage when using the materials. Print materials are familiar and portable, and a teacher or student can digest them at his or her own pace. Student books summarize the television series so that the students can review the material through reading. Workbooks structure activities and help students to use the software. The workbooks also provide parallel activities that do not require computers, thereby accommodating classrooms with little access to technology.

Content and Themes

The television series from *The Voyage of the Mimi* consists of 13 half-hour episodes. Each half hour includes a 15-minute segment of an adventure drama and a 15-minute documentary-expedition. Through a visit to a place where interesting science is done, the expedition expands on an idea or issue from the preceding dramatic episode. One of the young members of the cast steps out of character to visit and ask questions of men and women engaged in a variety of scientific activities.

The drama in the first voyage concerns two young scientists and their teenage research assistants. They are studying humpback whales in the Gulf of Maine aboard the ketch *Mimi*. The story focuses on the adventures of the crew as they locate and study whales and on their survival on an uninhabited island after the shipwreck of the *Mimi* during a storm. Their ingenuity in finding food, water, and shelter and in fashioning their own *rescue* from the island provides a context, in addition to whales, for problem solving with science and mathematics. The whale theme was chosen because research indicated that children were fascinated by the subject and that it was a subject that transcended sex, race, and socioeconomic status. Research has also shown that the dramatic format is especially appealing to students in this age range. The students not only are readily engaged by narrative, but research has shown it to be a powerful vehicle for communicating information in a way that students can absorb and retain (Char, Hawkins, Wooten, Sheingold, and Roberts, 1983).

The momentum of the story, however, constrains the extent to which the narrative can expand upon or illustrate important scientific or mathematical concepts. The expeditions offer the opportunity to do so. Great depth of discussion about important or difficult concepts is possible in the documentary format. Through the expeditions it is possible to show children asking questions of adults in a curious, spontaneous way. The expeditions model how the teacher can use the drama to provide starting points and problems for further inquiry and discussion. For example, the depiction of the captain of the *Mimi* experiencing hypothermia can occasion lessons on survival, loss of body heat, surface/mass ratio, and heat transfer.

The theme of studying whales proved to be richly connected to multiple areas of science and mathematics (marine biology, oceanography, the earth sciences, physics, and navigation and associated technologies). Four learning modules focus on particular concepts and engage the students interactively in examining the concepts in depth. *Maps and Navigation* builds on the information about navigation in the television series—locating whales and sailing on the ocean. This module contains a series of software programs that help the students to learn navigation skills (compass direction, coordinate systems, and triangulation). These programs culminate in a simulation program (*Rescue Mission*) in which the students combine the skills in the challenge of locating a whale trapped in a net somewhere at sea.

Whales and Their Environment engages the students in exploring the physical properties of the world and contains hardware and software for a microcomputer-based laboratory (*Bank Street Laboratory*) that enables the students to collect physical data in real time (temperature, light, sound) and to display the data as graphs. *Introduction to Computing* provides software and materials that help the students learn computer technology and critical programming concepts. *Ecosystems* includes activities and software for students to set up and study the relationships in simple ecosystems. *Ecosystems,* a modeling program in game format (*Island Survivors*), allows the students to plan and play out strategies for maintaining and surviving in a balanced ecosystem.

Philosophy and Expectations of Use

The Voyage of the Mimi was designed as a new approach to science and mathematics learning in classrooms, taking advantage of the particular qualities of different technologies in a carefully integrated package. In contrast to traditional curricula that follow a scope and sequence, we intended the materials to support multiple patterns of use, depending on the interests of teachers and students and the curriculum in place in schools. In addition, the materials do not simply teach particular concepts or skills, but stimulate interest and encourage the students to explore beyond the package. In this way, the materials encourage inquiry in science and mathematics, as well as other parts of the curriculum, such as in social studies—the history and current controversy about whaling.

Thus, when these materials are examined in actual use in classrooms, questions need to be asked about how, and how successfully, the materials lead to various patterns of use. What kinds of support do teachers need for different levels of functioning? We also need to discover the strengths and outcomes of this package overall and of its individual components.

THE MATHEMATICS SCIENCE AND TECHNOLOGY TEACHER EDUCATION PROJECT

Because the multimedia *Voyage of the Mimi* accommodated a variety of teaching agendas, it provided an opportunity to create a training model that would address the inservice needs of a representative sample of science classes. We undertook a three-year project—The Mathematics Science and Technology Teacher Education Project (MASTTE)—that used the first *Voyage* materials as a model for integrating technology in upper elementary and middle schools. This project also afforded the opportunity to see how these multimedia materials fared in a wide range of circumstances, with respect to both school characteristics and the teachers' level of development. Ellis compares the MASTTE training model to other models in Chapter 14 of this volume.

Philosophical Approach

Bank Street's approach to education rests on the premise that children's development is dependent on their interaction with peers, adults, and materials in their environment. Materials allow children to represent and manipulate the properties of the world around them, to develop their own reasoning processes, and to develop their physical capabilities. Children benefit from shared problem solving by cuing one another, reminding one another, simultaneously maintaining alternative arguments, and acting as co-constructors and elicitors of information. Teachers, on the other hand, raise questions, provide alternate perspectives, create the learning activities that stretch the capacities of children to new levels, interpret and externalize the actions of children, and relate children's experiences to wider contexts.

We believe that teachers are a primary agent of change in classrooms. The school environment—the support of administrators, the curriculum, the involvement of parents, the availability of resources, the provision of training—can promote or inhibit teachers' performance. To understand what affects teachers' performance, and particularly their ability to change, we relied on the "change" literature, including the Rand studies (Berman and McLaughlin, 1978) and the Concerns Based Adoption Model (Hall and Loucks, 1981).

These studies suggest that an innovation in schools is likely to be maintained if attention is given to several critical elements. First, the change to be made should have high priority for both the administration and the staff. Second, a strong and active communications system is essential among staff and administrators. Third, the change should address the perceived needs of the school community, with priority given to the concerns of teachers.

Finally, these studies also speak to the influence of outside agencies, such as Bank Street, in introducing change. To be effective in helping teachers to make a change, such agencies should communicate clearly the nature of the innovation and the expectations held, maintain a regular means of communication about the progress of change, offer technical advice and sound training, make consistent progress in developing and strengthening local expertise, and accept local adaptations that do not threaten the integrity of the innovation. We concluded from these studies that the greatest effect would be achieved by working with teams of staff developers and teachers at the same time: staff developers, who could provide in-district support and training; and teachers, who could identify areas they wanted to change.

Project Goals

The training focuses on the scientific and mathematical concepts and processes contained in *The Voyage of the Mimi*. There were four goals for the training:

1. *Content and Concepts:* to help teachers improve their understanding of science and math concepts. Content issues were not addressed directly but to incorporate science and math content into sessions about the modules. In training teachers experienced the same things their students would: we had them raise questions and then figure out what they need to know to answer those questions.
2. *Philosophy and Pedagogy:* to enable teachers to gain a clearer grasp of a sound pedagogy and philosophy of math and science instruction. Training sessions modeled the processes we hoped the participants would adopt: questioning and inquiry techniques, curriculum webbing, colloquia, and small-group work. Formal presentations and opportunity for discussions concerning philosophy and pedagogy were provided.
3. *Classroom Management:* to help teachers deal with the practical classroom issues that arise when using new technologies in instruction. This goal addressed the management issues teachers face daily when using television, microcomputers, and telecommunications as tools for teaching and for their own development. Discussions and demonstrations and use of various technologies were used as training aids to help the participants identify their management questions (that is, physical arrangements, grouping patterns, or use of video) and to consider alternative solutions.
4. *Planning:* to assist teachers in planning and integration of science and math instruction in their classrooms and to assist staff developers to plan and provide support and training for teachers regarding the same. Teachers and staff developers identify their concerns about any aspect of the materials or processes we present. Through a series of guided steps, the participants developed a tentative plan about the initiation, implementation, and institutionalization of the change to be made.

Training Activities

Formal Training. The MASTTE Project provided 35 hours of training in a week-long program at Bank Street College. The training week addressed the four goals of the project directly but in a nonlinear fashion. Training was structured around the four *Mimi* modules. Approximately ten hours were devoted to content, twelve hours to philosophy/pedagogy, six hours to planning, and four hours to management. Time also provided for administrative tasks and socialization.

In a given day, participants were likely to experience a mixture of lecture, demonstration, discussion, video viewing, small-group work on the computer, and small- and large-group, hands-on work with primary materials (such as snails and baleen). Participants helped conduct the sessions and shared their ideas and materials with each other. Training was conducted by project staff and consultants who brought a variety of perspectives and expertise.

Follow-up Support. During the training, the teams from each site were encouraged to develop a tentative plan that they could use as a discussion and planning document upon their return to home. MASTTE staff used this plan as a blueprint for the post-training support we offered participants. Basically, we offered four types of support after training: on-site observation and consultation, additional training at Bank Street, print-based support, and telecommunicated support. We relied heavily upon the staff developers from each site as the coordinators of local activity and as the conduit of information between MASTTE staff and teacher participants. This was done to encourage the school system to institutionalize the project from the beginning and to strengthen local capability to continue planning and training.

Research. The research component of the MASTTE Project evaluated the MASTTE model of training so that staff developers could apply the model in different settings. Research described the support needs of teachers, particularly concerning the uses of new technologies in classrooms; and the processes and progress of diffusion of MASTTE activities and materials. Research concerning the participants' backgrounds, interests, and expectations was essential to our own planning. Evaluations conducted during and after training sessions have led to improvements in the content and processes of subsequent training and support. Finally, post-training observations and interviews provided important information on the applicability of training to instruction in classrooms and useful insights concerning the structures and practices that foster innovation.

Population

During the period of 1984-86, 48 teachers and 33 staff developers who participated in the MASTTE Project familiarized themselves with the materials, the instructional methods, and the content of *The Voyage of the Mimi*. They participated in a one-week intensive training program at Bank Street College of Education, followed by additional workshops, consultations, and in-service activities at their home sites. These teachers and staff developers came from thirteen sites across the country and represented rural, urban, and suburban districts and consortia; public and private schools (including an archdiocese district of 135 schools); and, mountain, desert, plains, woodland, and coastal areas. The teachers came from 37 schools. The following is a list of the states in our sample: California, Massachusetts, Colorado, New Jersey, Georgia, New York, Hawaii, Ohio, Kentucky, Washington. School districts selected the teachers for participation according to local criteria, resulting in a fairly heterogeneous population. The participants had much experience as teachers. With low variance from the mean, teachers averaged 14.5 years of experience; staff developers averaged 16.4 years. Not all, however, had experience teaching or coordinating science programs. The majority had studied science methods (70 percent) and mathematics methods (65 percent). Many had science courses in college (72 percent of teachers and 83 percent of staff developers), but relatively few had studied mathematics (16 percent of teachers and 30 percent of staff developers). Some of the training participants (16 percent) had no computer experience.

The situations in which teachers worked varied considerably too. The teachers represented a wide range of grade levels, from third to tenth grade teachers, with the majority teaching in one of the levels of fifth through seventh grade. Teachers also taught science in different circumstances: homerooms or departmentalized settings and during unscheduled time or in fixed periods.

Patterns of Use in Different Schools

Not surprisingly, variety characterized the use of the *Mimi* package. It proved adaptable, however, to heterogeneous circumstances in districts and in classes. At the end of the second year of the project, the twelve sites who were then part of the MASTTE project used the materials in different ways. These generally fell into four categories.

1. *For science instruction in various configurations.* Seven of the sites used the materials primarily as a science curriculum, but varied with respect to age group and circumstances:
   - by tenth grade remedial science, seventh grade science, and in sixth grade Chapter One classes;
   - as sixth grade science curriculum (a science specialist supplemented homeroom teachers' lessons);
   - by fifth and sixth grades;
   - as the basis of the fifth grade science curriculum, with the Ecosystems module used by the sixth grades;
   - by fourth, fifth, and sixth grade teachers in teams;
   - at two middle school sites, in sixth grade science classrooms along with components from the revised Science Curriculum Improvement Study (SCIIS).
2. *As the basis for integrated curricula.* Four of the sites emphasized cross-curricular connections in addition to the science focus of the materials:
   - in a three-year cycle through sixth, seventh, and eighth grades, integrated with English and Religion classes;
   - in all areas including bilingual education (the videotapes are closed captioned), special education, social studies, language arts, and math, primarily by middle school teachers;
   - in one middle school by the science teacher, the computer teacher, and the English teacher;
   - in another school by the sixth grade science teacher and as the core of the bilingual program;
   - in another by a third grade teacher;
   - with sixth grade science and in interdisciplinary teams with middle school students.
3. *Through a use that focuses on the software.* One site exemplifies a pattern of use seen in other schools, selecting and emphasizing one of the

technologies – using *Introduction to Computing* module in the fourth grade, *Maps and Navigation* and the video in the fifth, *Ecosystems* module and the *Bank Street Laboratory* MBL in the sixth.

4. *With an emphasis on particular curriculum topics.* One site demonstrates another pattern, using the material selectively as it integrates with particular topics in the curriculum – as a six-week oceanography unit in a seventh grade science course.

Therefore, this set of instructional materials successfully supported different patterns of introduction and use in districts, in some cases providing for integration across curricular areas.

When individual classrooms were examined by observing lessons and interviewing teachers and staff developers, the research team discovered some difficulties for introducing this novel configuration of technology and content and identified some effective methods of facilitating implementation. Different teachers took home different messages from the training – depending on their background experiences, their level of awareness of the purpose of the multimedia package, and their local curricular demands. The nature of the materials also made certain lessons more or less salient to teachers because the different technologies placed different demands upon the teachers vis-a-vis their traditional roles in the classroom.

Integrating the Hardware

The research demonstrated that a variety of equipment configurations were workable, although the teachers preferred some over others. For instance, having a video cassette recorder (VCR) located in the classroom rather than outside of the classroom was the best arrangement for facilitating discussion. A classroom VCR also made it possible to review segments of the show as a reference for discussion. Not having a VCR in the classroom meant teachers had to take time to move the students to the auditorium or library. With the VCR outside of the classroom, its schedule for use was often inflexible, and the change of setting from the classroom disrupted the natural pacing of lessons.

The ease of introducing and integrating computer technology into lessons did not relate directly to the amount or location of equipment in a school. Teachers set up computers singly in classrooms, rolled them into classrooms, or clustered them in classrooms or labs. Each configuration of computers allowed the teachers to integrate the technology into *Mimi* lessons in ways that satisfied them. Teachers who were new to computer use and who had equipment in their classrooms tended to have their students work at the computer during non-instructional time – before and after school or during lunch and recess. Children also asked to be excused from gym or art to work on the computer modules. Teachers who had experience with instructional computing were able to organize small-group work at the computers while other class work was going on.

Integrating the Materials

The ways teachers used *The Voyage of the Mimi* were quite varied in content and form. Overwhelmingly at the outset, the teachers in the sample arranged their classes in a teacher-centered, teacher-directed fashion, often holding discussions that turned out to be fact-laden lectures. It was noted, however, that the technology could influence these patterns and that staff developers could expand this influence with proper follow-up. For example, computer work in schools often means groups of children will be working together. As others have, we observed that when students were working together in small groups at computers teachers often realized for the first time that their students are capable of independent work. They also realized that small-group activities do not have to be disruptive nor constantly monitored.

There was also some relationship between teachers' science backgrounds and their approach to using the materials, and this relationship interacted with the kind of on-site support they received for their implementation efforts. So, for instance, teachers with weak science backgrounds and poor on-site support tended to emphasize language arts activities related to the science content in the video (for example, research reports, trip logs, and character sketches). In contrast, many novice science teachers who received on-site help experimented with hands-on activities. Initially they conducted activities they had seen modeled in training but eventually they were able to create their own hands-on projects.

To various extents, the experienced science teachers developed a range of units based on the *Mimi* that were creative and responsive to their students' interests. Hands-on work, computer activities, and exploratory discussions were features of these programs. When working in teams, the experienced teachers created school-wide or district-wide programs that often served as models in their schools' efforts to upgrade science and math programs. Experienced science teachers and specialty teachers emphasized computer-based activities more than other classroom teachers, who tended to use the computers as casual tools.

Video. Using video as a device to promote children's curiosity in science topics was very successful. The discussions that teachers organized around the videotapes varied in their organization, directedness, and purpose. Despite the variations, the medium was universally appealing. Teachers, too, found it easy to introduce both the narrative and documentary portions of the show as part of the flow of the units.

Watching videos in some cases broke down familiar teacher-question/student-answer routines in classes. The children offered many spontaneous comments, which the teachers permitted them to make. The students even asked questions. Such effects offer very promising handholds for staff developers who sought to promote inquiry methods among teachers. In contrast, lessons the teachers built around the *Mimi* texts were quite often traditional in structure and approach. Furthermore, the majority of teachers, experimented with alternative questioning techniques.

Microcomputer Software. The content of each computer module held its own appeal for teachers of differing backgrounds and teaching situations. The *Navigation* simulation was the most frequently used module in every grade. This simulation and the ecosystems microworld that are part of the first *Mimi* package were the easiest for all teachers to integrate with their lesson plans. The content in these computer modules related well to focal topics in the corresponding video pieces. Furthermore, ecosystems is a standard unit in most elementary science curricula, and the *Ecosystems* module was a pleasing illustration of many central ecological concepts. *Navigation* represented an unusual but exciting mathematics theme, one that teachers enjoyed learning and demonstrating. Many classroom activities, including land navigation exercises, were possible for them to devise in conjunction with this module. Although the modules took some demonstrating or explaining, both modules offered complex game formats that maintained the students' attention and enabled the students to collaborate productively for the duration of the game. The teachers usually introduced the module and then let the students work by themselves.

In contrast, the teachers did not easily integrate the MBL module into their instructional programs. Although many teachers simply didn't receive it in time for training, or, received hardware that wasn't working properly, others found the concepts complex (temperature, light, and sound) and difficult to master. They also found the hardware tricky to use and difficult to calibrate. This module placed a greater instructional demand on the teacher. Generally, only the more experienced science instructors used it consistently, although others experimented with it. A major problem with integrating this set of computer activities into lessons is the same as that of introducing any hands-on activities. They are difficult to organize and time-consuming, messy, and expensive, and because they frequently involve many supplementary materials.

The least experienced teachers needed a good deal of on-site support to learn how to carry out hands-on work. While they often performed activities that project staff demonstrated in training sessions, these teachers had difficulty expanding their instruction in that direction. Lack of time for planning was the most frequently cited obstacle to increasing the number of hands-on activities.

Teachers infrequently used *Introduction to Computing*—the computer module that provided a Logo-like environment and clarified features of programming that children do not easily grasp. Here, the connection to the whale themes of the *Mimi* was tenuous, and often, teachers were using Logo with their classes already, so this module seemed somewhat superfluous to them. Where teachers introduced it to classes that were inexperienced with programming, these teachers reported that the module was very helpful in illustrating principles of programming.

We found that most teachers needed training to tackle the *Mimi* materials and to take advantage of what the materials had to offer. Important, general factors in the training included

- an overview of the materials and the pedagogical principles embodied in them;
- concrete ideas for implementation;
- achieving comfort with managing equipment;
- multiple models for the use of the materials; and,
- access to resource people for consultation about lesson development.

System Factors Affecting the Integration of Technology

Districts that participated in the MASTTE training project sought to introduce technology into their schools for different reasons. Those districts that used the program as an occasion to integrate technology into the regular curriculum (as opposed to the computer classes alone) were among the ones that developed the richest programs, ones that were consistent with the developers' notions of optimal use.

Other district features associated with successful implementation and diffusion of the program were

- clear goals for organizing training and for using the materials;
- staff developers who had regular contact with classrooms and with district decision-makers;
- support for teacher experimentation with the materials;
- informed administrators; and,
- teams of teachers and of staff developers working together.

In addition, when school districts included teachers in decisions on the use of the materials, the teachers felt more positive about their work with the materials. Furthermore, including the teachers as trainers strengthened the implementation.

In summary, despite good intentions, teachers can superimpose expository teaching styles on materials that developers designed to promote inquiry-based activity, and districts can fail to take advantage of the opportunities the technology affords. A developmental process occurred, however, in which the media and content allowed teachers to teach in new ways and to see new aspects of their students' learning capabilities. With support, staff developers can accelerate this process to help teachers produce lessons that promote true inquiry activities.

Maintaining this approach to learning in classrooms, however, requires a rich base of materials for teachers to use. Accordingly, while the schools were putting the first *Voyage* to use and staff developers were training the teachers, plans were underway for developing *The Second Voyage of the Mimi. The Second Voyage* was designed to expand and deepen the materials available to teachers to continue this multimedia approach to learning.

THE SECOND VOYAGE OF THE MIMI

The philosophy and format of the second in the *Mimi* series was patterned after the first, taking into account a few lessons we learned. The second *Voyage* consists of 12 half-hour segments that again make use of the design of an episodic drama interspersed with expeditions. A substantial theme was sought in which children had demonstrated an interest, and which could lead easily to a range of scientific and mathematical concepts and activities. Archeology in the Yucatan (Maya archeology) was chosen because it proved to be of great interest to students and connected easily to many aspects of science and mathematics. It also enlarged on areas of science and mathematics the first *Voyage* had emphasized.

The adventure story of the second *Voyage* revolves around the work of two young scientists and their assistants, all of whom set out to investigate, through an underwater archeology project, the trading routes of the ancient Maya. Their work leads them inland to Maya sites and to an adventure with looters, as the scientists race to protect the archeological treasures of a lost city. The plot turns on the discovery and interpretation of scientific clues and evidence.

Archeology is a wonderful combination of careful, scientific methodology—measuring, mapping, classifying, decoding—and the most compelling of scientific flights of imagination. It is always based on what can never be complete evidence. It is informed by many diverse sciences, such as earth sciences, physics, chemistry, and astronomy, and it is supported by an increasing array of technologies (for example thermoluminescence, which is used to date pottery). Thus, the story easily wove many different mathematics concepts, science concepts, and technologies from archeological research.

Two learning modules were created for this series. One, *Maya Math,* is to help students explore another number and calendar system—the Maya system, which uses base 20. The module was designed as a context in which teachers and students could treat mathematics as an inquiry activity. The print materials encourage the teachers and their students to use an hypothesis-building and testing approach that is open-ended to learning mathematics.

The software is composed of three computer programs—two in a game format that helps the students to practice basic skills in the Maya number and calendar systems. and a utility that enables the students to use a base-20 calculator (and other bases as well) to solve problems. This module uses a different number base to help students step outside of the base-10 system and gain an articulated understanding of place value. This approach is intended to encourage procedures for discovery and an orientation toward mathematics as inquiry that will carry over to other areas in the math curriculum.

The second learning module, *SunLab,* introduces the students to concepts in astronomy. The students who use the software explore multiple facets of the earth/sun system (seasons or day-night) through a simulation/animation program. With *SunLab,* students can experiment with various dynamic perspectives on the earth/sun relationship (for example the horizon view or view from outer space). Because the information is available in multiple representations, the software offers to students different entry points into understanding these complex relationships. The students can browse through and experiment with multiple explanations to phenomena, for example, the story of the seasons.

Like the first package, *The Second Voyage of the Mimi* supports multiple uses in the classroom and offers a motivating, integrated way of engaging students in their own explorations in science and mathematics. *The Second Voyage,* particularly in its software, attempts to support children's explorations of fascinating and fairly abstract conceptual material.

CONCLUSION

Our research tells us that devoting attention to the needs of teachers who are to use materials for guided-discovery lessons is imperative for successful implementation. Consequently, meeting teachers' needs is a very useful strategy to employ for school districts who seek to integrate the new information technologies into the flow of traditional learning activity.

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Using Change Theory to Manage the Implementation of Educational Technology in Science Classrooms

Robert K. James

A true story about implementing educational technology:

> A new young junior high school principal related, "I looked out at the loading ramp, and there was a truck unloading 15 new microcomputers and all the paraphernalia! I didn't know what to make of it. I checked with my assistant principal and he didn't know where they came from either. So, we hauled them inside and a few days later the Superintendent came by."
>
> "Did you get the computers?" he asked.
>
> "Ya," I said, "but I was surprised!"
>
> He said, "The Board had decided you needed'em. Dr. Brown said that he learned at the Bates County Medical Society meeting that yours is the only school in the country that doesn't have computers.
>
> By the way, the Board wants to meet in your building for next month's meeting and have your staff make a report on how they are using them in their instructional program," he added and dashed out the door.

Isn't educational change wonderful? This and other horror stories about "real world" experiences with change are all too common. Suppose you were faced with implementing educational technology in a junior high school, how would you go about it?

Facilitating the implementation of educational technology in science classrooms, given the current context of educational reform, requires the understanding of three major factors:

1. There exists a body of common practice in guiding educational change that is not research based and not entirely valid;
2. Educational technology is unique among educational innovations and those unique characteristics must be recognized and dealt with; and
3. Useful current knowledge about change in education is available and can provide the information necessary to make data-based decisions about implementation management.

Current Approaches to Change in Science Education

The educational reform movement has brought new awareness of change in education. Pronouncements of *A Nation at Risk* (1983) and the avalanche of reports, studies, recommendations, regulations and the legislation that followed it have given us all grist for thinking and challenged us to restructure education. Members of these review panels display an amazing lack of direct connection with what happens in classrooms. When it comes to understanding the change process in education, it will come as no surprise that their recommendations for change reveal they are equally ill informed.

For example, many states have recently responded to recommendations about the doubling of science graduation requirements in high school without any apparent thought about the ramifications or appropriateness of that instruction to all youngsters. There is apparently a general principle here, that *more is better.* On what research was that principle (or fallacy) based? Proponents of this concept apparently think its truth to be self evident! There are numerous principles and/or fallacies about making change in education that are finding wide acceptance today. As we consider the ramifications of implementing technology in science classrooms, it seems wise to further delineate them.

One need not go far to hear an academic (sometimes a scientist) remarking about the terrible conditions in our schools and how we need to . . . Then to support his conclusion, he verbally reviews his data with something like, "*Why, when I was in school . . .* " It seems never to have entered his mind that his sample size must be called into question! Whether they are academics or not, it is common practice to hear people generalize about the need for change based on their own experience or that of their family. As one retired friend recently remarked to me, "Well Bob, how did we ever learn science without computers or even calculators?"

Another widely accepted generalization about change is that *we should rely on the judgment or performance of experts*. It certainly does seem appropriate to recognize those teachers and schools that have demonstrated excellence in science education. However, there always seems to be the implication that, *All of us should perform like them*. What does the research say about experts? *Does it suggest that we can all be like them?* I think not. If it were possible, *would it be desirable for all teachers and schools to be like the experts?* Can we be sure that a local science department staff made up entirely of Presidential Award winners would be good? Not necessarily.

A view of educational change that is often heard from the federal level today is that educational improvements should not require any more money. Succinctly stated, the principle is that *change does not cost money*. This author recognizes that there is much that can be done that will improve education and that does not require an increase in taxes. Further, there are times when expanding resources for education may not be possible. However, we must ask, "What changes will not cost money?" Increasing teacher's salaries does, and so do updating school science facilities, retraining teachers, providing teachers with current materials, and equipping and furnishing laboratories. Why should it cost to provide for the "common defense" and not for the "best hope for our future"—education? Whatever one's political stripe, some important kinds of education change will cost money. In an enlightened society it would seem to be important to give careful thought to how and when to provide support for educational change, rather than relying on this simplistic approach of budget containment.

Those who engage in the struggle to ensure that curriculum programs are implemented can frequently be heard describing a guiding principle that has to do with helping classroom *teachers gain ownership* in the new program. They claim that the key to success is to orchestrate the change process so that teachers develop ownership in the change. That really is a very attractive idea, because apparently many school programs fail in part because teachers do not seem to have a personal stake in their success. The problems with this generalization are twofold: (1) ownership can only accrue to those teachers who have direct involvement in the change (although, it is commonly assumed or hoped that if some teachers have ownership, all do); and, (2) carried to its extreme, every teacher would develop his own program, leading to an endless variety of programs. This condition is considered chaotic by those currently supporting curriculum alignment.

Perhaps the most pervasive and seductive misunderstanding about change is what might be called the *developers syndrome—what is needed is a new (and improved) science program.* The logic goes that, given a better program, the problem will be resolved. Many well-meaning groups have tried this in the past and are still doing so today. An obvious example can be seen in the experience of the 1960s curriculum projects. Elsewhere (James and Hord, 1988) this author concludes, ". . .the real failure of the 1960s NSF-supported elementary science programs was not their failure to produce appropriate learning outcomes, but their failure to be implemented." To be sure, *new and improved programs are needed*. As long as we live in a dynamic society, and as long as science is changing, new programs will be necessary. But unless attention and resources are focused on implementation, new programs are not apt to be implemented.

One can repeatedly observe local schools making changes because "everybody is doing it." The vignette at the beginning of this chapter provides a sad illustration of this. There was no needs assessment, advanced planning, curriculum development, or staff training. There wasn't even any consultation about providing software. The superintendent and board had decided what their school needed. This is a kind of *"bandwagon" or social acceptability* principle. In fact, those who would orchestrate change frequently attempt to create an environment in which the social acceptability of a program will enhance its implementation.

That is wise. The problem is that the "bandwagon" begins to drive the process, not logic about what is good for children and teachers, and how that may be achieved.

There is a widely held idea that the *teacher is the key*—the key to effective change in education, the key to effective schools, and the key to solving the problem of implementing new educational programs. This author agrees. Regrettably, this principle has frequently led to inaction. That is, it has lead to a course of action which fails to begin with or focus on the teacher. In fact it often leads to a logic which suggests that since the teacher is the key, nothing can be done. Any change process that does not take the teacher's needs, goals, concerns, skills, and training into account appears to be doomed to failure. As noted above, a major problem with the current educational reform movement is that while one frequently hears critics say the teacher is the key, few have sought guidance or input from teachers as to which direction education should go, and in fact have frequently blamed teachers for the failure of education to meet society's expectations.

The need for excellence in education has never been greater. Never before have so many stated so clearly that education is central to our competitive stance in the world market, the strengthening of the institutions and values of our society, and defense of our own borders. All of us today would probably agree that what is needed are clearer heads about the direction of education in the 1990s. What is needed is a research based approach to change in science education.

Unique Problems in Implementing Technology

Where does educational technology come into all of this? Clearly, most of the above principles have been applied to the implementation of microcomputers as one example of educational technology. Many science classrooms do have microcomputers today. This does not mean anyone is using microcomputers. One science educator has quipped, "The layer of dust on most microcomputers in science classrooms suggests that they rival oscilloscopes in terms of frequency of use!" There are numerous aspects of educational technology which seem to impede its effective implementation in science classrooms. Sometimes the problems are described in rather simple terms, but are really more complex than first evaluation might suggest.

Resources are frequently cited by practicing teachers as the initial barrier to implementation. Teachers frequently respond to discussions of microcomputer use in their classrooms with sneers about the numbers of computers available to them. It becomes clear that teachers generally know little about how to make use of one (or a dozen) computer(s) to enhance instruction in their classrooms. However, the solution is not as simple as training teachers to use a small number of computers. Science teachers have models for the kind of instruction they believe should occur, and the most common model is dominated by information assimilation and regurgitation—memorizing and repeating facts! Any model that does not allow for the systematic accretion of massive amounts of vocabulary will likely not get a hearing. Hence, while teachers may talk about the lack of hardware and software resources, there is an even larger problem of their being unwilling to make use of technology. Teachers have commonly used computers as "page turners" where the goal is dissemination of information. It seems a fortunate happenstance that the resources simply are not available to provide every child with a "page turner!"

Many teachers complain about the availability of appropriate *software*. They seem to mean that it doesn't fit either their instructional model, their curriculum, or both. Undoubtedly this is true. Perhaps time will resolve some of this problem as new software is developed. On the other hand, someone needs to look at this problem from the pure profit perspective. Would it be hypothetically possible for there to be enough variety of copyrighted software on the market at any one time to meet the needs of all teachers? Is it likely that future software will enable the teacher to generate all the software they might want without their being experts in programing?

In classrooms that are already overburdened with concepts, testing and paperwork, the opportunity to add one more "great idea" to their classrooms is not appealing to teachers. Further, it is increasingly clear that *we are simply trying to teach too many ideas and facts,* especially in science classes in which all youngsters enroll. The press of "covering the material" is so great that the decisions about good teaching must be sidelined in favor of instructional efficiency and a strategy that helps kids memorize information. (It is a hopeful sign that educational technology has not yet demonstrated itself more efficient than teachers at teaching vocabulary—or has it?) Our growing commitment to the use of performance examinations as a measure of school (and teacher?) effectiveness, only adds to this problem.

The *anxieties of teachers* are well documented as deterrents to the use of technology. Most of us can identify with that, if we think back to our first encounter. One computer math teacher recently described her husband's only involvement with their home computer as the time he became entangled in the cord! School teachers are not unique in this regard, as businesses also report that their non-clerical staff hesitate to use the technology.

The *complexity of educational innovations* is widely regarded as a factor in their implementation. Educational technology often interjects considerable complexity into the classroom. Having new and complex equipment is only part of the innovation. It usually also includes programmatic elements—the software and perhaps an entirely new curriculum. Further, it may imply or require a totally new instructional approach. Managing the instruction of children who are at different places in the program at any one time is much more demanding than managing a classroom with the widely accepted "lock step" approach. Simulations and laboratory interfacing complicate the picture even further. The realities of classroom instruction in the late 1980s are that with teacher evaluation based on a state- or district-wide assessment instrument, the implementation of the directed teaching model, competency testing, aligned curriculum, at-risk prevention, and paperwork, paperwork, paperwork!—all mean that an innovation requiring any additional level of complexity may have difficulty gaining wide acceptance among science teachers.

Given the prospect of all these problems in the implementation of educational technology in science classrooms, one may ask, "Is there any prospect for successful implementation?" Yes, there is. The widely held concept that "the teacher is the key" is the key to the successful implementation of educational technology. If change happens, it will happen at the classroom level—the classroom is the unit of change. Too often, in the past, those who introduce new ideas into classroom practice have failed to recognize the truth of these two axioms. Because of this, these two axioms are the topic for the remainder of this paper. This author will describe how these two ideas formed the basis for the Concerns Based Adoption Model (CBAM) and how it can be used effectively for the successful implementation of educational technology in the classroom.

Understanding Change

Based on their extensive involvement in research on change over the past 15 years, Hord and others (1987) cite six basic conclusions that can provide starting points for understanding the change process. They are:

1. *Change is a process, not an event.* It does not happen because a rule is promulgated that all schools will introduce computer literacy at seventh grade. In the opening vignette, it won't even happen because the board is expecting a report!
2. *Change is accomplished first by individuals, then by schools.* Teachers who use the technology will do so, one at a time. There is no justification for assuming that delivering 15 computers to 15 classrooms means 15 teachers are using them.
3. *Change is highly personal.* All who have had to deal with a new word processing system can testify to this. And, once we have mastered it and become dependent on the new system, we can relate to the trauma of having the technology taken away by power outages or maintenance problems.
4. *Change entails developmental growth in both feelings about and skills in using new programs.* Think about any new technological device that you have learned to use. Think about how you felt at first use, then after you'd mastered most but not all of the features, and finally how you feel now that your use has become routine. There is a pattern there and we'll examine it more carefully when we come to concerns.
5. *Change is best understood in operational terms.* Teachers demand practicality in the resolution of educational problems. They want to know what educational technology will demand of them, and how it will affect their student's outcomes.
6. *The focus of facilitation should be on individuals, innovations, and the context.* The temptation among facilitators is to become distracted by the computers and forget the people. The focus of our facilitation must be on the people, and how the innovation and context have an impact on them.

These conclusions will be helpful in guiding our thinking about how educational technology can be implemented effectively. The reader may wish to consult Hall (1981), which provides a review of other knowledge of the change process and applies it to the implementation of microcomputers.

The Process of Change

Most persons who have worked in some kind of facilitative, supervisory or administrative capacity in helping schools and teachers to make change will have little difficulty agreeing with the first assumption that change is a process. That process is not unfamiliar. None the less, it must be remembered that the record for successful implementation in science education over the past 25 years is not good. Most of the 1960s curricula were never widely implemented. Careful attention to all the elements of that process will be necessary if the record is to be changed.

Hord (1987) has provided a rather thorough review of the parts of the change process. She describes it as being circular and fluid, with numerous dynamic interactions. This model (Figure 1) has been simplified some in Hord and James (1988), where it is presented in a five-step, linear form. These steps are summarized and applied here. It is recognized that the limitations of time and resources will limit the application of each step in real situations.

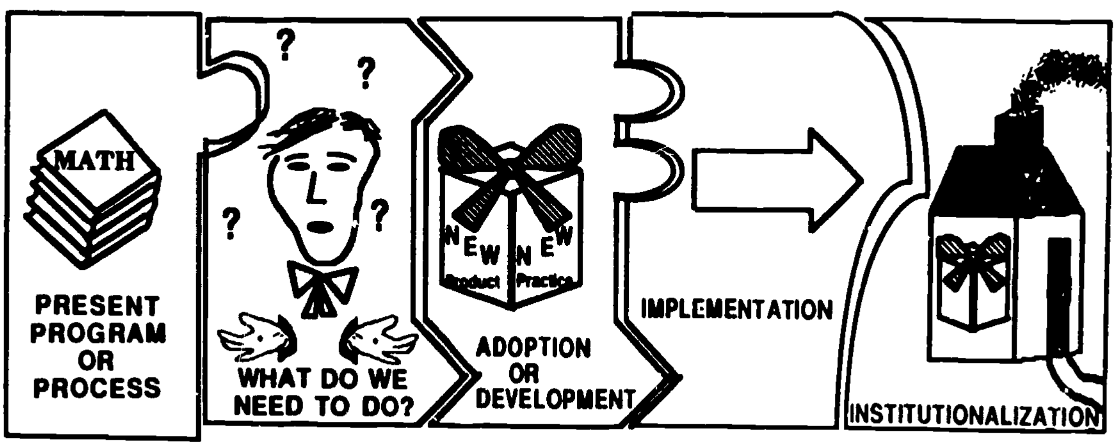

Figure 1: The Puzzle of the Change Process

Step 1. *Assessment of current practice (Needs Assessment).* Rationally, this would be done in the broadest sense possible with the involvement of all constituent groups and thorough data collection. In the case of educational technology this might include, but not be limited to: the current level of technological literacy among students and teachers; a broad assessment of community groups and their views of the importance of the inclusion of educational technology in the school program; contextual assessments including local resources, climate for change, and the prevailing attitudes of teachers, administrators, and students; determination of the possible relationship and impact of educational technology on the curriculum; and finally, assessment of the current level of use of technology by teachers and students. The culmination of this first step is a determination of needs or areas targeted for change.

Step 2. *Examination of, and selection from, the options (Adoption).* Given the needs identified in Step 1, there may be commercial products available or they may have to be developed. The exploration of options should be carried out at many levels: teachers, administrators, a selection committee, community group, etc. If the innovation is to affect a large number of students or classrooms, it seems wise that the exploration be carried out by as many groups and individuals as possible. Change takes time. The examination of options should not be rushed. This includes a pilot or test process in which the option is used and evaluated in terms of its appropriateness in the local context. With educational technology, it must be clear that the innovation being chosen involves the technology plus the program it facilitates. The program will frequently consist of a new curriculum and may require new instructional methods. By the end of Step 2, the adoption decision has been made.

Step 3. *Mobilization for, and beginning, use (Initiation).* This step is concerned with all that must be accomplished to ensure that use does begin. In practice, this step may not be separated from Step 2 nor should it be. It involves all the activities that "grease the skids"... get the innovation on its way to classrooms. These may be the activities that get news coverage in the local paper. Those who make decisions must lend their approval, budgets must be provided, people must be mobilized, the innovation must be communicated, and users must be trained. Creating social acceptability for changes involving educational technology is not difficult today. Regrettably, that acceptability may drive the process, rather than logical decision making. Another problem in this step is that those who orchestrate change may feel that their job is done when they get this far, and tend to exclude steps 4 and 5 below. When Step 3 is completed, all is ready for use to begin.

Step 4. *Implementation.* This is what happens after the educational technology reaches the classroom door. It may be an extensive period of time, beginning with first use by teachers, and it blends into Step 5. Implementation is the step in the change process that has been shortchanged in the past. This is the step which the Concerns Based Adoption Model addresses and later in this article will be greatly elaborated upon. Here, change facilitators will choose interventions that will provide support, encouragement and pressure on teachers to use the educational technology. The choices of interventions need not be of the reactive sort, where the facilitators act to "put out fires" as they erupt, but should be carefully planned and based on data from the monitoring of local use. Implementation is often the point at which the change process breaks down. Administrators must attend to the need to sustain the innovation. Simplistically, if they don't continue to pay the electric bill, they won't need computers! The completion of Step 4 means implementation has been accomplished.

Step 5. *Institutionalization.* One of the common misunderstandings about change is that this "step" is an endpoint. It is that step at which the teacher or school's use of the educational technology has reached a level of quality expressed in terms of how a teacher uses the technology. On the other hand, it must surely be described as the stage in which use of the technology continues and may even be more broadly integrated into the instructional process. Hence, it is not an endpoint, but through a continuing assessment process, it is simply a stage in the cycle of change in schools.

Monitoring and Managing Implementation

The serious study of educational change has been the focus of efforts by Gene Hall and others (1973) at the Research and Development Center for Teacher Education at the University of Texas at Austin. Their work, known as the Concerns Based Adoption Model (CBAM), has focused primarily on the concerns of teachers experiencing an educational change, the nature of their use of that change, and the extent to which the parts of a program are being used in the teacher's classroom.

The attention of the CBAM staff was directed to the innovation itself: its parts and how they were being used in classrooms (Conclusion number five above). It had been observed (Emrick and others, 1977) that when teachers begin to use a new program, most begin by implementing only selected portions. Other teachers modify methods or materials initially. Hence it is likely that what one observes in classrooms will be somewhat different from what was originally intended. This suggests the necessity of focusing on the parts of the innovation and how they are operationalized by the teacher in the classroom.

In individual classrooms, it is clear that teachers need help with knowing how they are expected to implement an innovation. Further, administrators, supervisors and facilitators need to know what the innovation should look like. As Hord and others (1987) conclude, ". . .it is critical to be able to talk about an educational program in clear, operational terms. To be truly helpful to teachers, you must be able to describe how a program will look in actual practice in the classroom." The application of this idea to educational technology is particularly important. Some teachers envision only a "page turner" implementation, while others expect to individualize with a computer for every student, and so on. How are they to know what is expected? It is conceivable that some districts might not care how microcomputers are being implemented, but that seems most unlikely.

Innovation Configuration. In order to be able to provide this program description, Hall and Loucks (1981) developed the concept they called Innovation Configuration (IC). IC provides a picture of how the innovation is "configured" by the teacher in the classroom. In understanding IC, it is necessary to keep track of a few terms. *Components* are the major operational parts of the innovation. Usually they consist of materials, teacher behaviors, and student activities. Certainly some may be more important than others and labeled essential or *key components*.

It should be noted that components must not be confused with *implementation requirements*, which are the products or processes that must be present in order to be ready for initial use. These include the training the teacher might need, the availability of a certain textbook or the presence of the equipment the innovation requires. Components differ from implementation requirements in that the former describe how the innovation is operationalized or configured.

To describe the various ways each component is operationalized in the classroom, the term *variation* is used. The set of variations for a particular component is specified so as to include the entire spectrum of variations one might observe for a particular component being used. They can then be labeled "ideal," "acceptable," "not acceptable," and "not using." Since "ideal" represents the developer's original intention for use of that component, it should be noted that this spectrum of variations represents a measure of fidelity to the original innovation. It will also be recognized that such designations are arbitrary. An example of a portion of a Microcomputer IC developed by Ellis and others (1988) is included in Figure 2. (The IC presented in this form is a matrix of components vs. variations).

Component 1: Availability of microcomputer hardware for science students				
One or more microcomputers are available in the classroom for student use in science at all times.	One or more microcomputers are available outside of the classroom for student use in science at all times.	One or more microcomputers are temporarily available in the classroom for student use in science.	Many microcomputers are located in a computer laboratory available for student use in science on a limited basis.	No microcomputers are available for student use in science.
Component 2: Availability of microcomputer hardware for science teacher				
A microcomputer is always available in the classroom for managing science instruction.	A microcomputer is available whenever the teacher is free to use it in managing science instruction.	A microcomputer is available for managing science instruction on a limited basis, when scheduled in advance.	A microcomputer is occasionally available for managing instruction.	No microcomputers are available for managing science instruction.
Component 4: Availability of management software for science teacher				
There is sufficient software for managing science instruction always available to teachers.	There is sufficient software for managing science instruction, but it is available on a limited basis to teachers.	There is some software for managing science instruction always available to teachers, but more is needed.	There is some software for managing science instruction available on a limited basis to teachers, but more is needed.	No software is available to teachers for managing science instruction.
Component 6: Frequency science students use microcomputers				
Most students use the microcomputer (individually or in a group) for at least 45 minutes in most science units.	Most students use the microcomputer (individually or in a group) for at least 45 minutes in one or a few science units.	Twenty-five to fifty percent of the students use the microcomputer (individually or in a group) for at least 45 minutes in most science units.	Twenty-five to fifty percent of the students use the microcomputer (individually or in a group) for at least 45 minutes in one or a few science units.	Students never or rarely use microcomputers.

Figure 2: Innovation Configuration: Integrating Computing Into School Science

James and Francq (1988) discuss numerous uses that can be made of IC in an application to elementary science. Uses that might be made in managing the implementation of educational technology include:

1. Summarizing the data from many classrooms directly on the IC provides an overall picture of the status of the implementation of educational technology;
2. Combining data points across all variations of use for one classroom is the configuration of use for a particular classroom. It will provide the supervisor with a basis for consultation with a particular teacher about how they are implementing educational technology;
3. Examining similarities or differences in the patterns of configuration of use across several classrooms may be helpful to the supervisor in deciding in which classroom or school to intervene;
4. Considering the summary data on a component-by-component basis will direct the thinking of the supervisor about which components the teachers are implementing well and which components should receive attention; and
5. Using ICs to communicate expectations for implementation of the technology—to teachers, supervisors and administrators. In this regard, it may be especially valuable to setting goals for the implementation process.

The development of an IC is a complex process which must be designed for each individual innovation. Those desiring to develop an IC for educational technology will want to examine the process as it is described by Heck and others (1981). Noyes (1983) developed an IC for microcomputers in his study of the status of microcomputer use. In practice, it has been helpful to limit the number of components to 10 or less and the number of variations to three to five, and the total instrument length to one or two pages. Another form of the IC is a checklist in which variations are listed under their respective components. The checklist form is especially convenient for data collection in which teachers check the variation representing their current use. A second dimension of the CBAM, stages of concern, focuses on the teacher's affective response to the use of the innovation.

Stages of Concern. In understanding change, a central assumption of the CBAM is that it is an individual matter. Teachers who use educational technology in their classrooms will do so on an individual basis (Conclusion number two above). Thus it is important for any plan for implementing change to attend to the needs of the teacher (Conclusion number three above). When one is helping teachers implement a new program, it is common to discover that they are still distracted by some management or personal concern instead of thinking about the impact of the program on students. This is what Frances Fuller (1969) found as she studied the concerns of preservice teachers in an innovative teacher education program. She reported that the concerns of these preservice teachers progressed through three developmental stages, including concerns beginning with *self*, moving to *task* and finally culminating in *impact* concerns. These concerns comprised the affective responses of these students to their situation. Hall observed this same developmental progression of concerns (Conclusion number five above) in college professors and used Fuller's results as a base to develop a seven-stage model known as the States of Concerns (SoC)(Hall, Wallace, and Dossett, 1973). Figure 3 provides definitions (Hall and Loucks, 1978) of these stages.

In the implementation of educational technology in science classrooms, the

6	Refocusing
	The focus is on exploration of more universal benefits from the innovation, including the possibility of major changes or replacement with a more powerful alternative. Individual has definite ideas about alternatives to the proposed or existing form of the innovation.
5	Collaboration
	The focus is on coordination and cooperation with others regarding use of the innovation.
4	Consequence
	Attention focuses on impact of the innovation on student in his/her immediate sphere of influence. The focus is on relevance of the innovation for students, evaluation of student outcomes, including performance and competencies, and changes needed to increase student outcomes.
3	Management
	Attention is focused on the processes and tasks of using the innovation and the best use of information and resources. Issues related to efficiency, organizing, managing, scheduling, and time demands are utmost.
2	Personal
	Individual is uncertain about the demands of the innovation, his/her inadequacy to meet those demands, and his/her role with the innovation. This includes analysis of his/her role in relation to the reward structure of the organization, decision making, and consideration of potential conflicts with existing structures or personal commitment. Financial or status implications of the program for self and colleagues may also be reflected.
1	Informational
	A general awareness of the innovation and interest in learning more detail about it is indicated. The person seems to be unworried about himself/herself in relation to the innovation. She/he is interested in substantive aspects of the innovation in a selfless manner such as general characteristics, effects, and requirements for use.
0	Awareness
	Little concern about or involvement with the innovation is indicated.

Figure 3: Stages of Concern of the Innovation [1]

SoC predicts that in the early stages science teachers would have *personal* concerns, concerns about the impact of the innovation on them—their role, their evaluation, their job description and their ability to use the technology appropriately. Once use has begun and personal concerns have been somewhat resolved, teacher concerns can be expected to mature to *management* concerns—

[1] Original Concept from G.E. Hall, R.C. Wallace, Jr., and W. A. Dossett, *A Developmental Conceptualization of the Adoption Process within Educational Institutions* (Austin, TX: Research and Development Center for Teacher Education, The University of Texas, 1973.)

the time it takes to get ready for class, the reorganization of classroom processes to make the technology useful, the testing of students who may be at many different places in the classroom at one time... The SoC predicts that as management concerns are resolved, the concerns of teachers will mature to *impact* concerns—the affect of the technology on these outcomes, how to measure these outcomes, the basic underlying philosophy and whether it squares with school or classroom philosophy, working with other users to improve student outcomes, and the possibility of making major changes in the innovation to improve student learning.

Assessment of SoC may be done using individual interviews, open-ended concerns statements, or the Stages of Concerns Questionnaire (SoCQ) (Hall, George and Rutherford, 1979). The SoCQ is particularly useful when dealing with the concerns of large numbers of teachers and in which assessment is to be limited to once or twice per year. Facilitators desiring to use any of these techniques are encouraged to seek training in their use and interpretation.

The value of concerns for facilitating the implementation of educational technology is grounded in the developmental nature of concerns. This makes it possible to predict where teachers might be, or given the knowledge of their present concerns, how their concerns might change through time. The developmental aspect of concerns suggests that it is necessary to resolve present concerns before the next stage can develop.

Interventions made to enhance implementation should thus be targeted at resolving the teacher's present concerns. Those seeking suggestions in selecting interventions targeted at specific stages will want to consult Hall, 1979. Whiteside and James (1986) have described how they used concerns data to intervene in the implementation of microcomputers in a small rural high school.

Given this brief review of concerns theory, it is especially important to view SoC as a humanistic management tool, not a method of coercing teachers toward desired ends against their will. As Hall (1979) states, "The concepts of the Stages of Concern and CBAM research are built upon positive assumptions about change facilitation. One of the strengths of the model is that it is virtually impossible to manipulate a person's concerns in an unhealthy way. If the innovations are inappropriate, if the change facilitator or administrators are coercive or exerting counterproductive pressure upon the individual, then the person's concerns will be self-protective. It is not possible to simply inform a person to *get rid of your personal concerns and indicate some concerns about kids.*"

Levels of Use. The research on implementation has revealed that many innovations still are not being used by large percentages of teachers years after their adoption by a district. We alluded to this in relation to the "dust" on microcomputers in science classrooms. The science education literature is replete with examples of the measurement of "non-events." That is, the assessment of the comparative effectiveness of this or that treatment without determining whether either treatment had been implemented. It is important to assess the nature of use of an innovation in some detail in order to monitor carefully the implementation process. While IC and SoC provide valuable assistance, one more dimension of the CBAM, Levels of Use (LoU), describes the *behaviors of users.*

LoU describes the behaviors of users of an innovation through various levels as the teachers begin to consider use, orient and train for use, learn to manage the innovation, and finally integrate use into their courses. Hall and others (1975) described eight levels, which are presented in Figure 4.

Level of Use	Behavioral Indices of Level
6 Renewal	The user is seeking more effective alternatives to established use of the innovation.
5 Integration	The user is making deliberate efforts to coordinate with others in using the innovation.
4b Refinement	The user is making changes to increase outcomes.
4a Routine	The user is making few or no changes and has an established pattern of use.
3 Mechanical Use	The user is using the innovation in a poorly coordinated manner and is making user-oriented changes.
2 Preparation	The user is preparing to use the innovation.
1 Orientation	The user is seeking out information about the innovation.
0 Nonuse	No action is being taken with respect to the innovation.

Figure 4: Levels of the Innovation: Typical Behaviors [2]

A range of behaviors is encompassed in each level.

Each level is limited by a decision point that denotes user actions that move the individual to the next level. Note that levels 0 (non-use), I

(orientation), and II (preparation) all denote levels in which *use has not yet begun.* The remainder of the levels are distinguished by the types of changes the users are making in their use of the innovation. Level III users are making changes to meet the user management needs, while level IVa users are not making any changes. Levels IVb through VI are for users who are making changes designed to refine the innovation.

In assessing LoU, a focused interview technique involving one-on-one data collection has been developed. The 20 minutes required for the interview in a one-on-one situation makes LoU assessment rather labor intensive. Valid and reliable use of the interview process requires interviewer training.

The data provided from these interviews is rich and will assist the facilitator in guiding the implementation in the innovation. For example, by being able to place the users at each of the levels will make clear just which teachers are, or are

[2] Procedures for Adopting Educational Innovations Program, Research and Development Center for Teacher Education, The University of Texas at Austin

not, using educational technology. It is likely that the facilitator will be surprised about the number of teachers who have not yet reached Level VIa, routine use, and may want to postpone evaluation of the effectiveness of the use of the technology until more teachers have reached this level. On the other hand, a large portion of the group may be at Level III, still struggling with management problems and the facilitator might want to intervene with a workshop aimed at developing management skills.

Designing a Plan for Implementing Educational Technology

Given our understanding of the aspects of change, knowledge of the change process and three diagnostic dimensions of the CBAM, we are now ready to synthesize a plan for the overall implementation process. Central to this plan are the actions or events (interventions) chosen to support the implementation of educational technology. Hall and Hord (1984) have reported on their study of interventions; while complete review of this complex subject is not possible here, one aspect of their report, the Game Plan Components, is especially useful in this presentation. It derives its name from the fact that like any coach planning for a successful triumph, the change facilitator needs an overall plan of action.

Hall and Hord identified six Game Plan Components which are defined in Figure 5. They are useful in that they provide a framework enabling the facilitator

1 Developing Supportive Organizational Arrangements
Actions taken to develop policies, plan, manage, staff, fund, restructure roles and provide space, materials and resources to establish and maintain use of the innovation. Examples would be to hire new staff, seek or receive funding, provide equipment.
2 Training
Actions taken to develop positive attitudes, knowledge, and skills in role performance in relation to use of the innovation through formal, structural, and/or preplanned activities. Examples are workshops and modeling or demonstrating use of a new program.
3 Providing Consultation and Reinforcement
Actions taken to encourage use and to assist individuals within the user system in solving problems related to the implementation of the innovation. Examples of such actions are consultant sessions with one or several users, arranging small problem-solving groups and organizing peer-support groups.
4 Monitoring and Evaluating
Actions taken to gather, analyze, or report data about the implementation and outcomes of the change effort. Examples might be end-of-workshop questionnaires, periodic assessment of concerns, use of the innovation or configuration of the innovation.
5 External Communication
Actions taken to inform and/or gain the support of individuals or groups of individuals external to the users. Examples are reports to the Board of Education, presentations at conferences, public relations campaigns.
6 Dissemination
Actions taken to broadcast innovation information and materials to encourage others to adopt the innovation. Examples are regular mailing of descriptive brochures to potential adopter, making charge-free demonstration kits available, training and providing regional innovation representatives, presenting the innovation at administrator conferences.

Figure 5: Game Plan Components

to be confident that she has "touched all the bases." The latter component, Dissemination, may not be useful in all situations. The application of this Action Plan is presented in Figure 6.

ELEMENTARY COMPUTER MATH PROGRAM

GAME PLAN COMPONENTS	STRATEGIES		
	Year 1 - 1988-89	Year 2 - 1989-90	Year 3 - 1990-91
Supportive Organization	•Select pilot schools •Select teachers •Provide materials (software, hardware, curriculum plans) •Release time for teachers to train	•Secure materials for all primary classrooms •Form primary grade user groups •Release time for teachers to train •Release time for quarterly grade group meetings •Release time for trainers	•Secure materials for all intermediate classrooms •Form intermediate grade user groups •Release time for teacher training •Release time for quarterly grade group meetings
Training	•Pilot teachers trained to use computers •Pilot teachers trained to teach other teachers	•Initial training for primary teachers •Mid-year training on management	•Train intermediate teachers •Mid-year training on management
Consultation and Refinement	•Supervisors allocate extra time to pilot schools •Supervisors meet quarterly to plan consultation and reinforcement process •Supervisors monitor courses of pilot teachers	•"Comfort caring" visits for teachers with personal concerns •Implement supervisor plans •Monitor concerns and intervene •Monitor implementation	•"Comfort caring" visits for teachers with personal concerns •Monitor concerns and intervene •Monitor implementation (IC)
Monitoring and Evaluating	•Assess concerns (SOCQ) of pilot teachers •Develop innovation configuration (IC) •Delay achievement testing to end of second year of implementation in all classes	•Monitor concerns (SOCQ) of primary grade teachers •Monitor implementation with IC	•Monitor concerns (SOCQ) of intermediate grade teachers •Monitor implementation with IC

Figure 6: Action Plan

The Action Plan consists of a time-line vs. game plan components. Goals for the implementation are laid out along the time-line. These goals can be stated in terms of the IC, SoC, and LoU which also constitute a major part of the monitoring and managing process.

A Team Approach to Change

Have you seen the latest of the "do it" bumper stickers? It says, "Nobody does it alone!" Teachers don't do implementation alone, and neither do administrators, supervisors or consultants—at least they don't do it as well alone as they do when they team up with others. In their study of principals as instructional leaders in the educational change process, Hord, Stiegtelbauer, and Hall (1984) reported that principals don't accomplish change alone, either. Hord and others (1987) provide a summary of their research and observations about the spectrum of persons involved in typical educational change activities. They had begun the study of principals as the "key to change," but quickly observed that other persons were significant: assistant principals, grade level chairs, resource teachers and teachers on special assignment at the building level and subject coordinators at the district level. It appeared that effective teams had these characteristics: continuous contact, complimentary roles, a common view of the goals of the change effort, and open planning.

In designing a team approach to implementing educational technology at the building level, it seems wise to choose a team so that at least the following roles are represented: the principal, department head or lead teacher, and at least one person who can represent the district to the team and vice versa. By the nature of educational technology, a person with the appropriate level of technical expertise to handle the hardware and software problems should be the team. But, a team is more than a group of individuals. The team leader will wisely choose to use time building team spirit and team effort. The team should have a central role in the design of the Action Plan for Change, and should make use of the Concerns Based Adoption Model and its application in carefully monitoring and managing the implementation.

Concluding Comments

Earlier, the reader was asked, "Suppose you were faced with implementing educational technology in a junior high school, what would you do?" There certainly is not a simple answer to that question, but in this chapter the author has presented a summary of points that are supported by most recent understandings of the change process. A brief review seems valuable in order to bring appropriate closure to this lengthy discussion:

1. Current practice in educational change is a mixture of misinformation, common sense, politics, and traditional practice. If educational technology is to be successfully implemented in science classrooms, an approach must be designed that is based on our most *recent understandings of change.*
2. The *unique nature and complex features of educational technology* as an innovation or a bundle of innovations must be recognized and dealt with.

3. The Concerns Based Adoption Model offers implementors of educational technology *specific insights into the nature of the change process.*
4. The Concerns Based Adoption Model offers implementors of educational technology specific *tools (Innovation Configuration, Stages of Concern, and Levels of Use) to use in monitoring and managing* the implementation.
5. An *over-all implementation strategy* (such as the Action Plan for Change) should be mapped out. Central to this plan is the selection of implementation goals, the monitoring of implementation progress, and the choosing of appropriate interventions to accomplish the task.
6. A *team approach* involving all the appropriate roles will enable the most efficient implementation of educational technology.

It should be clear to the reader that the CBAM is complex, and will require considerable effort to understand and use. Therefore, local implementation teams will require CBAM training or should secure the support of a carefully trained consultant who could assist them in the design of an Action Plan, the construction of an Innovation Configuration for the local implementation effort, the interpretation of implementation data, and making decisions about choices in interventions needed for successful implementation.

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The Promise of Staff Development for Technology Education [1]

Paul J. Kuerbis
Susan Loucks-Horsley

I think the only way we're going to get from where we are to where we want to be is through staff development.

Ernest Boyer

When it comes to the routine use of information technologies for teaching science in today's schools by today's teachers, the distance from "where we are to where we want to be" is indeed great. But while the challenge is great, it can be met through staff development. Fortunately, a decade of research and experience has taught us a great deal about effective staff development, and there is much that can be applied to helping teachers use new learning technologies.

Earlier chapters presented compelling scenarios of how such new technologies as microcomputers can enhance science teaching and learning. While schools continue to acquire microcomputers and other emerging technologies, research indicates that teachers make little use of the equipment for instruction. Weiss (1987) found that typical science students spent fewer than 15 minutes per week working with computers. Lehman (1985) and Becker (1987) reported similar findings.

Several researchers have recommended that science teachers need more training to implement educational computing (Lehman, 1985; Winkler, et al., 1986; Weiss, 1987). James, in the preceding chapter, has indicated how the Concerns

[1] This chapter was written with support from the National Center for Improving Science Education, funded by the U.S. Department of Education's Office of Educational Research and Improvement. All opinion's are those of the authors.

Based Adoption Model (CBAM) is useful to educators who are designing a framework for training teachers. Recently, other researchers have sought to determine what constitutes effective inservice and staff development efforts (Winkler, et al., 1986; Stecher and Solorzano, 1987).

Staff development is relatively new to education. Since its emergence in the 1970s, the concept of staff development has become a major force in the improvement of education and "offers one of the most promising roads to the improvement of instruction" (Sparks, 1983). Inservice education, whether it consists of a single workshop by an expert or a more carefully planned sequence of homegrown activities, is only one part of staff development. In urging educators not to interchange the terms "inservice" and "staff development," Dale (1982) argues that the function of inservice education is the improvement of teachers' skills, and their knowledge of subject matter. Staff development, on the other hand, includes these additional functions:

- *organization development*, such as building a positive climate through increased communication among staff,
- *consultation*, including assisting with implementation and evaluation,
- *communication and coordination*, including provision of information and resources for teachers and administrators,
- *leadership*, by providing suggestions about new approaches in curriculum and instruction, and
- *evaluation*, through assessment of district and teacher needs and the evaluation of existing staff inservice efforts.

The National Educational Association defines staff development as education mandated for practicing professionals, while the National Staff Development Council places an emphasis upon individual, personal, self-improvement efforts. We prefer a broader definition: staff development is the totality of processes and experiences that lead to an increase in a teacher's job-related knowledge and skills. Whereas inservice education is often perceived as something meaningful *done to teachers*, staff development implies a series of growing experiences (Loucks-Horsley, et al., 1987).

In this chapter, we consider what the research tells us about effective inservice education and the broader processes of staff development, as well as their organizational context. We then examine several approaches that can increase the instructional use of microcomputers. We conclude by describing a useful paradigm for teacher development that supports the implementation of microcomputers in schools.

A SHORT REVEIW OF RESEARCH ON INSERVICE EDUCATION AND STAFF DEVELOPMENT

In 1957, the *NSSE Yearbook* focused on inservice education. The authors could cite only 50 studies, few of which were experimental, that looked at training, improvement of the curriculum, or implementation of new techniques and ideas (Showers, et al., 1987). Throughout the 60s and well into the 70s, researchers investigated inservice education. They found that, while educators agreed that inservice education was necessary, it was deplorably practiced. Davies (In Orlich, p.73, 1986) described it as "the slum of American education." Too often

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administrators did not plan inservice sessions well, did not have clear objectives, and did not support the effort at the district level. They did not make the sessions part of a long-term organizational plan and they viewed the sessions as "a means for overcoming teacher shortcomings rather than as a continuation of professional development" (Evans, p.14, 1986).

In spite of its shortcomings, all inservice education has not failed. Several extensive studies, including some on training teachers to use microcomputers, have demonstrated that certain elements can ensure the success of inservice programs. In reviewing the research literature on basic skills instruction at the elementary level, Gall and Renchler (1985) identified six categories within effective inservice programs.

- *Teachers' objectives*. Within this category are elements that suggest inservice programs should focus on instructional methods validated by research; that programs should include operationally stated objectives for teacher behavior; complex skills should be introduced gradually; and that teachers need specific directions on their expected level of performance.
- *Students' objectives*. This includes the recognition that the goal of inservice programs must be improved student performance and that teachers need to believe that theirs is the primary role in doing so.
- *Delivery system*. The program should deal with the concerns of teachers and build consensus to participate. Attention should be given to the instructional process with manuals describing the methods covered in the program, and discussion sessions with feedback on teachers' skill performance. The program should include maintenance and monitoring components, take place in the teachers' building, use credible trainers, and be scheduled appropriately.
- *Organizational context*. Programs should focus on school improvement rather than personal professional development, use activities that allow the teachers to work together, and include the building principal.
- *Governance*. Teachers should help plan the program, with mandatory participation and a variety of incentives (e.g., released time, credit).
- *Selection and evaluation*. Inservice programs result in improved student performance, particularly in those areas needing improvement, and the content should be relevant to the teachers' situations. Educators should monitor both teachers' and students' performance to determine the level of implementation.

These categories encompass the 15 factors described by Stecher and Solarzano (1987) as contributing to the successful training of teachers to use microcomputers. These authors learned the value of training in a comfortable, supportive environment, with focused instruction and sufficient practice. Opportunities for peer interaction and applying theory to practice, especially in classrooms with heterogeneous groupings, contributed to their success.

By the end of the 1970s, researchers were accumulating evidence to support the idea of staff development, a process that encompassed more than inservice education as then practiced. The publications of McLaughlin and her colleagues (Berman and McLaughlin, 1978; McLaughlin, 1976; McLaughlin and Marsh, 1978)

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were benchmarks for the coming change. Educators established a new professional association, the National Staff Development Council, with a new focus solely on staff development. Many school districts established a new position: Director of Staff Development. Certification renewal efforts sometimes reflected the change. Colorado, for example, mandated that experienced teachers write professional development plans as part of their certificate renewal process.

The recent past has known a proliferation of synthesizing research findings on staff development. In the *1986 AETS Yearbook*, Evans (1986) reviewed published studies on inservice and staff development, synthesizing the findings of these studies into 21 factors that can guide the development of effective programs. In 1987, a guidebook produced by the Northeast Regional Laboratory and the National Staff Development Council, (Loucks-Horsley, et al., 1987) synthesized the literature on staff development research and practices. The authors identified ten characteristics of successful staff development efforts that support and sustain a "community of learners":

- collegiality and collaboration,
- norms of experimentation and risk taking,
- incorporation of available knowledge bases,
- appropriate participant involvement in goal setting, implementation, evaluation, and decision making,
- sufficient time to work on staff development and assimilate new learnings,
- leadership and sustained administrative support,
- appropriate incentives and rewards,
- designs built on principles of adult learning and the change process,
- integration of individual goals with school and district goals, and
- formal placement of the staff development program within the philosophy and organizational structure of the school and district.

That same year, Showers, Joyce, and Bennett (1987) also produced a synthesis of the research on staff development. Their meta analysis of nearly 200 studies served to validate many of the learnings of other syntheses, but illuminated in particular the strength of research on training design. The authors found that "perhaps *the* major dimension of teaching skill is cognitive in nature." The purpose of providing training is not just to have teachers demonstrate certain instructional "moves," but to "generate the cognitions that enable the practice to be selected and used appropriately and integratively." They found in their own research that the four components of training—theory, demonstration, practice, and feedback—are essential for an instructional strategy to be incorporated into a teacher's natural repertoire. As many as 25 practice teaching episodes may be necessary before a strategy is fully incorporated into a teacher's regular set of available strategies (Showers et al., p.85, 1987).

Other analyses of the staff development literature have discerned various models for staff development that incorporate different inservice approaches. In the *1986 AETS Yearbook*, Orlich proposed three typologies that included at least 14 different inservice approaches:

- *Organization-based models,* which focus on the building or institution. While considering the teacher, their primary emphasis is on correcting deficiencies in the system.
- *Individual-based models,* which focus on the individual teacher who can make the difference between an effective and ineffective organization.
- *Role-and-trainer based models,* which focus on a teacher's determination of needs but within the context of the organization. Trainer-based models rely on an external, certified trainer to conduct the inservice.

Sparks and Loucks-Horsley (in press) organize existing approaches to staff development into five models:

- *Training,* incorporating all four components determined to be critical by Showers and her associates (1987).
- *Observation and assessment,* including all forms of peer coaching and clinical supervision that are based on observing classroom behavior and providing improvement-oriented feedback.
- *Involvement in a development or improvement process,* where teachers develop curriculum, design programs, or engage in a school improvement process to solve general or particular problems.
- *Inquiry,* where teachers identify an area of instructional interest, collect data, and make changes based on interpretation of the data.
- *Individually guided staff development,* where individual teachers identify and pursue an area of special interest.

The value of these alternative frameworks is in helping staff development planners incorporate characteristics of effective programs, going beyond the standard inservice workshop format.

The literature on staff development for microcomputer use is far less robust than that on staff development in general. What research exists, however, appears to validate the importance of attention to teachers' individual learning needs as well as the organizational supports that help people make and sustain changes.

In 1985, Winkler, Stasz, and Shavelson reported on a study of school district administrative policies for increasing the use of microcomputers in instruction. Their review of extant research on inservice education and staff development and their national survey of teachers actively using microcomputers yielded several recommendations:

- districts and schools should continue to acquire microcomputers and courseware as a means of encouraging teachers to use the new technology,
- districts and schools should provide teachers with "centralized, routine assistance in integrating computers into instruction" in the form of advisors who can help teachers match computer-based instruction to their instructional objectives,
- administrators should compensate computer-using teachers through master teacher programs, salary credits, and summer stipends for computer and curriculum development,
- districts should continue to provide district-level inservice training and study ways to enhance training effectiveness.

In the past decade, we have learned a great deal about how to influence the continuing growth and development of teachers. We also know some factors that can encourage teachers to use microcomputers to enhance their instruction. But how do science educators select from dozens of alternative approaches to teacher development?

SOME ALTERNATIVE APPROACHES FOR STAFF DEVELOPMENT

In this section we explore three approaches that lend themselves to helping teachers develop such new strategies and innovations as using the microcomputer for instruction. They are the following: training, with peer coaching; peer dialogue; and action research. We selected these because of the promise they show based on reports in the literature (Showers, Joyce, and Bennett, 1987; Glatthorn, 1987) and on the experience of one current staff development effort, *ENLIST Micros* (Ellis and Kuerbis, 1988), which employs all three approaches.

Training, with Peer Coaching

Training is the best researched approach to staff development, with clear indications of its effectiveness in changing teacher knowledge, skills, and attitudes (Sparks and Loucks-Horsley, in preparation). Over the past ten years, Bruce Joyce and Beverly Showers have conducted intensive research and development on training designs that help teachers make such new teaching strategies as inquiry teaching and cooperative learning natural parts of their teaching (Joyce and Showers, 1982, 1988). Training should include the theory and rationale of the new strategy, demonstrations of the strategy, practice of the strategy under controlled conditions, and practice of the strategy in the classroom with observation and feedback by a colleague. "Coaching," the term that describes this last step, is the component most frequently missing from training sessions, yet it is critical to success. Shalloway (1985) reports that teachers may need up to 30 hours of instruction in theory and rationale, 15 to 20 demonstrations, and 10 to 15 coaching sessions to acquire even moderately difficult strategies. The research of Joyce and Showers (1988) indicates an effect size of 1.68 when coaching is combined with the other components, but an effect size of only .39 when coaching is excluded. Their research also indicates that up to 30 coaching sessions may be necessary.

Coaching involves teachers working together to support each other as they acquire new teaching behaviors and refine extant ones. It helps build communities of teachers who share a common language and who continuously study their craft for the purpose of developing their professional decision-making abilities. Coaching provides a structure for practicing new skills and strategies learned in a formal training session, and for acquiring the ability to know when and how to use those skills and strategies appropriately.

One model of coaching is designed for collegial teams who want to examine their instruction and incorporate new approaches. It provides professional development in a safe, non-evaluative environment where colleagues can engage in the mutual study of their craft. Since coaching provides support for instruction rather than evaluation of instruction, peers are appropriate partners rather than administrators. Research substantiates that teachers can and should coach each other (Showers, 1985; Wu, 1987).

Coaching in collegial teams serves four major functions (Showers, 1985). The first is to provide companionship and support so that the teacher-pairs can discuss their frustrations and successes as they try a new skill or strategy. The challenge of learning about a new strategy and practicing it in a workshop for teachers pales compared to the challenge of using it in the classroom with students. The new procedure will create awkwardness and anxiety in what are usually automatic teaching patterns. Companionship gives the teacher reassurance that the problems encountered in implementing a new procedure are normal. Moreover, the support provided by a colleague makes the experience enjoyable and helps ensure that the new procedure gradually becomes a part of the teacher's regular teaching pattern.

The second function of coaching is to provide feedback. Feedback helps to keep the teacher focused on developing the new procedure, skill or strategy. The feedback is not evaluative; the coach provides feedback to the teacher on such matters as whether all parts of the new strategy were incorporated into the lesson. The coach might point out how the room arrangement was compatible with, or interfered with, the new strategy. In observing the teacher and providing feedback, the coach also benefits by seeing how his or her own use of the strategy and classroom arrangement might be confusing to students. Of course, the coach might also see creative or new practices that can be incorporated into his or her own teaching repertoire.

Another function of coaching is to analyze application. Coaching enables the team to help each other learn how and when to use a new skill or strategy. The team's goal is to internalize the new strategy so that it becomes a natural part of the teachers' instructional pattern. The team, for example, can discuss how the new strategy can be used with the existing curriculum and then make specific plans for using the strategy.

The fourth function of coaching is for the team to explore how they can adapt the new skill or strategy to the needs of students. Learning how to use the new strategy with students is challenging, for both teacher and students are used to approaches that are common and comfortable for them. Moreover, a teacher may need to use the new strategy differently with different groups of students. It is easy to be discouraged when students do not respond positively to a new approach. The coach becomes the teacher's ally and companion and helps ensure the long-term incorporation of the strategy into the teacher's instructional repertoire.

Trust-building at the beginning is an important component of coaching. For this reason, the process should be voluntary and team members should select each other. There are several ways to begin: two teachers might want to learn how to use microcomputers to enrich their instruction; a school or department might establish microcomputer use as a goal; a school district might mandate that school buildings explore a new instructional strategy with computers, such as cooperative learning.

Implementing peer coaching does not mean that a school or school district must incur excessive expenditures for substitute teachers so that the teams can

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have time for observations and conferences. Principals can cover a class, teachers can have conferences during a common lunch or planning period, and teachers can combine classes so a colleague can be free to coach a partner. Coaching can be a practical professional development procedure when a team wants to learn together and has support from other teachers and from administrators.

In practice, coaching involves a three-stage process. First, the teacher and coach arrange for a pre-conference when the teacher can share concerns and describe what the coach is to observe. This is usually an outgrowth of a prior training experience. They decide what kind of written record, if any, the coach is to make. Finally, they decide when the observation should take place and when to hold a post-conference. The second stage is the lesson that the coach observes. Immediately after the lesson both teacher and coach write sets of notes about the lesson for use during the third stage, the post conference. During the post conference, the coach's comments are descriptive and supportive, not evaluative (for example, "That was a great lesson!"). The coach reports observations and suggests how that information might help (for example, "The first group at the computer worked well together and followed their defined roles, but the second group did not. Perhaps if you....what do you think?") The teacher compares notes with those of the coach and seeks clarification of points the coach made. Together, both can learn a great deal about effective instruction.

Implementing a new instructional strategy takes time and the coaching teams need to observe and coach one another many times over an extended period. The first coaching experience will seem awkward and both teacher and coach may seem uneasy at sharing feelings, beliefs, and observations. When properly carried out, however, peer coaching can enhance a teacher's ability to solve instructional problems and to refine instructional approaches.

Peer Dialogue

In many ways the schools of today differ little from the one-room school house of yesterday. A variety of physical and scheduling barriers assure that most teachers teach in isolation and have little time to visit classrooms of colleagues and discuss educational issues. The current organizational contexts of schools send strong messages that teaching is a simple, straightforward set of tasks and that teachers themselves have little to contribute to their own development and to the improvement of schooling.

Planned, thoughtful dialogue among teachers represents one attempt to engage teachers in guiding their own development and in contributing to the improvement practice throughout the school. The key component of peer dialogue is teachers meeting regularly for structured discussions of their own teaching as it relates to current research and developments in education. A major goal is to encourage teachers to *reflect* about their current teaching practices so that their performance improves in three areas:

- teacher planning both before and after lessons,
- teacher thinking and decision making during actual teaching, and
- teacher beliefs, attitudes, and theories about teaching.

Glatthorn (1987) summarizes the important steps that ensure that teachers engage in deliberate dialogue about teaching and that the discussions put cognition at the center. A structured approach is necessary and usually prevents the activity from degenerating into simple, verbal "messing about." First, the teachers who wish to engage in the dialogue agree on such parameters as frequency of their meetings and times for their discussions. The group then plans an agenda for the first few months of sessions. The teams pick issues that are significant and important to them, ones on which the experts differ and for which background materials are available. For example, the group might want to discuss cooperative learning and how they can use that strategy with microcomputers. As the topics are selected and meeting dates established, the group also identifies a discussion leader for each session.

The discussion sessions follow a three-stage format that ensures the meetings are productive (Glatthorn, 1987). During the first stage, the leader summarizes the research that is available on the topic of study. The leader encourages the team members to analyze this body of external knowledge so that they understand the agreements and disagreements that exist among the experts. Once they have a thorough understanding of the research, they move to the second stage, which focuses on the team's understanding of their personal (or internal) knowledge base. The leader of this session encourages team members to share what they know about the topic from their own experiences. This includes areas of their experience that either mesh or do not mesh with the research shared in earlier sessions. The sharing is an important step, for team members discover insights into what works and doesn't work under the varied conditions in their school. The sharing also ensures that the teachers don't blindly accept, nor reject, the research base.

The last stage involves the team members taking action based on their dialogues. Each member considers how both external and personal knowledge bases can help him or her make decisions about teaching. Finally, they discuss openly how the dialogues have led them to think about, and perhaps change, their theories and beliefs about teaching.

Action Research

"Teacher as researcher" is another model of staff development that holds promise for bringing about a substantial, lasting change in how teachers use microcomputers to enhance instruction. While there is not yet empirical evidence to support this contention, there is evidence that action research results in teachers who are willing to change, who focus on finding out what their students know and then try to help them, and in teachers who ask more questions and listen more (Rich, 1983). Another study reports that teachers who engage in research change their thinking skills, habits, or styles, develop new theories of action in the classroom, and change their classroom practices (Simmons, 1985). Lieberman (1986) reports that the process can facilitate reflection about teaching, promote interaction among colleagues, increase teachers' interest in applying research findings, and give teachers a sense of empowerment.

While educational research has typically been done *on* teachers, in this model teachers define the research questions and collaborate with other teachers and a researcher to find answers to those questions. Other variations on this model include individual teachers pursuing their own studies while consulting with a researcher as needed and teachers responding to relevant research and then collecting and analyzing data they gather in their own classroom.

Lieberman (1986) suggests that action research involves four general steps: team members identify a researchable problem; the team decides upon the research questions and methodology; the team carries out the research while attending to the variables of the classroom; and the team uses the results to design an action or intervention that they can implement. Within this general model of action research, additional steps are also helpful. The team might complete one or more trial runs to gain experience in conducting research, discuss and provide several examples of research methods, seek advice from others on where the design might be modified, and explore ways they can share the results (Hovda and Kyle, 1984).

The questions teachers usually pose revolve around instruction and student learning. The questions may only be germane to the team posing them. As an example, teachers might form a team to see how a particular piece of courseware can best be used. They might try it in a demonstration mode or as a station activity or in a cooperative learning format. They may discover that the courseware is more successful in just one of these instructional modes or that one or more classroom variables can influence the successful use of the courseware in one or more of the modes. The research strategies do not have to be highly technical and quantifiable. A case-study research design, in which teachers gather descriptive information, lends itself to many aspects of action research. Teachers can observe in one another's classrooms, make audio or videotapes, interview students and other teachers and, in general, gather valuable qualitative information about teaching and learning. This approach is of particular value in the early stages of classroom research when the questions asked by the team are more broad or general ("I wonder if the students will respond positively to this courseware if I use it in a demonstration mode?") As the action researchers become more facile with research design and as the questions they pose become more specific ("Will using this courseware, in a learning station, versus not using it at all, increase the student's level of understanding?"), then a quantitative, experimental research design might be more appropriate.

As we saw earlier with peer coaching, time to engage in the staff development activities is important. The suggestions made earlier to free teachers to participate in coaching can also work for action research. Also necessary is a location that is conducive to open, honest discussions, planning, and reflection. It is important to remember that the process of action research is probably as important as the actual product or research data produced by the team. Thus, more experienced teachers, those whose instruction is already stable and whose classrooms already run smoothly, may benefit more from action research compared to novice teachers whose concerns, as noted in the previous chapter by James, may be focused on survival issues. These teachers may benefit more from engaging in peer coaching and peer dialogue.

SUMMARY AND RECOMMENDATIONS

The three approaches discussed above have four salient features in common. Each is characterized by an emphasis upon teacher *autonomy* in selecting how they are to engage in the specific activity and on what specific problem or area of expertise the teachers will focus. This is quite different from most inservice programs that take a deficit-model approach to determine what the teachers are lacking and then provide training in the missing ingredient, frequently a skill. Second, the approaches all emphasize *collegiality*. Although action research does not demand a team approach, it does require at the minimum that the teacher seek the advice of a researcher or other teachers. Peer dialogue and peer coaching can only be carried out in a team context where teachers openly share and examine their craft. Third, *time* to carry out the staff development efforts and to reflect on those efforts is essential. Finally, all three approaches emphasize not just the learning of a new skill, but guide teachers to think about their particular settings, and when to use the new skill. These approaches, therefore, are *cognitive* in nature.

Whereas inservice focuses most of its attention on developing specific teaching skills, staff development efforts take teachers beyond the acquisition of specific skills to guide them to think about how and when they will use their new knowledge of instruction. We suggest that a reductionist mode of thinking has guided inservice efforts in the past and they have failed to bring about lasting changes in teacher behavior. Staff development efforts, on the other hand, have been guided by broader, more robust notions of human learning and by the belief that knowledge of teaching and conceptual understanding of instruction is complex learning. These hold promise for successful change in the future.

Wildman and Niles (1987) suggest some parallels in how teachers and children develop which may prove useful in improving professional growth experiences. The authors point out similarities in the Piagetian developmental ideas of assimilation and accommodation and the ideas of accretion and restructuring proposed by Norman (in Wildman and Niles, 1987) for the route by which novices become experts. In developing a model for training teachers on cooperative learning, Sharon and Sharon (1987) proposed that teachers use experiential learning model as a framework for sequencing training activities. The model, based on Kolb's experiential learning theory and grounded in John Dewey's and Kurt Lewin's view of the importance of personal experience, begins with concrete experience as the catalyst for learning by teachers. This is followed by activities that give teachers time to observe and reflect, after which the teachers focus on the formation of abstract concepts and generalizations concerning the new instructional strategy. In the final step, activities allow the teachers to test the implications of the concepts in their classrooms. This later experience then becomes the beginning of a new cycle of learning. The Kolb learning theory is also the basis for Bernice McCarthy's (1985) 4MAT System—an eight-step cycle of instruction that appeals to four major learning styles and two different brain-processing strengths. This model has been used by staff developers for designing activities for teacher workshops that appeal to different styles of learning and thinking. Guskey (1985) proposed yet another model for staff development. Based on his research and that of Crandall (1983), his model suggests that teachers need to experience success using a new instructional strategy in their classrooms with their students before they will commit firmly to the new practice and change their beliefs and attitudes about it. Active engagement, with reflection on the consequences, appears to reinforce and strengthen the learning of new strategies.

We propose that educators need to restructure their way of thinking about how to help teachers develop new instructional behaviors and new ways of thinking about instruction. The constructivist model of how students learn (Champagne and Hornig, 1987) provides a model of how teachers learn as well. The report on teacher development produced recently by the National Center for Improving Science Education, also proposes that constructivism should guide our thinking about how teachers develop and change (Loucks-Horsley et al., 1989).

Constructivism asserts that learners construct unique organizations of their emerging knowledge of the world by integrating new information with prior knowledge. Constructivism is not new, but recent research has given it a new impetus among science educators (Novak, 1988). Constructivism has given science educators a way of conceptualizing the appropriate curriculum content and instructional approach for students (Bybee et al., 1989). We have learned, for example, that teachers need to recognize that students come to them with certain scientific conceptions that may be naive. We need to recognize the students' point of view and provide activities (concrete at an early age and more abstract in later years) that guide the students to reconstruct their current view into a new view. From a Piagetian perspective, the students accommodate their own way of thinking about a concept. They can then assimilate more closely related information until they uncover, perhaps with the teacher's "help," some additional information that doesn't make sense. This state of disequilibrium forces students to once again reconstruct their emerging view of the concept. This process, while idiosyncratic to each learner, probably is achieved more effectively when the learner has opportunities to share viewpoints with his or her peers and the teacher (Champagne, 1987). The traditional model of education, which assumes that an already developed and organized body of knowledge can be easily transmitted to the students through passive. direct instruction, is not a viable model for students to develop conceptual understanding.

The model we have described for the K-12 student in science has striking parallels to what staff developers know as sound practices in teacher development. Some educators have suggested that teachers (prospective and experienced) have developing conceptions (that is, naive conceptions or misconceptions) of effective instructional practices (Kuerbis, 1985; Clark, 1987). Many approaches to staff development, including those discussed earlier (peer dialogue, peer coaching, and action research), recognize that teachers need to guide their own learning by selecting a relevant problem or topic and by working within a framework that focuses them on restructuring their thinking about a new instructional practice. These approaches recognize that social interaction among peers is a significant learning strategy and that a teacher's view of instruction is continually developing. The traditional model of inservice education, which assumes that we can give teachers a developed body of knowledge about instruction through passive, direct instruction (e.g., the one-shot workshop), does little to result in long-term change in teacher knowledge or behavior.

The three approaches to staff development that we described earlier in this chapter exemplify the constructivist model of teacher learning that we have proposed. Much research needs to be done on the effectiveness of these approaches for increasing teachers' use of the microcomputer to enhance instruction, although preliminary indications from the *ENLIST Micros* project show that the approaches are promising. There is a great need for staff developers to explore constructivism as a viable paradigm for their efforts. Perhaps this paradigm will enable us to build the professional-development culture proposed by Lambert (1988) in which teachers have access to varied opportunities to learn within a supportive environment that fosters learning.

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14

Preparing Science Teachers for the Information Age

James D. Ellis

The authors in the previous chapters developed a rationale for integrating information technologies into science education, provided a vision of how information technologies might enhance teaching and learning in science, and described exciting educational materials that are commercially available or experimental. They paint a picture of teaching and learning, however, that differs much from what currently takes place in schools.

To make the change to a technology-oriented program, science teachers have to change their approach to teaching, their teaching behaviors, and occasionally revise their philosophy of teaching and their understanding of the nature of science. The chapters by James and Kuerbis et al. point out that for teachers to make such changes requires careful planning, an educational program to present the content and skills involved in the innovation, an environment conducive to change, follow-up activities to help the teacher overcome the barriers to implementation, and time.

This chapter describes several models for preparing preservice and inservice teachers to use microcomputers in science teaching. Researchers have based these models on the research on implementation, adult learning, and staff development and on theories of the process of educational change. This chapter begins with a summary of this research. The next section describes the competencies that science teachers need to use microcomputers in science teaching. The central section of the chapter describes models that researchers from institutions around the United States have designed to help science teachers master those competencies. The chapter ends with recommendations for preparing science teachers for the information age.

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RELATED RESEARCH

Implementation and Educational Change

Change is a process, not an event is the motto of educators who study the implementation of educational innovations. Educational change is a long and tedious process that does not end with the adoption of a new curriculum or approach to teaching. The decision to change is only the beginning. Hord and Huling-Austin (1987) found that it takes three or more years for teachers to make a substantial change in teaching.

Implementation is a complex process that involves all people who have a stake in education. To be successfully implemented, a program requires:

- Leadership from the school principal to provide supportive organizational arrangements that encourage the use of the innovation; opportunities for teacher training and weekly consultation and feedback; and, mechanisms to monitor and evaluate the implementation of the innovation.
- Support from a leadership team (lead teacher, principal, and instructional specialist) that sanctions the innovation, provides resources, gives technical coaching and assistance, arranges training, reinforces attempts to change, and puts the program in the spotlight for everyone in the school community.
- Support from an implementation team of fellow teachers that provide peer coaching, support, and encouragement and that share the work.
  - Recognition by all people involved that change takes time, that innovations change as they are adapted to local situations, that implementing a new approach to teaching is a difficult process, and that implementation requires resources in the form of time, people, and materials.

Staff Development

Staff developers are responsible for designing programs that will help teachers use new approaches to teaching. Many researchers (Showers, 1988; Joyce and Showers, 1987; Leggett and Hoyle, 1987; Wu, 1987; Garmston, 1987; and Stecher and Solorzano, 1987) have identified procedures or factors for successful staff development. What follows is a synthesis of those recommendations.

Successful staff development programs provide teachers with:

- A comfortable and relaxed environment that is conducive to change.
- The theory and the rationale behind the innovation.
- A detailed description of the innovation.
- Assistance with integrating the innovation into the extant goals and objectives, scope and sequence, and instructional activities.
- Demonstrations (models) of the new teaching behaviors.
- Opportunities over a period of several weeks or months to practice the behaviors with fellow teachers and with students and to receive corrective and supportive feedback, peer coaching.

- Opportunities to discuss the innovation with fellow implementors and how it is changing their teaching.
- Guidance from teachers who have mastered the innovation.
- Assistance, whenever it is needed, with solving problems associated with implementing the innovation.
- Continued and consistent support for the life of the innovation.
- Assistance with managing the logistics, hardware, software, and learning materials.

You can implement the recommendations from the researchers and staff developers in many different ways, according to your specific goals and objectives. Many projects have used these recommendations to mold models for training teachers to use information technologies in science education.

OBJECTIVES FOR PREPARING SCIENCE TEACHERS TO USE MICROCOMPUTERS

Before designing a program that is to prepare science teachers to use microcomputers, you must know what a teacher must know and be able to do to use microcomputers in science teaching. In 1984, there was little consensus among educators about what teachers ought to know and be able to do to be a computer-using educator. Questions under consideration included: Is computer literacy the same for a science teacher as it is for other teachers? Is it the same for students, teachers, and general citizens?

Ellis and Kuerbis (1985) conducted a national survey of professors in science education and computer education, school administrators, and science teachers who were using microcomputers. They identified the competencies that teachers need to use microcomputers in science teaching. Elllis and Kuerbis believed that certain skills of operating a computer were mandatory for all teachers and that other knowledge and skills were specific to science teaching. They also believed science teachers did not need to be able to program a computer to be able to use it effectively. Through a five-step process they reduced 160 objectives for computer literacy to 22 essential competencies for science teachers, which 75 percent of the survey respondents rated as important or very important. Table 1 lists those competencies. Computer programming did not make the list.

Table 1
Essential Competencies and Factors

Awareness of Computers

Upon completion of *ENLIST Micros* the participant will be able to

- Demonstrate an awareness of the major types of applications of the computer—such as information storage and retrieval, simulation and modeling, process control and decision making, computation, and data processing.
- Communicate effectively about computers by understanding and using appropriate terminology.
- Recognize that one aspect of problem solving involves a series of logical steps, and that programming is translating those steps into instructions for the computer.
- Understand thoroughly that a computer only does what the program instructs it to do.

(Continued)

- Demonstrate an awareness of computer usage and assistance in fields such as:

health	business and industry
science	transportation
engineering	communications
education	military

- Respond appropriately to common error messages when using software.
- Load and run a variety of computer software packages.

Applications of Microcomputers in Science Teaching

Upon completion of *ENLIST Micros* the participant will be able to

- Describe ways the computer can be used to learn about computers, to learn through computers, and to learn with computers.
- Describe appropriate uses for computers in teaching science, such as:
  - computer-assisted instruction (simulation, tutorial, drill and practice)
  - computer-managed instruction
  - microcomputer-based laboratory
  - problem solving
  - word processing
  - equipment management
  - record keeping
- Apply and evaluate the general capabilities of the computer as a tool for instruction.
- Use the computer to individualize instruction and increase student learning.
- Demonstrate appropriate uses of computer technology for basic skills instruction.

Implementation of Microcomputers in Science Teaching

Upon completion of *ENLIST Micros* the participant will be able to

- Demonstrate ways to integrate the use of computer-related materials with non-computer materials, including textbooks.
- Plan appropriate scheduling of student computer activities.
- Respond appropriately to changes in curriculum and teaching methodology caused by new technological developments.
- Plan for effective pre- and post-computer interaction activities for students (for example, debriefing after a science simulation).

Identification, Evaluation, and Adoption of Software

Upon completion of *ENLIST Micros* the participant will be able to

- Locate commercial and public domain software for a specific topic and application.
- Locate and use at least one evaluative process to appraise and determine the instructional worth of a variety of computer software.

Resources for Education Computing in the Sciences

Upon completion of *ENLIST Micros* the participant will be able to

- Identify, evaluate, and use a variety of sources of current information regarding computer uses in education

Attitudes About Using Computers in Science Education

Upon completion of *ENLIST Micros* the participant will be able to

- Voluntarily choose to use the computer for educational purposes.
- Display satisfaction and confidence in computer usage.
- Value the benefits of computerization in education and society for contributions such as:
  - efficient and effective information processing,
  - automation of routine tasks,
  - increasing communications and availability of information,
  - improving student attitude and productivity, and
  - improving instructional opportunities.

Using those competencies as a guide, the Biological Sciences Curriculum Study (BSCS) developed the *ENLIST Micros* project to help science teachers use microcomputers to enhance science teaching and learning (Ellis and Kuerbis, 1987 and 1988). The next section describes *ENLIST Micros* and many other models for teacher preparation and enhancement.

MODELS FOR TEACHER PREPARATION AND ENHANCEMENT

Researchers have developed several models for training science teachers. For this chapter, I assign the models into the major categories of teacher preparation through colleges and universities and teacher enhancement through inservice. Within the section on teacher preparation, I discuss projects that teach preservice teachers to use information technologies. Within the section on teacher enhancement, I discuss projects that provide inservice training on information technologies.

Teacher Preparation through Colleges and Universities

Generic Course. According to a survey by Jeffrey R. Lehman (1986), two-thirds of colleges and universities offer teachers training in educational computing. The most common method to offer this training is as a generic introductory course in educational computing for preservice teachers in all grade levels and subject areas. These courses are equally distributed between colleges of education and divisions outside of the college of education (typically in computer science).

These generic courses in educational computing, however, are evolving. When colleges first offered these courses they typically emphasized learning to program a computer and covered computer architecture, how a computer works, the history of computing, and the impact of computers on society. Often those courses began in the department of computer sciences, and were adapted for teachers from introductory computer science courses.

These generic courses now are shifting toward an emphasis on content and skills that directly relate to what a teacher needs to know and do to use computers for instruction. Bitter (1988) has implemented a course at Arizona State University that exemplifies the shift toward practical applications. As part of this program, all students must complete the one semester-hour course *Computers in Education.* The students develop six competencies in this course: (1) an understanding of computers and their applications; (2) the ability to use a word processor, a database, and a spreadsheet and to cite educational applications of each; (3) an understanding of how to use teacher utilities including graphic print programs, worksheet generators, test generators, and computerized grade books; (4) an understanding of the characteristics of educationally sound software; (5) the ability to design lesson plans applicable to software programs for their academic major; and (6), the ability to access an electronic bulletin board. An emphasis on programming is noticeably missing.

These generic courses are effective and important for preparing teachers to use microcomputers, but they rarely offer the opportunity for science teachers to integrate what they are learning about the technology into what they are learning about science and science teaching. If the only training that a science teacher receives on educational technologies is unrelated to science teaching, then the teacher may lack the knowledge and skill to transfer that training to classroom practice. In addition to generic courses, science teachers need training on how to use educational technologies in science teaching. Jeffrey R. Lehman (1986) found, however, that only 24.5 percent of colleges and universities he surveyed offered courses on educational computing specifically designed for science teachers.

Course in Science Education. Okey (1984) recommended that we should provide special courses for science teachers that deal directly with the skills they need to use computers in science teaching. He also indicated that such courses will become unnecessary as teachers become acquainted with computers as part of their schooling. Okey recommended that the central emphasis of the course should be on applications of the computer for science instruction. In less than 15 percent of colleges and universities surveyed, however, did science educators teach a course for science teachers on educational computing (Lehman, Jeffrey R., 1986).

Nevertheless, some institutions do offer these specialized courses for science teachers. Researchers at the University of Northern Colorado, Tufts University, and the BSCS have described such projects.

Blubaugh (1988), at the University of Northern Colorado, has developed an elective course for preservice science teachers on *Computer Uses for Mathematics or Science Instruction.* The goals of this course are not only for the participants to understand computer capabilities but to be aware of math and science problems amenable to programming solutions and to be aware of the types of extant software for science and mathematics. In the course the participants learn to use telecommunications, a word processor, a spreadsheet, and a database. They learn to apply these tools to develop instructional materials, manage the classroom, solve math and science problems, manage equipment and supplies, and manage student records. The program also acquaints the teacher with methods for reviewing software of all types, writing simple programs to solve science problems, and learning how to evaluate software.

Thorton (pers. com., 1988), of Tufts University, has proposed an innovative approach to teacher preparation. He proposed a project that will create and evaluate laboratory investigations that use microcomputer-based-laboratory (MBL) instruments. These investigations are to be integrated into physics courses and into science methods courses for teachers of middle school science. The project will identify misconceptions related to physics topics that students cover in the middle school curriculum. Then the project will develop MBL investigations that demonstrate to preservice teachers how they can use computers for remediating those misconceptions. The project will field test the MBL investigations at three diverse sites to ensure that the materials will be appropriate for use by other institutions of higher education throughout the country.

Furthermore, the BSCS, with support from the National Science Foundation (NSF), has developed *ENLIST Micros*—a curriculum for training preservice and inservice science teachers to use microcomputers to enhance teaching and learning (Ellis and Kuerbis, 1989). *ENLIST Micros* is a three-phase project. The first phase developed the curriculum, the second is developing a model for implementing educational computing in science teaching, the third phase will replicate the implementation model at regional sites throughout the United States. Later sections in this chapter describe the second and third phases.

The BSCS designed the curriculum for both preservice and inservice teachers who are from grades K-12 and from all science disciplines. The materials consist of a text, a videotape, and computer software. The first five chapters of the text introduce novice or non-users to the use of microcomputers in science teaching. The sixth chapter presents methods for using the computer as a tool, and the last two chapters provide information for teachers who may become leaders in their districts.

The curriculum also incorporates four video programs that include interviews with teachers and scenes depicting students who are using computers. We use these video programs to introduce computer competencies for science teachers and to illustrate how to integrate microcomputers into instruction. Furthermore, the BSCS staff wrote computer software that demonstrates and illustrates applications of microcomputers. We recommend that instructors supplement the curriculum with commercial software and catalogs of commercial software.

The BSCS designed the *ENLIST Micros* curriculum to be used as a one-hour course, to be integrated into extant science education courses (taking about 5-15 hours of class time), or to be used in an inservice program for science teachers. These specialized courses satisfy the requirements of the generic courses and present practical information on applications of educational computing to science teaching.

Part of a Course in Science Education. Only 40 percent of colleges and universities surveyed integrate educational computing into extant courses on science education (Lehman, Jeffrey R., 1986), even though this may be the best approach. By integrating educational computing into undergraduate and graduate courses on science education, these courses will be taught by science educators who are able to link educational technology to the pedagogy and curricula for science teaching. An effective approach might be to offer a one-hour course that introduces science teachers to the operation of microcomputers and to word processing, spreadsheets, databases, and teacher utilities (which could be offered as a generic course). Further, the use of educational technology might then be integrated into all science education courses. In that way, science educators can model how science teachers can integrate educational technology into instruction.

The University of Pittsburgh has a model program of this type. The board of education of Pennsylvania requires that all preservice science education students study computer applications in science teaching, emphasizing computers as tools for instruction. The University of Pittsburgh accomplishes this requirement by integrating the training into its five-part series of courses for preparing science teachers. O'Brien (in press) described the model in a paper that won the 1988 award for the NSTA-Gustaf Ohaus Program for Innovations in College Science Teaching.

In the introductory course, the model integrated the following topics: operation of the computer, running software on a computer, distinguishing different modes of software (for example, tutorial, simulations, and drill and practice), characteristics of exemplary software, and software evaluation and adoption. In courses that follow, the model integrates the following: operating a word processor, database, and spreadsheet; using peripheral devices such as printers and probes; planning instruction involving one or more computers; and, planning for the use of a computer laboratory. In these courses, the instructors modeled lessons that integrated computers into science instruction, presented information through lectures and demonstrations, and provided time for hands-on use of the computer. O'Brien indicated that the plan is to integrate microcomputers into student teaching and field-based experiences through seminars and by helping the participants plan and prepare microcomputer-based lessons.

Since 1987, Johns Hopkins School of Continuing Studies has offered a graduate course titled *Using Computers in the Secondary Science Curriculum* (Roseman, personal communication, 1988). Students explore the use of software applications and interfacing probes as a means of integrating microcomputer tech nology into the secondary science curriculum. The course is required for all science majors in the Master of Arts in Teaching (MAT) program and is elected by many science teachers enrolled in the Interdisciplinary Master of Science program.

Part of Course in Science. Another great way to train science teachers to use computers is to integrate computers into college science courses. In that way, science teachers learn to use computers in doing a. d learning science and can transfer that experience to their own teaching. Unfortunately, Jeffrey R. Lehman (1986) found no examples of this approach in his survey. Two recent projects funded by the NSF, however, have explored this approach.

James D. Lehman (1988) directed a project at Purdue University on *Integrating Computers in the Biology Education of Elementary Teaching Majors*. The Purdue project integrated 12 computer-based activities into the laboratory portion of a two-semester biology course for elementary teaching majors. Activities covered drill and practice, tutorials, simulations, databases, interactive video, telecommunications, computer software evaluation, and limited software development. Discussion focused on how to integrate computers into instruction using limited numbers of computers. The Purdue project integrated the computer into its science instruction and used the computer as a supplement rather than a replacement for traditional activities.

In the other NSF project, Neville (pers. com., 1988) at Temple University developed and conducted a *Demonstration and Computer Workshop for Secondary Science Physics Teachers*. This approach exemplifies how science departments at colleges and universities can help science teachers improve their use of educational technologies. The workshop focused on using demonstrations to teach physics (20 percent of the workshop involved using the computer as a teaching device). The course emphasized how to interface the computer with probes to gather and analyze data on physical phenomena. The physics department at Temple now offers this as an elective graduate course for teachers, which achieves NSF's goal of projects becoming self sustaining.

Teacher Enhancement through Inservice Education

We can't reach all science teachers through preservice or graduate courses at colleges and universities. We need comprehensive inservice programs that help practicing science teachers develop the knowledge and skill they need to use microcomputers and that support them as they implement information technology in their classrooms. With the renewal of NSF funding and with support from the private sector, many institutions have developed such inservice programs. What follows is a description of three approaches to inservice education: the inservice workshop, the inservice workshop with follow-up, and trainer-of-trainers programs.

Inservice Workshop. The most common approach to teacher inservice has been to offer a workshop on special topics, such as using microcomputers in science teaching or an inquiry approach to teaching science. Workshops are a good way to deliver information to science teachers and to get them started on developing skills they can implement in their classrooms. For many years, the NSF sponsored summer institutes for enhancing the preparation of science teachers that were one-shot workshops. Now the NSF requires projects to provide follow-up to these workshops (the next section describes several of these projects). Several institutions, however, offer inservice workshops that do not emphasize follow-up. I describe below two such programs.

Western Kentucky University uses inservice workshops and other approaches to help teachers implement educational computing (Brunson, 1988). Brunson has offered one-day workshops on general applications of microcomputers and a one-day workshop that explores the overlap among equity, problem solving, and microcomputers. In addition to workshops, Western Kentucky University provides a software resource center and a speakers bureau, which are services that are available from institutions throughout the United States.

California, as a leader in educational technology, has established mechanisms to train their teachers in the use of microcomputers. It has established regional Teacher Education and Computer Centers throughout the state. These centers provide training and technical assistance in the use of computers and have offered many workshops on educational computing to teachers. Furthermore, California has developed a series of resource guides, which it calls *Technology in the Curriculum (TIC)*, that match quality software and other technology to particular state learning objectives in science subject areas. These resource guides describe the software and provide sample lesson plans for integrating the software into instruction.

The Lawrence Hall of Science has been a leader in delivering inservice workshops to math and science teachers in California. Through the *EQUALS in Computer Technology Project* (Gilliland, 1984), the Lawrence Hall has provided 5-day workshops for more than 1,000 teachers, computer coordinators, and administrators that serve Kindergarten through grade 12. *EQUALS* focuses on attracting and retaining women and minority students. The workshop provides hands-on time with computers, off-line activities, worksheets, and begins with startling statements, which are statistics about women and minorities and their involvement with technology. Topics include thinking skills, problem solving, software review and evaluation, Logo programming, classroom management, career education, an introduction to the *TIC* resource guides, and operation of a computer. The *EQUALS* project publishes a newsletter and is now offering 3-day workshops as follow-up for teachers who have participated in one of the 5-day workshops.

Inservice Workshop with Follow-up. In 1984, the NSF reinstated a grant program to enhance the preparation of science and math teachers. The revised guidelines, however, emphasized that the one-shot workshops that had no follow-up implementation support had been proven to be effective neither for changing teachers behaviors nor increasing student learning. The NSF, therefore, included in its guidelines that, after the initial workshop, teacher-enhancement projects should include follow-up activities that helped the teachers implement the content and teaching strategies into their classrooms.

With NSF support, several institutions have developed models for providing inservice training on using microcomputers for science and math teachers. The typical model of these projects is to offer a summer institute of two or more weeks followed by one or more seminars (two hours to one day in duration), one or more site visits, and a newsletter that disseminates practical ideas for the classroom. Some of the more innovative projects use a computer to establish an electronic bulletin board on which the participants can share ideas and seek answers to implementation problems. Other projects use a telephone hot-line to resolve implementation problems.

Table 2 provides information about seven projects that use inservice workshops with follow-up. In addition, I shall describe the projects by Moursund; Watt et al.; and Ellis, et al. in greater depth.

Moursund (1986), at the University of Oregon, is developing one of the most complete inservice projects, which he calls *The Computer-Integrated Instruction Inservice (CI^3) Project.* The purpose of CI^3 is to develop an inservice model for educating general elementary and secondary science and math teachers in methods of integrating databases, spreadsheets, graphics programs, and science tool kits into their curriculum and to develop a method for training inservice trainers in the use of the CI^3 model. The project begins by working with teams that consist of an administrator and a group of teachers from the same building. The training consists of eight two-hour sessions. Each session provides an idea that can be used in the classroom, that introduces a computer tool in an instructional context, that presents each activity at two levels (teacher as participant and teacher as evaluator of the activity), that includes small group work, that has the participants discover the methods and models of instruction, and that ensures that the participants have fun. Furthermore, the project weaves problem solving throughout the activities.

In one of the more innovative NSF projects, Watt and Watt (1988) at the Educational Technology Center provided inservice training through an approach they called *Teachers as Collaborative Researchers: Professional Development Through Assessing Logo Learning.* The project focused on Logo and problem solving. They worked with six teams (a teacher and a computer coordinator) in three all-day meetings and eight after-school meetings. They provided the teams with a circulating library on research techniques and Logo. Their seminar topics included learning to see (defining the innovation and research problem), giving

Table 2

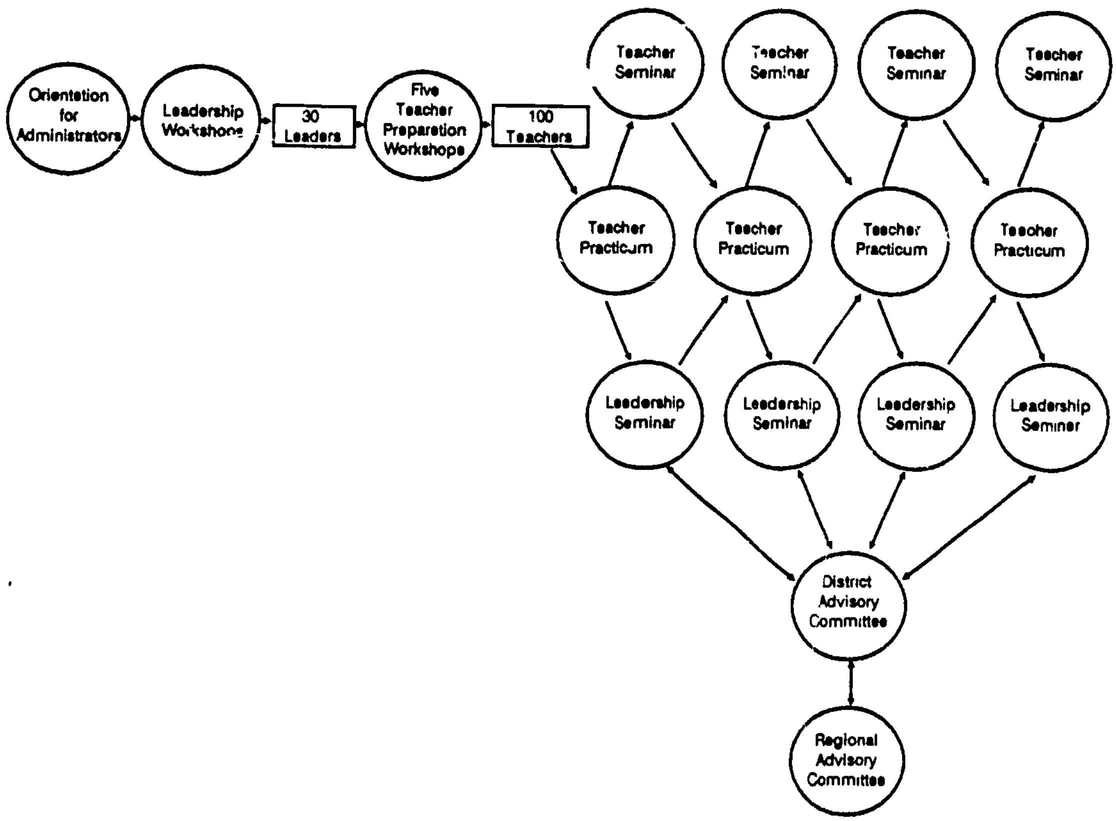
Principal Investigator	Title	Target Population	Approach	Focus
Ellis et al. BSCS Colorado Springs, CO	ENLIST Micros Phase Two	Science teachers (K-12) Lead teachers Administrators Teacher educators	2-day leader workshop 2-day teacher workshop administrator seminar 4 leader seminars 4 teacher seminars Dissemination workshops	integrating educational technology into extant science programs
McCarthy Bank Street College New York, NY	Mathematics, Science, and Technology Teacher Education Project (MASTTE)	Teachers (grades 4-6) who are to use the *Voyage of the Mimi* and staff developers	1-week institute site visits additional training print-based support computer bulletin board	implement the *Voyage of the Mimi*
Moursund University of Oregon Eugene Oregon	Computer-Integrated Instruction Inservice (CI^3) Project	Secondary science and math teachers and general elementary teachers	leadership teams 8 2-hour sessions	integrating general computer tools into curriculum and developing a method for training inservice trainers
Seligmann, et al. Ithaca College Ithaca, NY	Enhancement of Secondary Science Laboratory Instruction	120 secondary science teachers	4-year project 3-week institute 3 site visits 3 seminars hotline	using computer for analysis of experimental data and for data acquisition and manipulation
Sullivan University of Wisconsin Superior, WI	Application of Electronics to Teaching High School Physics and Computer Science	25 physics and computer science teachers	2-week institute 1 seminar develop units	electronics, developing strategies and materials for their classroom
Tweeten, et al. University of New Mexico Alburquerque, NM	Computers in the Science Classroom	75 high school science teachers	3-year project 8-week institute leadership institute computer bulletin board	general computer science and computer applications in science education
Watt, et al. Education Development Center Newton, MA	Teachers as Collaborative Researchers: Professional Development Through Assessing Logo Learning	6 teams of a teacher and a computer coordinator	3 1-day meetings 8 seminars circulating library	Logo and problem solving and developing and conducting a research project
Roseman, et al. Johns Hopkins University Baltimore, MD	Computers to Enhance Science Education	100 Baltimore city science teachers 20 leader teachers	13-day teacher workshop 4-day leader workshop 5-week curriculum development workshop Annual conference Users group with newsletter Hardware acquisition	Integrating computer technology into extant science programs

more structure to the research (designing the study), looking at patterns in the data, and writing research reports. Each team designed and carried out a research project on using Logo to enhance problem solving. Their idea is that if teachers become involved in improving their teaching through conducting research on their teaching in their own classrooms, then the teachers will commit to making their plans work and will have skills that will help them adopt other innovative teaching behaviors.

In phase two of *ENLIST Micros*, the BSCS is developing a complete implementation model to increase teachers' use of microcomputers in science instruction (Ellis and Kuerbis, 1988). There are four goals for the project.

- Train 260 science teachers and administrators in the Pikes Peak region's 22 districts to use the computer for enhancing the teaching and learning of science.
- Establish a network in the Pikes Peak region to implement educational computing in science teaching.
- Develop and test a model of teacher enhancement for educational computing in science teaching.
- Disseminate a model of teacher enhancement for educational computing in science teaching.

Phase II has eight activity areas: planning, curriculum development, teacher preparation, leader preparation, networking, dissemination, a software resource center, and evaluation. Figure 1 presents the implementation model.



The first year of the project we focused on building an implementation network; administrators and science teachers from each district learned how to serve as leaders and facilitators. In all, 61 science teachers and administrators participated in the training. Usually, each team contained an administrator and at least two science teachers.

During the second and third years of *Phase II*, the BSCS staff are continuing to build the implementation network. The leaders trained during the first year are now helping more than 200 science teachers in the Pikes Peak region to implement educational computing. During the second and third years, the full model begins with an orientation for administrators, during which building principals and district administrators receive information about the project and agree to support the teachers who will participate in the project. Next, the BSCS staff conducts a two-day workshop, during which the leaders develop their leadership skills and work with the BSCS staff to plan the teacher-enhancement activities for the new participants. Each leader works with three to five teachers from one district and helps them implement educational computing.

The teacher-enhancement activities begin with a two-day workshop that focuses on the *ENLIST Micros* curriculum and provides the knowledge and skills needed to begin use of microcomputers in science teaching. Follow-up to the workshop is the critical factor in the implementation model. The leaders participate in follow-up seminars during the year and refine their skills, share information, collaborate on solving barriers to implementation, and plan the seminars for the participating teachers. The participating teachers attend four seminars, during which the BSCS staff and leaders demonstrate software, model the integration of microcomputers into science teaching, and organize small groups that study areas of special interest.

The leaders guide their teams as the participants begin using microcomputers in their classrooms. The participants develop action plans for implementing educational computing, design lesson plans and unit plans, review software, and begin using the microcomputer in science teaching. The leaders and BSCS staff meet with the building teams on a regular basis and discuss their implementation and observe the teachers as they begin use.

Trainer-of-Trainers Program. The trainer-of-trainers (TOT) model is being used in projects as a way to replicate teacher-enhancement programs. The CI^3 project is using a TOT model to replicate its program. Its approach is to offer short workshops to staff developers and teacher trainers on the curriculum and procedures that the CI^3 staff developed and implemented at the University of Oregon.

The BSCS has proposed to the NSF a replication project for *ENLIST Micros* (Ellis, 1988). To examine the cost effectiveness of different approaches, the BSCS will test three ways to replicate *ENLIST Micros*: a consultation model, a dissemination model, and a trainer-of-trainers model. For all three models, the project will work with teams consisting of a science teacher, a science educator, and a staff developer or administrator from the same region. In the consultation model, BSCS staff meet with the regional team at their site and explain the *ENLIST Micros* curriculum and implementation model and help design a program specifically for that site. In the dissemination model, the BSCS staff conducts a one- or two-day workshop on *ENLIST Micros* for the members of several training teams and follow-up with one or two consultation visits. In the trainer-of-trainers model, the BSCS staff conduct a two-week summer institute with members of training teams and follow-up with two one-day conferences during the year, two consultation visits, and a computer bulletin board.

The University of Michigan has produced the most elaborate project for training trainers in educational computing (Berger, 1986; and Carlson and Berger, 1988). I describe this project because it is an excellent model for replicating in-service programs, even though it does not focus on science teachers. This project developed *Training Modules for Trainers (TMT)*, which is a competency-based curriculum for educators who will train teachers to use microcomputers. This curriculum consisted of 14 modules covering training methods, the process of district planning, software evaluation, technical skills, software design, computers in the curriculum, administrative uses, future images, and other topics.

Once the project developed and field tested the curriculum it began training trainers to use the curriculum with teachers. The trainer-of-trainers project began by introducing the TMT project to 200 educators. Fifty of the 200 who participated in the initial training formed a TMT cadre and received four additional days of training. The TMT cadre then returned to five regional software evaluation and training centers and offered training on educational computing to teachers. Some of the TMT cadre added another level to the trainer-of-trainers model and trained eight to ten trainers who in turn trained the teachers. The project included a computer bulletin board as a follow-up activity for the TMT cadre. It was the responsibility of the TMT cadre to provide follow-up support to the local teachers.

As a Topic within a Teacher-enhancement Project. Several teacher-enhancement projects supported by the NSF introduce microcomputers within the context of training teachers to improve the delivery of content in science and math. For example, in an NSF project at Arizona State University, Staley (1988) has introduced microcomputers as part of *A School-Industry-Community Approach to the Development of Scientific and Technological Literacy Among Elementary School Pupils*. Even though computer technology was only a minor component of the project (a 2.5-day module), this project is of interest because Staley designed an excellent approach to implementing improvements in science teaching. The project involved teams consisting of the principal, a lead teacher, and local community leaders, all of whom planned the innovation (often involving the interface between science, technology, and society) that they would implement in their school. Then the project provided the team leaders a summer institute and seminars during the spring semester on issues in science, technology, and society. During the year, the principal and leaders offered community workshops for training teachers to implement the program.

In Binghamton, New York the Board of Cooperative Educational Services (BOCES) is offering the *Cycle 22 Project*, which is an institute for astronomy teachers for grades five through nine (Rhodes, 1988). In this project, the teachers study solar activity at the Roberson-Kopernik Observatory for three weeks, participate in three seminars and four sharing sessions during the following school year, receive a bimonthly newsletter, and use a hot-line and a computer bulletin board to resolve problems and share information. This project introduces teachers to using computers to store and access sunspot data, plot 200 years of solar data, simulate solar motions, and share information through telecommunications. In a second project, BOCES is using telecommunications to share daily weather data, make forecasts, and provide forecasts through local radio and TV stations (Rhodes, 1987).

At Indiana University of Pennsylvania, Butzow (1988) has used NSF support to help teachers use technology to expand learning in mathematics and the sciences. The first part of the project provided a two-week workshop on using the computer as a tool in science and math. More than 100 teachers worked in small groups to study how to use the computer for their particular courses. The teachers developed unit plans for integrating computers into instruction that they were to implement in their schools. During the year, faculty from the university visited the schools to assess how the teachers implemented the plans.

In the second part of the project, Butzow used a trainer-of-trainers approach to expand his first project. He provided two three-week leadership institutes for 120 teachers and coordinators. Following the leadership institute, the participants implemented the activities during the first semester and then trained their peers to implement the activities during the second semester. The project used a computer bulletin board with a WATTS line for follow-up support.

RECOMMENDATIONS FOR PREPARING SCIENCE TEACHERS FOR THE INFORMATION AGE

After reviewing the models in this chapter and the previous chapters, which describe the discrepancy between what information technologies can do and what schools are doing, it is apparent that we need comprehensive programs for teacher preparation and enhancement that help science teachers use information technology. We need to provide teacher education programs that include the following components:

- A requirement for certification that science teachers (K-12) be competent at using information technology in science teaching.
- Multiple approaches to educating science teachers in information technology, including
  - courses in science and science education that use information technologies to learn and do science and to learn and do science teaching;
  - introductory courses on the mechanics of using information technologies in education;
  - intermediate courses, whether separate from or part of courses in science education, dealing specifically with the why, what, and how of using information technologies to enhance science teaching and learning;
  - advanced courses that lead to graduate degrees (M.A. and Ph.D.) in science education with an emphasis in information technology; and
  - inservice courses that are relevant, motivating, practical, enjoyable, rewarding, and accessible.

- Courses that keep abreast of new developments in information technology relevant to science education.
- Implementation programs that provide a school environment conducive to change; continuous and effective support to science teachers as they change; and, the resources of hardware, software, curriculum materials, people, and time science teachers and students need to use information technology.
- Science curricula that integrate information technology into the mix of teaching and learning activities of the core instructional program.
- Reward and incentives for science teachers to learn about information technology and to begin using it to enhance science teaching and learning.

Science teachers are dedicated, hard-working people. Given the opportunity, appropriate incentives, and support from the educational system, they will use information technology. As we determine effective uses for information technology in science education, develop technology-oriented programs that integrate those effective uses into the science curriculum, and provide support systems for the implementation of information technology, science teachers will improve their use of information technology in their classrooms and enhance the efficiency and effectiveness of their science teaching and their students' learning of science.

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