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ABSTRACT

The Educational Technology Center (ETC) was established by the National Institute of Education in October, 1983, in order to find ways of using the computer and other information technologies to teach science, mathematics, and computing more effectively. This report describes the ETC, presents its framework for research, and summarizes work on 12 research projects. These projects dealt with the following topics: (1) weight and density; (2) heat and temperature; (3) scientific theory and methods; (4) complex systems; (5) fractions; (6) word problems; (7) programming; (8) applications of computers; (9) videodisc technology; (10) computers and television; (11) speech technology; and (12) science teachers' networks. (TW)

EDUCATIONAL TECHNOLOGY CENTER

Second Year Report

The Educational Technology Center is operated
by a consortium comprising

Harvard Graduate School of Education
Cambridge Public Schools
Children's Television Workshop
Educational Collaborative for Greater Boston
Education Development Center
Educational Testing Service
Interactive Training System
Newton Public Schools
Ware Public Schools
Watertown Public Schools
WGBH Educational Foundation

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1.0 INTRODUCTION

The Educational Technology Center (ETC) was established by the National Institute of Education in October of 1983 to find ways of using the computer and other information technologies to teach science, mathematics, and computing more effectively. This Second Annual Report describes ETC, presents our framework for research, and summarizes work to date across more than a dozen distinct research projects. It also outlines our outreach activities over the past year.

A research center -- not a service, software development, software evaluation, or curriculum development organization -- ETC is a consortium based at the Harvard Graduate School of Education. In addition to HGSE, the consortium includes the Cambridge, Newton, Ware, and Watertown, Massachusetts school systems; Children's Television Workshop; Education Collaborative for Greater Boston; Education Development Center; Educational Testing Service; Interactive Training Systems; WGBH Educational Foundation; and the ETC Rhode Island Satellite, based at Brown University.

Stated briefly, the challenge facing ETC is to help reverse what many believe is the deteriorating quality of elementary and secondary education in science and mathematics. Though pre-collegiate education in computer science, a technology-oriented blend of science and mathematics, is in an early stage of development rather than one of decline, its improvement is also crucial. Thus, the central question guiding our research is, "How can new information technologies be used to enrich, extend, and transform current instructional practice in science, mathematics, and computer science?"

Given this broad question and limited resources for addressing it, we have created a research framework that includes five elements: (1) a conception of the subject matter to be addressed, (2) a conception of the pedagogical potentials of computers and related technologies, (3) a view of how various pedagogical styles can be employed to teach the subject matter, (4) a strategy for identifying the most crucial topics for research within this framework, and (5) a research orientation and process for addressing these topics. The next five sections deal with the five elements in turn; we then provide an overview of current research projects and a summary of each project's work.

2.0 A CONCEPTION OF THE SUBJECT MATTER DOMAIN

We believe that focusing on physical and biological sciences and on the uses of mathematics and the computer in the sciences offers a powerful, integrated way of conceiving the subject matter domain. Such an approach can motivate and provide a practical, concrete, and problem-oriented basis for understanding mathematical ideas and acquiring mathematical skills. It can provide an equally appropriate context for learning computing by doing computing.

2.1 Science, Mathematics, and Computers

In this section, we present a conception of scientific knowledge which incorporates mathematics and computing. Specifically, we propose a view of science as comprising three kinds of knowledge: theoretical, procedural, and factual. Theoretical knowledge refers to models or schematic representations of phenomena. Procedural knowledge includes not only "procedural thinking skills" of the sort associated with structured computer programming (e.g., breaking a large problem into a set of smaller, more manageable ones), but also a broad range of concepts and techniques involved in formulating questions and hypotheses, acquiring data (e.g., observation, measurement), and manipulating data (e.g., storage and retrieval, application of statistical techniques). As we conceive it, mathematics constitutes a major subset of procedural knowledge. Factual knowledge is more fragmentary and remains closer to the level of observation and measurement than does theoretical: the sun is approximately 93,000,000 miles from the earth, water freezes at zero degrees Celsius, and the human heart has four chambers. Clearly, there is a complex set of interrelationships among the three kinds of knowledge; they blend into one another in various and subtle ways, and all three are subject to evolution and revolution. Nevertheless, they remain useful categories for describing scientific knowledge and for approaching the improvement of education in science, mathematics, and computer science.

2.1.1 Theoretical Knowledge

Quite spontaneously and without much self-consciousness, children and adults try to make intuitive sense of the world around and within them. Children tell themselves stories about the world: "The moon follows me around. I saw it from my driveway, and when we got to Grandma's house, it was still up there where I could see it." Adults also tell themselves stories: "The sun and the other planets revolve around the earth." These stories about the physical and biological world may be thought of as models or schematic representations--sometimes diffuse and confused and sometimes well-defined--which people use to understand their surroundings. Science is a way of improving our intuitive understanding of the physical world, including the parts of it that are alive. Although it is commonly obscured by the sheer complexity and technical vocabulary of modern science, there is a certain continuity from the child's self-centered model of the solar system to Ptolemy's earth-centered model to Copernicus' heliocentric model to Newton's and Einstein's progressively more precise and complete formulations. All of us reformulate our models of the world in the face of evidence or logic that undeniably contradicts them. Scientists simply exercise special care and skill in formulating models and in seeking evidence concerning their accuracy.

Too often, however, science education has presented theoretical knowledge as dry, technical, and specialized--bearing no recognizable relationship to the familiar world of everyday experience. In ways that we shall elaborate below, interactive technologies offer new ways to make vivid the connections among experience, intuition, and theory.

2.1.2 Procedural Knowledge

In the process of formulating and testing theories, scientists use mathematics to describe the world quantitatively, to create precise and frequently complex models of phenomena, and to check these models against data taken from observations and measurements. In this sense, mathematics may be viewed as the handmaiden of science. Obviously, mathematics is a discipline in its own right, a discipline of great logical beauty. But as an Educational Technololgy Center designed in part to help the nation respond to the challenge of international competition in science and technology-related fields, we propose to emphasize the power of mathematics rather than its beauty. That is, we propose to concentrate on examining ways in which students may learn and use mathematics to describe, model, and solve problems concerning physical and biological phenomena.

As they construct and reconstruct quantitative models, scientists rely increasingly on the computer. In this process, computers are useful tools for conjecturing or hypothesizing as well as for storing, retrieving, and manipulating data. To be sure, the computer is also an important object of study in itself. But consistent with our integrated view of science, mathematics, and computer science, we propose to emphasize the uses of the computer as a tool for understanding and affecting the world rather than Ptolemaically placing the computer at the center of the world.

In addition to its instrumental uses, the computer has also made a subtle contribution to scientific knowledge, demanding as it does a rigorously systematic approach to problem definition and resolution. To a substantial extent, structured or modular programming embodies an approach to problem solving long practiced by mathematicians and scientists. But structured programming demands an attention, both to the overall architecture and to the detailed craftsmanship of thought, which has undoubtedly enriched our repertoire of procedural thinking skills, thus extending the range of procedural knowledge properly considered part of scientific knowledge broadly conceived.

In addition to mathematics and procedural thinking skills, procedural knowledge in science embraces a profusion of concepts and skills involved in experimentation and investigation, such as hypothesis formulation, observation, measurement, and the like. Modern instrumentation has become extremely sophisticated technically and is tied up with the computer in diverse ways. However, the fundamental logic of investigation remains reasonably stable and accessible--an especially important point in an educational context.

2.1.3 Factual Knowledge

The "knowledge explosion" which threatens to inundate us all in a tidal wave of information has resulted in considerable measure from the application of procedural knowledge in the context of theoretical knowledge--of investigatory and problem-solving processes employed to test theory-based hypotheses. In physics, for example, the development of knowledge about subatomic particles has depended heavily on theoretical interpretation of tracks laid down by evanescent bits of matter not themselves directly observable. At times, the interplay of observation and the revision of theory has been so rapid that this "knowledge" has appeared almost as perishable as the particles themselves. Virtually all scientific fields are blessed and afflicted by acceleratings change in and additions to "the facts." This sustained explosion presents an enormous challenge to practicing scientists, to those who use scientific knowledge, and--to a quite dizzying degree--to educators.

2.2 Science, Mathematics, and Computers: Summary of Our Viewpoint

In summary, then, our research incorporates science, mathematics, and computing into an integrated view of scientific knowledge. This view emphasizes the utility of mathematics and computing in the generation and manipulation of scientific knowledge. It provides a basis for illuminating the relationship between science and everyday experience, for teaching mathematics through problem solving and the modeling of real world phenomena, and for enabling students to learn computing by using the computer as it is used by scientists and mathematicians.

3.0 A CONCEPTION OF THE PEDAGOGICAL POTENTIALS OF COMPUTERS

3.1 Modes of Computer Utilization in Education

Many, if not all, present educational uses of computers fall into one or the other of two categories: the computer as a medium or the computer as a tool. By computer as medium, we mean the use of the computer to convey to the user, or to instruct the user in, some body of knowledge. By computer as tool, we mean the use of the computer to accomplish some task for the user, including the most significant task of creating new tools.

3.1.1 Computer as Medium

There are four broad categories of the use of computers as instructional medium: drill and practice, tutorials, games, and simulations. Attempts to use the computer as a drillmaster or tutor have a rather long history, and a large proportion of existing educational software in mathematics and science falls into one of these two categories. As a drillmaster, the computer simply presents problems and checks answers. Most drill and practice programs constitute automated workbooks, in which the computer functions as a high-priced page turner. Some predominantly drill and practice programs also include limited tutoring or prompting on missed problems. As a tutor, the computer guides the student through segments of subject matter, asking questions, approving correct answers, and going back over material not mastered. Implicit in the concept of a tutorial program is the assumption that the program can interact intelligently with the user.

Educational computer games divide into two distinct groups: those that attempt to convey some portion of the content of a discipline (content games) and those that attempt to sharpen the use of a cognitive strategy that may be applicable to a variety of subject matter (process games). Games that attempt to teach skills such as problem solving have recently become more and more available (e.g., Rocky's Boots, Gertrude's Secrets, Gertrude's Puzzles).

Closely related to games are simulations, which can be used in two ways: to explore the applicability of models of the real world, and to develop insight into phenomena that cannot be directly, or easily, observed. A simulation of the behavior of a pendulum, or one of the various simulations of the Milliken oil-drop experiment, for example, can be compared to the phenomenon in nature. In contrast, programs like Birdbreed (a simulated genetics laboratory) and Three Mile Island (in which students "operate" a nuclear-powered reactor), represent simplified models of complex, real systems.

3.1.2 Computer as Tool and Tool Maker

Tool computer programs designed to carry out a specific task and require no programming on the part of the user are commonly used in the business world to handle such problems as budget projection, inventory control, accounts receivable, mailing lists, and telephone directories. In education, such systems are also employed to help the user solve a particular type of problem. For example, a system may provide a graphic representation of data derived from a particular experimental situation--as does the heat probe and software designed by Robert Tinker of Technical Education Research Centers (TERC) of Cambridge, Massachusetts, which provides a continuous reading of temperature as a function of time.

Several more general purpose, symbol-manipulating tools are now in widespread use. The hand calculator is everywhere, including the schools, and its utility is well accepted. Coming into equally wide use is a microcomputer extension of the hand calculator--the spread sheet program. The word processor, which has displaced the typewriter in many offices, is also beginning to find its way into the classroom. At EDC, Judah Schwartz has developed a general purpose tool called the Semantic Calculator (SemCalc). SemCalc allows the student to use the computer to carry out calculations involving both numbers and the units to which the numbers refer. Schwartz and his colleagues in the NSF-supported Dimensional Analysis Project found that SemCalc gives students and teachers a purchase on "the word problem problem" which neither group felt they had before.

It is as a creator of new tools, however, that the computer differs most dramatically from other technologies, such as the textbook, the audio recording, or television, each of which has been used both as medium and as tool in education. Each of us now has, or will soon have, the opportunity to use the computer to design a tool to fit our own perception of a task we want to perform or a problem we wish to solve.

We may have some difficulty at present in imagining how we can use such a tool or what it will mean for our lives. Yet it is likely that a generation from now every educated person will consider a procedural approach to problem solving of all sorts natural and commonplace, will be comfortable with many strategies for structuring data and representing knowledge, and will regularly create unique tools for applying these strategies.

What role the tool-making capacity of the computer should play in education today is one of a set of questions about the ends and means of education that are raised by the introduction of the computer into the classroom. We address some of these questions below.

3.2 Computer-based Education and Educational Philosophy

The computer is a Rorschach ink blot test for educational philosophy. The computer is so versatile, so rich in possibilities, that virtually any view of what education is or ought to be can be implemented through it. Thus, when people approach the question of the computer's educational applications, they "see" in it a realization of their own beliefs about education. Consciously or unconsciously, we are acting on an educational philosophy when we choose a certain approach to the use of computers in education. The philosophy is not a "given" of the machine.

Most current thinking about education in the United States may be located along a continuum between two polar views, directed instruction and open education. The two views constitute ideal types rather than descriptions of actual practice in classrooms, but most educational theories and practices--whether computer-based or not--may be located somewhere along a continuum between these two views. The two are therefore useful points of reference for discussing the pedagogical questions inevitably entailed in educational applications of microcomputers. Accordingly, we shall briefly characterize each approach and its consequences for computerized instruction both in general and in science and mathematics, and then turn to a third, eclectic approach which promises to surmount the limitations of the first two by incorporating their complementary strengths. The third approach addresses the need to teach all three types of scientific knowledge discussed above, and takes advantage of the full range of computer capabilities both as medium and as tool and tool maker.

3.2.1 Directed Instruction

For many, "education" means formal instruction, a process in which knowledge is divided into domains, each with a set of concepts, skills, and facts more or less agreed upon by experts in the domain. These bodies of knowledge are introduced to students by a teacher through presentations, assigned readings, and exercises of various sorts. Over the past twenty years or so, directed instruction advocates have technologized the ideal conception if not the practice of formal instruction in ways that bear no necessary relation to hardware. This new conception of formal instruction emphasizes analysis of what is to be taught into discrete elements, hierarchically arranged; translation of these content hierarchies into goals and specific behavioral objectives for students; and student progress through the hierarchies under strict teacher control, achieved either through methodical group instruction or through individual diagnosis and prescription.

Some varieties of directed instruction are explicitly based upon behaviorist learning theory, which sees learning as the acquisition of new behaviors through guided performance of bits of behavior followed by "reinforcement," leading cumulatively to complex behavioral repertoires.

Other varieties are more loosely related to learning theory. For present purposes, however, a broad range of diagnostic-prescriptive, individually guided, and "continuous progress" programs may be viewed as variants upon the directed instruction approach. Although they differ from each other in non trivial ways, they share an emphasis on teacher control of student progress through well-defined content domains. In this view, learning is an additive process, and while some discretion over the pace of addition may be surrendered to the student, the teacher clearly retains authority over its path.

Directed instruction lends itself readily to implementation on the computer. In fact, most computer-assisted instruction amounts to the automation or computerization of the directed instruction approach. Traditional CAI generally uses the computer in two ways, as a tutor and as a drillmaster.

3.2.2 Open Education

In contrast with directed instruction's reliance on the teacher to guide the student through meticulously specified content hierarchies, open education emphasizes relatively free, intuitive explorations by the student, directed by his or her natural curiosity. To the extent that the teacher structures or directs the student's activity, it is by designing an environment rich in materials and resources and by posing problems, questions, and challenges that engage the student's interest.

In this view, grounded in Piagetian notions about cognitive development, children are more or less continuously engaged in attempts to make sense of the world around them. Exposed to diverse experiences, they fashion working mental models of parts of the environment, and they try to understand new experiences in terms of these models. In fact, to understand something is to assimilate it into, or see it in terms of, one of these working models. When the child notices that a new experience won't quite fit any of the models already in hand--or, more accurately, in mind--the child may adjust the model. Or, as fallible scientists sometimes do, the child may doubt or deny the "data." So the child is always tinkering with the models in his or her repertoire, changing features, adding new features, or putting simple models together to make more complicated models that match up better with his or her observations.

A central claim of the Piagetian view of learning is that teaching concepts and skills didactically--that is, in isolation from experience that gives rise to an intuitive feel for the meaning of the concept or the logic of the procedures--results at best in parroting, or the acquisition of behaviors empty of understanding.

For some time, while directed instruction lent itself readily to computerization, open education seemed almost antithetical to computer implementation. The need to master one or more rather complex computer languages, together with the deeper concepts of programming that underlie them, appeared to stand between the pre-college student and the machine, thus ruling out autonomous exploration and problem solving with the computer by all but a few advanced high students.

Within the past few years, however, the LOGO group at Massachusetts Institute of Technology completed development of a language and a mode of computer utilization that make computers far more acccessible, even to relatively young children, than was possible previously. Particularly through its Turtle Geometry capabilities, LOGO offers a powerful but easy-to-learn computer language appropriate to tasks and challenges which many children appear to find engaging. Thus, LOGO makes the "tool making" capabilities of the computer available to children at an earlier age. The activity of children in a LOGO classroom or laboratory is generally consistent with open education principles.

3.2.3 Summary of the Polar Approaches

The differences between directed instruction and open education can be summed up in terms of their contrasting positions on three issues: (1) the role of intuition, (2) the nature of learning as an additive versus a transformational process, and (3) control. Open education views an intuitive grasp of concepts or procedures as the basis for meaningful learning; directed instruction generally ignores intuition or views it askance, as mystification. This is partly because directed instruction considers learning a process of adding up many bits of information or behavior, while open education sees learning as a matter of connecting new information or behavior with pre-existing understandings and experiences, transforming both the existing understandings and the new information in the process. Finally, because open education sees learning as an active, transformational process intimately tied to prior experience, it takes the position that the student should control the path of his or her own education as much as possible. Directed instruction takes precisely the opposite view: the teacher should control the path, pace, and details of the student's learning in order to ensure mastery of carefully engineered sequences.

4.0 APPLICATION TO COMPUTER USE IN SCIENCE AND MATHEMATICS EDUCATION

Applications to computer-based instruction in science and mathematics of both the open education and directed instruction approaches have significant weaknesses that derive from their extreme positions on the role of intuition, the nature of learning, and the issue of control.

On the one hand, the strong emphasis of the open education-LOGO approach on independent discovery or invention of concepts or principles by each child tends to exclude the teaching of important scientific ideas and facts. This has resulted in an unfortunate tendency which might be caricatured in the slogan, "Every child his own Newton." Moreover, LOGO has not generally been used to model the physical or biological world in any deep sense. Rather, Seymour Papert's exposition of the LOGO philosophy as well as virtually all of the classroom implementations of LOGO which we have observed employ the language largely to create Turtle Graphic images which at most represent the world pseudo-artistically (e.g., pictures of houses, flowers, bicycles) and which more commonly amount solely to geometric designs. To be sure, some of these images reflect significant geometric understanding and emergent procedural thinking skills. These are important strengths. But too seldom has the power of LOGO been directly exploited to advance children's scientific understanding. Nor is there a clear connection between LOGO and the conventional mathematics curriculum.

In contrast to LOGO's focus on independent discovery, applications of CAI in science education (as in other disciplines) have typically discounted the utility of discovery, experience, and intuition. In the process, the importance of connecting new knowledge to what the child already knows--how the child already thinks about the phenomenon under study or similar phenomena--is also discounted. A common result appears to be the partitioning off of common sense or intuition from knowledge acquired through formal instruction.

A great challenge in science education is therefore to find better ways of integrating intuition with formal instruction so that the student is neither left to re-create the evolution of Western scientific thought <u>de novo</u> nor tediously plied with information which sits on the shelves of the student's mind without much affecting his or her working understanding of the world.

Another challenge is to provide all students with the experience of being in control of the computer, as well as being instructed by it or using it for routine data processing. Both individually and as a society, our lives are profoundly influenced by our relationship to the dominant technololgy of our time, which is clearly no longer the assembly line but the computer. A critical issue in this relationship is whether on balance people initiate and control their interactions with the machine or react to and feel controlled by it--whether the technology enhances their sense of efficacy or increases alienation and feelings of subordination. We believe that students' experience with computers will bend the twig of this relationship.

For students whose only direct experience with computers occurs in schools, including the poor and many others, the twig may be bent in fateful ways. Exposure to computers exclusively through traditional CAI prepares students to take charge of the computer not as scientists or engineers do, but only routinely as do clerical data processors. To be sure, the society will need clerical computer personnel, but just as surely all students deserve the opportunity to experience the computer in ways that open to a broader range of careers.

Accordingly, it is important to find more ways of enabling students to use the computer in a manner analogous to the way scientists and engineers use it: as a tool for modeling, simulation, and calculation, as well as for storing, retrieving, and organizing data. In employing the computer for the latter three functions, students need to gain experience not only with conventional data base management programs and techniques, but also with "expert systems" as they are now coming into use to aid diagnosis and treatment choice in medicine or structure and materials choices in of the aerospace industry.

We should stress, however, that we do not reject all uses of traditional CAI. Many neurosurgeons in training have relied on programmed textbooks as aids in mastering the details of neuroanatomy. Analogously, students must sometimes master well-defined bodies of factual information. At these points, CAI--the computer-based equivalent of the programmed text--can prove appropriate and helpful. We may well use CAI to teach facts and skills needed in the course of ongoing problem solving or investigatory tasks.

4.1 An Eclectic Approach to Computer Utilization in Education

Our comprehensive approach to computer utilization in education therefore incorporates both the LOGO-open education and CAI-directed instruction approaches, but overcomes the weaknesses of both. This third approach is designed to determine which are the most appropriate modes of computer utilization for educating students in the different types of scientific knowledge. The governing hypothesis of our research program is that the various modes of computer utilization (drill and practice, tutorials, games, simulations, and tools) are appropriate to different degrees and in different ways for the three types of scientific knowledge (theoretical, procedural, and factual).

For theoretical knowledge--understanding phenomena in terms of models or schematic representations--the simulation/game and tool modes appear most appropriate. Simulations model phenomena, frequently in graphic form, and permit students to gain increased understanding of a phenomenon by manipulating or playing with it in various ways. Such play may prove an effective way of mastering a model, thus laying the basis for a deeper understanding of the phenomenon than could otherwise be achieved. The tool mode--and here we include original programming by the student (tool making) as well as use of software analogous to VisiCalc or VisiPlot--permits the student to construct his or her own models of phenomena, perhaps starting with very simple models in the elementary years and progressing to quite complex models in the late high school years. At an interesting midpoint between the simulation and tool modes are partially formed or modifiable models which students can complete or reconstruct to fit observations or measurements which they make themselves.

For procedural knowledge--concepts and skills involved in hypothesis formulation, observation and measurement, quantitative representation of data, calculation, problem solving through modular programming, and the like--at least three modes of computer use seem appropriate. First, tutorials may prove useful in teaching new procedures, especially mathematical and measurement techniques, that would be useful in solving a particular problem or in creating or understanding a model. Second, a number of games designed to teach or exercise procedural thinking skills for problem solving have become available commercially. The questions of (1) what influence experience with such games can exert upon scientific problem solving, and (2) the ways in which they might be integrated with the elementary school science curriculum are intriguing. Third and finally, a wide variety of tool programs could prove valuable for exercising procedural skills. For example, students might use data base management programs to search specially created data bases for data or factual material required to solve problems, in the process learning about Boolean logic (e.g., "A and/or B not C") and about classic search strategies (e.g., binary search). A number of programs designed to enable students to make and record measurements are becoming available, and these should also be examined.

It is commonplace to observe that proliferating information has rendered obsolete the notion of education as mastery over a set body of facts. But this proliferation has not rendered facts obsolete. The challenge is to decide which facts are important for whom to know at what times, and to find ways of helping students acquire necessary facts rapidly and appropriately. Tutorial and drill and practice programs may prove useful in this context. As a class or small group of students study some phenomenon, a teacher might assign one or more students to master some set of crucial facts. Simulations and games might be used in the same way. For example, a simulation might permit a student to explore the inner workings of a rocket, learning its parts, their functions, and their interrelationships. In this sense, a schematic representation of a rocket would become a kind of factual environment for students to explore. Finally, the data base management programs and data bases which students use to practice searching for information by employing Boolean logical expressions would also provide the occasion for learning facts related to a problem or phenomenon.

Figure 1, "Modes of Computer Utilization Appropriate to Three Types of Scientific Knowledge," presents a summary of the applications of different modes of computer use to the teaching and learning of different types of scientific knowledge.

5.0 A STRATEGY FOR IDENTIFYING RESEARCH TOPICS

The foregoing three sections provide a broad framework for addressing our central question, "How can new information technologies be used to enrich, extend, and transform current instructional practice in science, mathematics, and computer science?" However, they provide only limited help in specifying the particular topics within each subject matter domain on which research should be concentrated.

Our strategy for choosing research topics is predicated on the notion of "targets of difficulty." That is, in science and mathematics, certain topics--some narrow, some broad--seem to plague every new cohort of students who encounter them. A narrow example from elementary school mathematics is the concept of area, which students confuse with perimeter. A broader one is the basic meaning of and relationships among fractions, decimals, and per cent. Most students eventually learn cookbook methods of dealing with each mode of representing ratios and even for converting from one to another, but their understandings are fragile and break down in the face of novel questions. A broad target of difficulty from middle and high school mathematics is "the word problem problem." Year after year, improving students' ability to solve word problems appears high on the agenda of the National Council of Teachers of Mathematics.

In the physical sciences, examples abound. The frequently counterintuitive laws of Newtonian action and reaction confuse students whose spontaneous theories are more Aristotelian in nature. The notion of energy conservation through transformations is far more difficult for

FIGURE I. MODES OF COMPUTER UTILIZATION APPROPRIATE TO THREE TYPES OF SCIENTIFIC KNOWLEDGE

Type of Scientific Knowledge	Mode of Computer Utilization			
	Drill and Practice	Tutorials	Simulations and Games	Tools
Theoretical			Manipulating models, observing effects, comparing models with nature	Creating and modifying models
Procedural		Learning new procedures for studying a phenomenon or solving a problem	Using procedural thinking skills to solve problems, puzzles	Solving problems, making and recording measurements, performing calculations, storing and retriving data, factual material
Factual	Mastering basic facts related to a phenomenon or problem	Learning new facts related to a phenomenon or problem	Learning facts related to a phenomenon by exploring a model as an environment	Finding and learning facts required to solve a problem, model a phenomenon

students to grasp intuitively and conceptually than for them to parrot. Similarly with the particle theory of matter. And what of a phenomenon which is partly wave-like and partly particulate?

Examples from computer science are not yet so perennial but are equally vexing. The concept of a variable as a location in memory where a value is stored--so fundamental to programming in any language--often eludes students. At a higher level, the concept of recursion becomes a hall of mirrors for many students.

In general, we think of a target of difficulty as a kind of cognitive or developmental obstacle, which if not removed from the learner's path, will impede further progress. Thus, failure to grasp the concept of place value can impede the acquisition of computational skills, failure to grasp the concept of a variable can impede the acquisition of algebraic skills, failure to grasp the concept of a procedure can impede the acquisition of programming skills, and so forth.

Such topics represent key obstacles to students' progress in quantitative and scientific domains. These are the topics about which many people say in retrospect, "I was all right until I got to...." Our hypothesis is that they not only turn many students away from courses leading to scientific and science-related careers, but also discourage the development and use of quantitative skills in areas outside the physical and biological sciences (e.g., business, industry, agriculture, social sciences). In a sense, therefore, they represent major obstacles to the development of quantitative competence in the broader society.

Paradoxically, these obstacles also represent major opportunities. If we can find ways of helping students surmount them, schools may be able to open the path to science and mathematics-based careers to many more students, contributing not only to individual students' attainment but also to the robustness of the nation's scientific and technological capabilities. In this sense, "targets of difficulty" represent targets of opportunity, as well.

A final reason for strategic concentration of our research on targets of difficulty is that these topics frustrate teachers--even the most accomplished teachers. These are the points where teachers feel the pain and <u>want</u> the help. Our sense is that a major difficulty with previous federally sponsored efforts to improve science and mathematics education has been their remoteness from the realities of students and classrooms. The tendency in development efforts has been to take modern science or modern mathematics themselves as <u>the</u> points of departure, for a group of scientists or mathematicians to define what students ought to learn and how they ought to learn it, and to pose the new vision as a more or less radical alternative to current practice. In many cases, insufficient attention was paid to what was <u>already</u> going on in classrooms--what teachers were attempting and what students were learning and failing to learn--and to the constraints and opportunities existing realities implied.

We believe that teachers learn in the same way children and everyone else learn: incrementally, by progressive transformations in and additions to what they already know and do. Accordingly, we believe that the starting point for the work of the Center must be the current realities of classroom practice, including subject matter, materials, and instructional methods.

The actual targets of difficulty on which we have concentrated our initial research were selected through a collaborative agenda-building process. In each domain, we established a working group composed of teachers and curriculum specialists, experts from the relevant disciplines, social scientists, and people with expertise in educational technologies. With teachers playing a key role, the working groups identified candidate topics for research. The groups set out to analyze three aspects of these topics:

- <u>the subject matter, itself</u>
  Expressed as simply and clearly as possible, what concept(s) and/or operation(s) constitute the essence of the topic? Does this concept or operation appear fundamental to the discipline, with broad applications, or is it isolated and narrow?

- <u>how students misunderstand the subject matter</u>
  What misunderstandings, partial understandings, and confusions about the subject matter are most common?

- <u>whether and how technology might be used to help students understand it more clearly</u>
  Is the topic amenable to treatment via the computer or another information technology?
  If so, what pedagogical approach seems most appropriate, and how might it be employed?

Through this process we have identified a set of topics for research that are central to each subject matter domain, troublesome for many students, frustrating for many teachers, and which seem amenable to technological treatment.

Thus far, this report has concentrated primarily on our principal research focus--the use of computers and other information technologies to improve instruction in science, mathematics, and computer science at the elementary and secondary levels. In this context, we have stressed the primacy of subject matter and pedagogy, with technology playing a subordinate, instrumental role. We have also emphasized current classroom practice as the starting point for improvement. We have quite deliberately chosen not to make the technology itself the starting point, not to cast the central questions in terms of the potentially revolutionary consequences of the new technology. We believe that students, teachers, and schools need help and need it soon.

We do believe, however, that the emerging technologies have the potential to transform the way all of us learn and that this potential deserves careful exploration in its own right. Accordingly, in a separate component of our research, we are examining the educational applications of increasingly powerful microcomputers, videodisc, microcomputers used in concert with broadcast television, speech synthesis and recognition, electronic networking, teleconferencing, and a variety of other innovations in information technologies. In this secondary but important component of our work, the transforming potential of new technology is the starting point and central focus. Here we are asking not only how emerging technologies may be used to teach better what our schools are already teaching, but also how they are changing the answers to the perennial question, "What is worth knowing?"

6.0 RESEARCH APPROACH

To find ways of using information technologies to improve education in science, mathematics, and computing, we are pursuing a collaborative research approach involving practitioners, university experts from the relevant disciplines, educational researchers, and thoughtful analysts of the role of technology in education.

Identifying topics that block students' progress and finding new paths through these obstacles clearly requires the participation of practicing teachers. To carry out the research in isolation from teachers and classrooms, or with teachers as last-minute partners in testing new treatments, is to repeat the mistakes of past reform efforts in the subject areas of concern. In our work, teachers are equal partners from the outset and remain so throughout the research process.

We hasten to add, however, that while the participation of scientists, mathematicians, and computer scientists is not sufficient to produce useful research results, it is absolutely essential. The emphasis of our conceptual framework on subject matter as a principal starting point for educational applications of technology clearly implies a central role for first-rate experts from the disciplines. Analysis of targets of difficulty to clarify the concepts and operations entailed in each requires these experts' participation, as does the development of technological applications that embody a clear and powerful grasp of the subject.

Understanding students' misunderstandings of targets of difficulty as well as the paths through which students get beyond these obstacles demands the participation of cognitive psychologists. Understanding the psychosocial, cultural, and sociological dimensions of learning in the domains of interest calls for additional social scientists, and understanding how teachers and students interact with subject matter and technology in classrooms demands yet another set of educational and social science perspectives. Thus, our collaborative approach includes the participation of educational researchers from a broad range of disciplines.

Finally, thoughtful analysis of technology's role is required. Teachers, subject matter experts, and educational researchers can make substantial contributions here, but the participation of people with a long-term, special interest in technology and education remains crucial to the success of the enterprise.

While a collaborative research approach brings to the table the resources needed to make powerful, practical contributions to education, it simultaneously poses the problem of getting people from such diverse perspectives to work together. University-based and school-based educators have a long history of bad communication (accompanied, in many cases, by ill will). To a large extent this stems from the different cultures of the two groups, the different demands placed upon them, and the different rewards they receive. But it also reflects an important difference in the way the two groups evaluate research. To caricature the difference somewhat, a researcher typically wants to advance theory, regardless of whether the theory helps anyone do anything better; a practitioner is interested in advances which help in his or her work, regardless of whether they correspond to theory. Each perceives the other's value system to be cockeyed, and the common result is a profoundly counterproductive division.

We do not expect to undo this history with a single center, however important its work. We can, however, increase communication and reduce the gap between researchers and practitioners in the Center's own work. To this end, we have entrusted the design and conduct of the Center's research to working groups, rather than individuals, and have constituted these groups from practitioners, disciplinary specialists, educational researchers, and experts in technology.

Simply constructing such groups did not, however, guarantee collaboration. We have taken two kinds of measures to achieve collaboration. First, we have taken care to make participation feasible and reasonably attractive for practitioners--by holding all meetings outside of school hours, by paying an honorarium for this work, which is beyond the call of duty for elementary and secondary teachers, and by a variety of other actions. The second kind of measure is easy to describe and hard to carry out--we have exercised patience, or at least persistence. Through a series of meetings, the groups have progressed from an early formality, to a continuing substantive struggle which is marked more and more by mutual respect in spite of sometimes sharp exchanges. We expected that the process would prove difficult. It has.

The procedure each group has followed includes these steps:

(1) Select members. The groups were constituted as described above. Guidance from the staff of the Education Collaborative for Greater Boston and the superintendents from the four Center school systems was especially helpful in choosing the practitioner members.

(2) Hold exploratory discussions. Each group began with relatively unconstrained discussions of the members' views of interesting questions, interesting applications of technology, and tough subject matter. These discussions were designed partly to begin substantive work and partly to initiate working relationships among group members.

(3) Draw up a preliminary list of targets of difficulty. One of the principal constraints and organizers given to the working groups was the focus on targets of difficulty. Somewhat surprisingly, there was general enthusiasm for and little dissent from the targets of

difficulty approach. Both practitioners and university people resonated to the notion and agreed that it provided a good guide for identifying research topics and a common focus for their diverse perspectives. The list of candidate targets they generated was based both on the personal experience and judgment of the participants and on a review of research in the areas.

(4) Select specific targets for initial projects. Selection of targets on which to focus our initial research projects was based on the following criteria: (1) how fundamental the topic is within its field, including the extent to which mastering it is essential to continued progress, (2) how widespread difficult with the topic seems to be, (3) how prominent it is within the present and anticipated curriculum of the schools, (4) whether practitioners and university people agreed on the importance of the topic and wanted to participate in research on it, and (5) whether the topic seems to be amenable to technological treatment in any of the pedagogical styles described in the foregoing conceptual framework. Obviously, applying these criteria involves considerable exercise of judgment. As a result, fierce debate has frequently marked the selection process. Yet we are now quite confident of the topics' importance and of the working groups' ability to find new ways of attacking them using information technologies.

(5) Form subgroups to analyze the topics in greater depth and propose research plans. For each selected target or target area, a subgroup involving both university people and practitioners was formed. The first order of business of each subgroup was to analyze the target in some depth, from a disciplinary point of view, from a cognitive developmental point of view, and from the point of view of the classroom teacher. At this point, the work of the subgroups began to diverge. On some topics, considerable analytic work was required. On others, the outlines of a pilot teaching and learning experiment emerged quite rapidly.

7.0 RESEARCH PROJECTS

Most of ETC's research projects examine a target of difficulty in one of the domains of interest: math, science, or computing. Each of these groups analyzes the conceptual and pedagogical basis of its target of difficulty and then devises teaching approaches that make use of both new technologies and traditional materials. A few projects depart from this pattern of subject matter first, teaching strategy second, and technology third. These groups start with the potential of emerging, but not yet widely available technologies and ask how they can be used to teach better what our schools are already teaching.

7.1 RESEARCH PROJECTS IN SCIENCE

Much of the elementary and secondary science curriculum deals with the study of matter and the study of energy. The first of ETC's research project, Weight and Density, is working on ways to help students learn a distinction that is essential to many topics encountered in school and a frequent obstacle to the development of a theory of matter. The second project, Heat and Temperature, focuses on energy and on helping students understand issues of energy content and energy transfer.

The third and fourth science projects explore ways to teach students about methods of scientific inquiry. The Scientific Theory and Methods Project concentrates on hypothesis formation and testing, while the Complex Systems Project has investigated the motivational and conceptual aspects of students' understanding of complex physical and biological systems.

7.1.1 Weight and Density

Group Members:
- Carol Smith, University of Massachusetts, Project Leader
- Micheline Frenette, ETC, Research Assistant
- Barbara Gard, ETC, Research Assistant
- Mary Maxwell Katz, ETC
- Grace LeBlanc, Watertown Public Schools
- William Radomski, Newton Educational Center
- Judah Schwartz, ETC

The notion of density of materials is a conceptual watershed in the pre-college science curriculum. An understanding of density is essential to many topics students encounter in school: how materials differ, what happens during changes of state, why some objects sink while others float. For most students, density is the first intensive physical quantity that can be understood in terms of an underlying model, the particulate theory of matter. This model--built on both observable and inferred properties and entities--is a major theoretical achievement. Teaching students about density, thus, provides them with explanations for a range of phenomena as well as an opportunity to develop their understanding of an intensive quantity and to engage in real theory construction.

Teachers report, however, that density is a difficult concept for students to grasp. The ETC Weight/Density research project explores the sources of this difficulty and the ways that students' naive notions can serve as a basis for building a solid understanding of density.

One source of difficulty may be that density is an intensive quantity. Intensive quantities generally have a ratio structure, such as the number of candies per bag or students per classroom. Research has shown that intensive quantities are difficult for students to understand, especially when, like density, they are not directly observable. Research also suggests students find highly visualizable intensive quantities easier to grasp. Another source of difficulty may be that some traditional teaching approaches require students to infer the concept of density from manipulation of real materials. This project's long range goal is to determine whether students might develop a better understanding of density by learning to conceptualize density within a particulate theory of matter and through interaction with a visual analog of density depicted in computer graphics.

The Weight/Density Research Group conducted a study during 1985 to determine whether elementary school children can more readily understand (and quantify) a visual analog of density presented in computer graphics than they can understand the concept of density inferred from manipulation of real world materials. A further goal was to understand students' mental models of the nature of materials.

The study included second, fourth, and sixth graders, half boys and half girls, selected by their teachers to represent a systematic range of abilities. Each child received two parallel sets of tasks: one involving the manipulation of real materials and one involving shapes presented on a computer display. The real materials were cylinders of steel and aluminum, the former being about three times denser than the latter. Steel cylinders were marked with a blue sticker and aluminum ones with a yellow sticker to help children visually distinguish the two kinds of metal. The computer displays consisted of arrays of dots contained in rectangles of two different colors. Red shapes contained one dot at each intersection of an imaginary matrix, whereas green shapes contained a little bunch of three dots at each intersection of the corresponding imaginary matrix. Thus green shapes represented a material three times as dense as that represented by red shapes.

For each task, children were first familiarized with the experimental materials and then required to predict either the relative weights of particular pairs of steel and aluminum cylinders or the relative number of dots that would be contained in pairs of colored rectangles on the computer screen. Both types of tasks required inferences. In the cylinders task, children were not allowed to lift the two cylinders to directly compare their weights; rather they had to infer the relative weights of the cylinders from knowledge of their relative sizes and their memory of the relative densities of the materials. Similarly, in the computer task, children could not determine which shape had more dots by counting since only the colored outline of the shape was indicated; rather they had to infer the relative number of dots in a shape from knowledge of their relative sizes and remembered dot densities for the different colored rectangles. The order of presentation of computer and cylinder tasks was

Additional tasks probed students' conceptions of the nature of matter, of weight as a property of matter, and of the correspondence between the computer displays and the tasks with metal cylinders.

The results of this study showed that children at all ages could more readily understand and quantify the intensive quantity presented visually in the computer displays than the quantity they inferred from manipulation of the real world materials. In addition, the results indicated that experience with the computer problems helped students to think about the difference between steel and aluminum cylinders as an intensive one--that is, stemming from the kind, not the amount, of material. The computer displays also appeared to help students think more precisely about the magnitudes of the intensive quantities. Thus, children who had the computer problems first performed better on the steel and aluminum cylinders task (and used more quantitative strategies) than children who had the steel and aluminum cylinders task first. Other aspects of the interview revealed that the majority of children at every age could see the analogy between the computer task and the cylinders task. However, it is likely that only the older children find the computer analog a plausible <u>model</u> of density. With increasing age, children were more likely to assume that weight was a fundamental property of matter; and many of the oldest children spontaneously used atomistic conceptions of matter to explain the density differences of materials.

Subsequent research by the Weight and Density Group will examine the ways that the computer displays may serve as a pedagogical tool, particularly for fourth and sixth grade elementary school students. The group is currently expanding the computer microworld used in this research to allow students to build objects of varying sizes, shapes, and weights (number of dots) from underlying constituents of a broad range of densities. The group is also planning a series of experimental lessons designed to teach fourth and sixth grade students to understand the computer displays as a model of density and to understand density as an intensive quantity. Plans are to begin testing components of the teaching unit in December 1985 and to do a study of the effectiveness of this teaching unit in February 1986. The group also plans to extend the computer model to dynamically represent sinking and floating and to develop a teaching unit concerned with this problem area in Spring 1986.

A fuller description of this group's work is contained in ETC Technical Report No. 85-15, <u>Weight, Density and Matter: A Study of Elementary Children's reasoning about Density with Concrete Materials and Computer Analogs</u>, June, 1985. The next report will be available by August 1986.

7.1.2 Heat and Temperature

Group Members:

Marianne Wiser, Clark University, Project Leader
Edgar Boucher, Newton North High School
Mel Levinson, Newton North High Schoo_
George Martins, Newton North High School
Lisa Teixeira, Clark University, Research Assistant
Robert Tinker, TERC

Heat and temperature are fundamental but difficult physics concepts for counterbalanced for individual students in each age group and ability level. high school students. Thermal physics is built on the distinction and relations between heat and temperature, and on the relation between heat and work as two forms of energy. Most students do not differentiate between heat and temperature, however. Instead, they have a single concept which combines some features of heat with some features of temperature. For most of them, "hotter" is an undifferentiated concept meaning both "has a higher temperature" and "has more heat".

The novice's conceptual scheme about heat and temperature is resistant to change, even after several science courses. Several factors may contribute to students' typical and resilient confusion on this topic. Everyday experiences are easily understood in terms of the novice's single undifferentiated concept. This inadequate concept is reinforced by the English language which uses the term "hot" to refer to both heat and temperature. Furthermore, the lay person usually has thermometers, which measure temperature, but no tools that measure heat directly.

The goal of this research group is to learn whether a Microcomputer-Based Laboratory curriculum can facilitate students' differentiation and thus comprehension of heat and temperature. Two hypotheses shape the lessons. First, microcomputers coupled with peripheral temperature probes and heat "dollopers" (devices that deliver a calibrated amount of heat) can permit students to measure heat directly and to display simultaneously heat input and temperature changes in conceptually powerful ways. Second, the particular phenomena that prompted progress in understanding thermal physics in the history of science may induce students to differentiate effectively between heat and temperature. For example, just as Black's discovery in the eighteenth century of specific and latent heat prompted him to establish the fundamental differences between heat and temperature, lessons focusing on phenomena that exemplify specific and latent heat may help students make the same distinction.

The four lessons of the experimental curriculum focus on the major differences and relations between heat and temperature: 1) quantitative relations among amount of heat, mass, and temperature change, 2) heat storage capacity, 3) cooling curves, and 4) latent heat. The lessons were developed in two formats: computer and traditional. Students in the computer lessons used the computer as a laboratory tool to record data (heat and temperature) and to display them as graphs and tables. The traditional lessons covered the same content as their computer counterparts, but in a form similar to that usually used by science teachers. The students, for example, read thermometers and drew their own graphs.

A study comparing these two lesson formats was conducted in a large suburban high school in six ninth-grade classrooms. Three experimental classes were taught the computer-based lessons while three matched control classes received the series of traditional lessons. Approximately one third of the 121 participating students were seen in clinical interviews before and after the series of lessons to probe their understanding of the relevant concepts in thermal physics. All students completed a multiple-choice written pre- and post-test to assess their learning of the concepts addressed by the lessons. Experimenters observed during many of the lessons and talked with teachers and students in both the experimental and control groups after the study to learn their feelings and expectations about the research process and results.

The analysis to date of pre- and post-test results indicates that, while all six classes made small gains, the computer classes showed significantly greater gains. A detailed item analysis of test scores suggests that this difference between the experimental and control groups was not caused by Hawthorne effects. In fact, in discussions shortly after completion of the lessons, the teachers and most students in both experimental and control groups predicted (incorrectly) that the students had learned more from the traditional lessons than from the computer-based lessons.

The pattern of test results is also not attributable to either sampling errors or a general effect of using the computer. Rather, it appears that the use of the computer in the first lesson helped students understand the quantitative relationships among heat, temperature, and mass in different substances. Specifically, the computerized heat pulse generator seems to have provided crucial help by giving students direct access to the concept <u>unit of heat</u>. In addition, the software used in this lesson caused the computer to display each "dollop" of heat as it was delivered, immediately under the temperature curve. This emphasized the independent reality of heat, and its quantitative correlation with temperature in different amounts and kinds of substances.

These findings point to three issues that will be the focus of this group's research during the coming year: (1) whether and in what ways the Microcomputer-Based Laboratory software and hardware lead to better learning of thermal concepts than other types of computer teaching interventions; (2) the importance of the lessons' contents--what thermal phenomena best exemplify the distinction between heat and termperature; and (3) whether students can generalize their learning from these lessons to explain novel thermal phenomena. The group plans to design experimental lessons using computer simulations and tutorial software as well as the Microcomputer-Based Laboratory equipment from the previous research. These lessons will be taught, varying content as well as method of delivery, in a total of twelve ninth grade classes during the 1985-86 academic year.

A fuller description of this research is contained in ETC Technical Report No. 85-17, <u>Designing a MicroComputer-Based Laboratory to</u>

Induce the Differentiation between Heat and Termperature in Ninth Graders, June, 1985. The next report from this project will be produced in August, 1986.

7.1.3 Scientific Theory and Methods (STAMPS)

Group Members:
- Carol Chomsky (on leave), Harvard Graduate School of Education, Project Leader
- Wayne O'Neil, Massachusetts Institute of Technology, Project Leader
- Diane Bremis, Watertown High School
- Mary Greaves, Day Junior High School, Newton
- Maya Honda, ETC, Research Assistant
- Jia Khurana, Morse Elementary School, Cambridge
- Robert Kilburn, Newton Educational Center
- Maxine Rosenberg, Newton Educational Center
- Chris Unger, ETC, Research Assistant
- Al Weinstein, Cambridge Public Schools

The Scientific Theory and Methods Project (STAMPS) is concerned with students' understanding of two areas of science in secondary schools. One is understanding what a scientific theory is, and the other is understanding the methods used in conducting scientific research.

In the science curriculum these topics are often described as the "process" of science, as opposed to scientific "facts". The research group recognizes that students, along with learning about the content of the different scientific disciplines, need an emphasis on the scientific process as well.

The STAMPS group is examining students' ability to handle various concepts within the domains of scientific theory and research methods. For example, the group wants students to learn that the goals of science include deriving principles and building theoretical constructs which account for observed facts. The group also wants students to develop an understanding of how theories differ from and relate to observations, and why there is a need for and interest in constructing theories that explain and go beyond what can be observed. Students should understand the role and purpose of experimentation in examining particular phenomena in the world, and they should realize that a theory is a product of the scientist's mind, not of the phenomena in the world nor of the data taken from them.

The group has prepared materials to use with students to introduce concepts and terminology in the areas of theory and methodology. The ideas include explanation (how a theory accounts for data), hypothesis formation and testing, prediction, inference, counterexamples, hypothesis revision, how to run an experiment, variables (independent, dependent, and controlled), graph construction, data vs. theory, cause and effect vs. correlation, and other relevant terms and concepts. The plan is to assess student reaction to these materials and to find a match between what students in junior high and high school can reasonably be expected to understand and learn, and appropriate materials for them to use towards these ends. By the end of the project period, the group plans to produce a month-long curriculum unit on scientific theory and methods for use in grades seven through nine.

So far the materials selected and/or developed for pilot testing cover three areas:

(1) Hypothesis formation and testing: computer-based "puzzle-solving." The microcomputer program King's Rule (Sunburst Communications) will be used to teach the ideas and terminology of hypothesis formation, testing, and revision, and for providing practice with these concepts. King's Rule was chosen after review of many pieces of "science" software considered potentially useful for this purpose. Within an interesting and challenging format, the program presents number riddles whose solutions require hypothesis generation and testing.

(2) Experimental method: microcomputer simulation of real-world physical phenomena.
A microcomputer program The Scientific Method (Cygnus Software) will be used to introduce scientific methods of experimentation with physical phenomena. The program includes practice with variables (independent and dependent) in an experiment, control factors, logical thinking, prediction, and so on. STAMPS selected this program over many others that deal with scientific methodology; the group has made certain revisions to the program in line with its particular goals and has specified points of departure from the program for group discussion, making predictions, recording data, and graphing.

(3) Theory construction: real-world abstract phenomena.
In this activity students use their own language as subject matter for scientific investigation. They derive rules of English to explain aspects of their own speech, such as how to form regular plurals, or when to use or not to use certain types of contractions. Students and teachers together use their own language as data and work out principles which account for possible utterances. They construct hypotheses, test them, look for counterexamples, and revise the hypotheses until they fit the data and can predict accurately. They finally arrive at theoretical principles which account for the facts. In this way students experience first-hand the processes by which scientific knowledge increases.

A fourth area, laboratory experiments with physical phenomena, remains to be developed as a next step. STAMPS also plans to develop computer simulations of laboratory experiments specific to the research group's purposes. Additional work includes student reporting of results and plans for formal evaluation of what students have learned.

Pilot testing of the materials described above occurred from February to June, 1985. Students from the Watertown, Newton, and Cambridge school systems participated in the pilot sessions which were held after school, once a week, for eight weeks. The students met in groups with STAMPS research people and their science teachers: five ninth and tenth graders from Watertown High School, seven seventh graders from Day Junior High

School in Newton, and seven ninth and tenth graders from Cambridge Rindge and Latin School. Four software sessions (#1 and #2 above) were held with two or three students at a time, and four language sessions (#3 above) were held with the larger group in each school. The Watertown and Newton students completed the software sessions first, followed by the language sessions. The Cambridge students reversed this order, doing the language session first and then the software sessions.

Analysis of the pilot sessions has been extremely valuable in assessing the materials, learning about what students in different grades and of different abilities can handle, judging what revisions to make in the materials, planning a desirable ordering of the materials, and planning for appropriate classroom organization in a full-scale classroom curriculum unit under preparaton.

In the coming year, STAMPS plans to complete revisions of the piloted materials and to develop the fourth area, sample laboratory experiments and related computer simulations. These materials will make up a curriculum unit of a month's duration, which will be pilot tested in two classrooms in the Newton school system, a seventh grade and a combined seventh/eighth grade class. In both cases the entire class of approximately 30 students will participate, yielding a total sample size of approximately 60 students. On the basis of results from these evaluations of the materials' appropriateness and effectiveness, the group will make the adjustments and revisions necessary for future research.

A more detailed discussion of this group's work is contained in ETC Technical Report No. 85-23, Doing Science: Constructing Scientific Theories as an introduction to Scientific Method, November 1985.

7.1.4 Complex Systems

Group Members:

Eleanor Duckworth, Harvard Graduate School of Education, Project Leader
Candace Julyan, ETC, Research Assistant
Robert Kilburn, Newton Educational Center
Eileen McSwiney, Education Collaborative for Greater Boston
Julianne Rabschnuk, Ware High School
William Read, Lexington Public Schools
Maxine Rosenberg, Newton Educational Center
Thomas Rowe, ETC, Research Assistant

The long-term goal of this group was to explore how computers could help teach children about the nature of complex systems. After reviewing existing curriculum materials and considering the theoretical issues raised by its own members, by other practitioners, and by developmental psychologists, the group determined that its first step must be to learn more about children's naive conceptions of an observable complex system. Although the group hoped eventually to develop teaching materials for biological and ecological systems, it was forced to turn temporarily to a physical system for the purpose of conducting interviews which would probe children's understanding. The group designed an experiment using helium balloons and interviewed both children and adults concerning it. In addition, a simple computer simulation of the helium ballon experiment was prepared, and children's responses to the real and simulated system were examined.

During the fall of 1984, the group conducted pilot interviews of both children and adults using the helium balloons and other materials. During the spring, fourteen high school students from Ware and Cambridge, Massachusetts -- twelve ninth graders and two twelfth graders -- were interviewed in small groups once a week for three to five weeks.

In the helium balloon experiment, students were presented with several balloons. The "standard balloon" was weighted to a height of three feet from the floor by several lengths of medium-weight twine. Three or four "worker balloons" were weighted to various heights less than three feet with finer twine. A similar number of "helper balloons" were let float to the ceiling, weighted only by a fine thread which made them accessible. The students' task was to make one of the "worker balloons" level with the "standard". As they worked, the experimenter questioned them. The balloons used different weights of string in order to discourage them from counting the number of strings to answer certain questions, as some had done in the pilot sessions. As the students became able to articulate their ideas of what was happening, the experimenter asked further questions to lead them to test their theories.

The computer simulation provided three variables for which the student must enter data: balloon size, number of strings attached, and height from the floor at which the balloon is released. The student then saw a representation of the behavior of a balloon -- rising, sinking or staying level -- accompanied by a coordinate graph of height by time. To begin the simulation experiment, the student was asked to try to make the balloon stay level at the point at which it was released. Two versions of the simulation were used with all of the students. One was quantitative: students entered the data in numerical form. Pilot observations showed that some children became more focused on numerical manipulation than on understanding the factors in the system. Therefore a second, more qualitative simulation was designed. In this version, three levels were available for each variable.

The younger students were often surprised by the balloon system and worked hard to understand what was happening, but they were unable to create a complete picture of the system. Only the two twelfth grade students were able to keep clear in their minds which aspect they wanted to work on at a given moment and to create experiments which would shed light on that particular aspect. They aimed for a simple understanding into which they could fit all the pieces and developed ideas of forces working against each other. The extended interviews also showed that the students' initial understandings, though often phrased in scientific terms, contained inconsistencies and were quite undeveloped.

Students' ability to understand the computer simulation varied considerably. Two students were able to get different sized balloons to remain level but were unable to explain how. A third student succeeded at the task involving the real balloons but found the computer model baffling. A fourth also succeeded with the real balloons but seemed to think that the variables of the string and helium were unimportant in using the simulation. For one group of students, the computer presented a problem -- the effect of height of release -- which they re-explored and solved with the real balloons. After an initial interest in the computer simulation, most students chose to focus on the real balloons. Their reactions may have been due in part to one confusing bug in the simulation and to a less developed interview procedure for the simulation.

These students' difficulties in understanding the helium balloon system suggest great caution in expecting children in ninth grade or under to understand the actions of multiple variables in complex systems. These findings also suggest questioning of students simple initial descriptions of a system; though couched in scientific vocabulary, these beginning conceptualizations may contain confusions and inconsistencies.

Difficulties in defining the complex systems problem from a technological standpoint and changes in the availability of key group members led ETC to discontinue this research group at the conclusion of the helium balloon experiments. The insights from its valuable exploratory work will be used to inform the work of the Center's other research groups. A full description of the group's findings is contained in ETC Technical Report No. 85-16, Understanding Equilibrium: The Study of Complex Systems, June 1985.

7.2 RESEARCH PROJECTS IN MATHEMATICS

Both ETC mathematics projects deal with notoriously difficult classroom hurdles. One tackles the problem of teaching fractions and decimals; the other is developing ways to help students solve word problems by learning to construct models of quantitative relationships and to recognize the prototypical situations for which a given mathematical operation is appropriate.

7.2.1 Fractions

Group Members:

Patricia Davidson, University of Massachusetts, Project Leader
Marge Bloom, Day Junior High School, Newton
Joanne Calnan, West-Marshall School, Watertown
Ruth Chapman, Newton Educational Center
Judy Clark, Harvard Graduate School of Education
Anne Dickenson, ETC, Research Assistant
Charles Garabedian, Watertown High School
Cheryl Larsen, Watertown Public Schools
Karen Quinn, Ware High School
Cornelia Tierney, ETC, Research Assistant
Mary Kay Tornrose, Newton Educational Center
Martha Stone Wiske, ETC

The ETC Fractions Group addresses the problem of students' well-documented difficulty understanding and using fractions. A central assumption underlying the group's inquiry is that students' difficulties in manipulating fractions frequently arise from their failure to understand the very nature of fractions. In order to learn operations with fractions, students must first understand the order properties of fractions and their nature as "numbers between numbers." The notion of betweenness, so essential to the perception of continuous quantity, is neither salient nor even evident in the symbol systems and notation schemes used to describe continuous quantity. Yet, understanding betweenness appears to be a prerequisite for effective manipulation of fractions. In addition, betweenness is an important theme pervading much of mathematical thinking. Thus, this project's focus on teaching students to understand betweenness is a means not only of addressing student difficulties with fractions, but also of teaching a concept fundamental to a great deal of other mathematics.

Traditional wisdom maintains that in learning a new concept, students should be presented with a rich set of different representations or models of the concept. Yet, most efforts to teach fractions in this way have been ineffective. The Fractions group's approach stems from a belief that multiple representations may be more confusing than enlightening at the early stages of learning about fractions. As a result, the group's approach uses a single model--the linear model--and focuses on the concepts of equivalence, order, and betweenness.

The work of the Fractions Group to date has consisted of designing and pilot testing components of an experimental curriculum. The pilot data have been analyzed both to clarify students' conceptions of fractions and to assess the utility of the lessons in helping students develop a clearer understanding of the order properties of fractions.

Based on its review of existing materials and prior research in this area, the Fractions Group designed the experimental lessons with several criteria in mind. First, the lessons should use a single model in order to reduce conceptual complexity. Second, they should use the linear model because it most clearly represents fractions as numbers for measuring continuous quantities. Third, the curriculum should build on the use of rulers, tools that students readily recognize as familiar and useful for measuring lengths. Fourth, the curriculum should combine manipulable materials, with which students gain immediate hands-on experience, and computer activities that extend the experience beyond the limits achievable with physical objects.

The unit consists of a sequence of four modules of lessons. The first asks students to measure lengths using common objects as units, emphasizing that the numerical magnitude of a continuous quantity is entirely dependent on the unit and may be expressed as an approximation of whole numbers of units. The second engages students in making rulers by folding paper strips and using them to measure continuous quantities less than one whole unit, emphasizing equivalent fractions through labeling and comparing arrays of number lines on a sheet of paper. The third requires students to measure continuous quantities longer than one whole, extending the folded paper rulers to microcomputer-based rulers with progressively finer subdivisions to permit increasing precision. In the fourth module students examine the order relationships of fractions through several microcomputer-based activities that encourage the development of strategies for ordering fractions by size.

The lessons for all four modules were pilot tested with small groups of fifth and seventh grade students. These pilot studies were undertaken to learn first whether students appeared to engage in and understand the tasks, and second whether the lessons appeared to be a promising curriculum for achieving the research goals of this group. Both questions were clearly answered in the affirmative. The students at both grade levels responded with interest to the series of activities and appeared (on the basis of informal observations) to gain insights about fractions. Based on the pilot-test data, the group will revise the lessons to clarify confusing activities, omit redundant ones, and add others to ensure a clear conceptual progression for students.

During the fall of 1985, the group will revise the modules as indicated and develop assessment instruments, including both pre- and post-tests and clinical interview guides. The clinical interview process will be pilot-tested with several of the students who participated in the May 1985, pilot study. In the spring of 1986, the experimental curriculum will be taught to four small groups of students, two each of fifth and seventh graders. All students will be tested before and after the unit to determine the extent of their gains in understanding of betweenness concepts and of how to order fractions. In addition, students will be closely observed and interviewed during the fourth module in order to clarify and record both their strategies for ordering fractions and the effects of the Module 4 activities on their thinking.

A fuller report of the Fractions Group's work is contained in ETC Technical Report No. 85-21, "Pies Are Hard to Find Out About....": An Inquiry into the Nature of Children's Understanding of Fractions, November 1985. Analysis of the group's work during the 1985-86 Academic Year will be presented in a report planned for September, 1986.

7.2.2 Word Problems

Group Members:

James Kaput, Southeastern Massachusetts University, Project Leader
Kathy Hollowell, Newton North High School
Mary Maxwell Katz, ETC
Eileen McSwiney, Education Collaborative for Greater Boston
Joel Poholsky, ETC, Research Assistant
Yolanda Rodriguez, Agassiz School, Cambridge
Judah Schwartz, ETC
Susan Weiner, School of the Future
Jane West, Newton South High School
Claire Zelewski, Lexington Public Schools

Focusing on students' difficulties in solving word problems, this group's 1984-85 efforts included two pilot studies and a review of the literature. These activities led to a tighter definition of the target of difficulty and to plans for developing software. The group's work is founded on the belief that the elementary mathematics of school should not be exclusively the mathematics of number, with applications regarded as separate, but rather should begin with the mathematics of quantity, so that mathematics and its "applications" are learned together from the very beginning.

The two pilot studies sought to define the types of problems that cause students the most difficulty. One asked students to generate single-step word problems requiring the application of a single operation. These were classified according to a taxonomy devised by the researchers and appearing elsewhere in the literature. The second study asked students to solve word problems classified according to the same task variables used to taxonomize the student-generated problems. Each study included 250-300 students in grades four through beginning college, from schools in Cambridge, Newton, and Watertown, Massachusetts. The second study confirmed that problem types not appearing among student-formulated problems were also the ones students were least able to solve. In particular, students had difficulty choosing the correct operation with problems requiring multiplication of two extensive quantities, and with division problems where the numerator was an intensive quantity.

The group then began a thorough review of the literature and a discussion of why these types of problems are so difficult. The review revealed a consensus among researchers that students lack rich and flexible cognitive representations of multiplication, division, and intensive quantities, and consequently fail to recognize situations that call for the application of these mathematical structures. Students' cognitive models of multiplication are dominated by a repeated addition model; their models of division by a partitive ("fair share") model. Their models of intensive quantities depend on familiar semantic-based structures or simple ratios. The operations of multiplication and division are intimately related to intensive quantities and proportions: they comprise a natural family of instructional topics based on a set of interrelated concepts developing within a student over a period of perhaps ten years.

The group next discussed a plan for a software environment that would help build the necessary cognitive models, one using linked representations that could be made available with multiple-window software. Interacting with such coordinated representations will help students to build and integrate an increasingly powerful repertoire of cognitive representations. The initial software will focus on intensive quantities using four representations: (1) iconic representations; (2) a vertical data table with appropriately labeled columns that change as the number of base sets changes; (3) a coordinate graph where the axes will be labeled to match the object labels and where points will be plotted to parallel activities in the other representations so that the numerical ratio associated with an intensive quantity is represented by the slope of the line of points; and (4) a calculator pad for arithmetic with formal expressions of the involved quantities. The first, third, and fourth components provide three very different cognitive tools for understanding a problem, and the second provides a numerical bridge between any two of the others.

The next year will be spent producing and testing the proposed software. Further information about the past year's work and software plans may be found in ETC Technical Report No. 85-19, Multiplicative Word Problems and Intensive Quantities: An Integrated Software Response, August 1985.

7.3 RESEARCH PROJECTS IN COMPUTING

ETC has two research projects in computing. The first, which is concerned with the problems of students learning to program, has looked this year at the behavior of novice programmers and experimented with teaching strategies to help novices learn the necessary problem-solving skills. The second computing project has been concerned with teaching and learning the use of applications software and with this software's potential impact across the curriculum.

7.3.1 Programming

Group Members:

David Perkins, Harvard Graduate School of Education, Project Leader
Betty Bjork, Education Collaborative for Greater Boston
Chris Hancock, ETC, Research Assistant
Renee Hobbs, ETC, Research Assistant
Fay Martin, ETC, Research Assistant
Jack McLeod, Newton Public Schools
Marie Salah, Watertown Public Schools
Nancy Samaria, Watertown Public Schools
Paul Shapiro, Newton North High School
Rebecca Simmons, ETC, Research Assistant
Tara Tuck, Tobin School, Cambridge
Martha Stone Wiske, ETC

The goals of the ETC Programming Group have been to clarify the nature of problems encountered by beginning programming students, to identify the behaviors and attitudes exhibited by effective novice programmers, and then to design and assess an experimental curriculum that explicitly teaches these behaviors and attitudes. The group's further goal is to develop an approach to teaching programming that helps students not only learn effective programming skills but also develop more general problem-solving skills.

During the 1984-85 academic year the group conducted a series of studies, starting with observations of students in beginning LOGO and BASIC classes, followed by structured clinical interviews with individual students from these classes. These investigations revealed several kinds of problems typically encountered by beginning programmers and particular ways in which effective novice programmers either avoid or invent solutions for the usual pitfalls.

The group observed that many beginning students can be classified as either stoppers or movers. When faced with a programming problem, the former stop and stay stuck. The latter try one idea after another, writing or modifying their code and testing it. Stoppers represent the most obvious sign of the powerful affective factors observed to influence novice programmers. Their lack of self-confidence and their tendency to view bugs as mistakes rather than clues foster a disengagement that reinforces itself by interfering with these students' development of greater competence.

Another typical problem for many novice programmers is "close tracking," or careful attention to the correspondence between the written code and what the program does. Many students commonly neglect to read the code carefully; some seem unable to do so and even unaware of the connection between code and the behavior of the computer.

Observers noted that students often approach programming by tinkering--that is, trying to solve a programming problem by writing some code and then making small changes in hopes of getting it to work. By definition, tinkerers are movers and are more likely to succeed than stoppers. To be effective, however, the tinkerer must be able to track code closely and make systematic adjustments to the program. Without this careful tracking, the tinkering strategy is likely to lead either to an unwarranted sense of competence thanks to accidental success, or to an accumulation of useless tinkers that render the program virtually incomprehensible.

Like all other forms of problem solving, programming requires skill in breaking the problem down into manageable chunks. To divide a problem into parts successfully, the student must not only recognize the need to isolate subproblems but must do so in a way that is appropriate to a particular programming language and environment. This kind of nontrivial breaking down of problems was rarely seen in novice programmers.

To summarize, these observations pointed to an inventory of skills, behaviors, and attitudes that seem to help students overcome common obstacles in learning to program. Referred to by the Programming Project as "controlled exploration", this inventory includes breaking problems down into manageable chunks, close tracking of code (mental simulation of what the computer will do, step by step), the tendency to persist through initial difficulties with a program, a systematic approach to tinkering with a program, and an attitude towards bugs as clues rather than as signs of failure.

The emergence of these factors prompted the group to undertake a more systematic study of the difficulties of unsuccessful novice programmers. This investigation focused on the question of whether these students lack knowledge of the specific programming language, or whether their behavior reflects a more general lack of problem-solving knowledge.

To investigate the locus of novices' difficulties, the group devised a study employing a scaffolded interview procedure. Twenty high school students enrolled in the second semester of a year-long BASIC course participated in the study. The investigator, working one-on-one with each student, presented a sequence of eight programming problems, ranging from easy to difficult. The investigator watched as the student programmed, asking occasional questions to track the student's thinking. If the student encountered a significant difficulty, the investigator intervened, first with prompts aimed to provoke strategic thinking regardless of the nature of the student's difficulty. If a couple of prompts did not help, the investigator provided hints, leading questions, or bits of information. If hints did not help, the investigator provided an exact solution to the immediate dilemma so that the student could get on with the rest of the program. This scaffolded interview both clarified the student's level of mastery and understanding, and demonstrated the value of each form of progressively tailored assistance.

Results from this study show that students' difficulties appear to stem from knowledge that is fragile in several senses:

(1) partial knowledge, when a student knows something about a command or other element of programming but has minor gaps that impair the student's functioning;

(2) inert knowledge, when a student has the knowledge, but fails to retrieve it when needed;

(3) lack of a critical filter that allows the student to reject erroneous candidate solutions;

(4) misplaced knowledge, when knowledge suitable for other circumstances invades occasions where it does not fit;

(5) conglomerated knowledge, when the programmer composes code that loosely expresses the intent without following the strict rules that govern the computer's actual execution of code.

The study confirmed that general problem-solving skills play a significant role in programming. About half the time, the examiners found that students were responsive to the prompts, indicating sufficient mastery of lower level programming knowledge, but a lack of strategic ability. Their findings also suggested that to make the most of general strategies, students need to solidify their fragile knowledge of the programming language commands and how the machine executes them.

All of this work indicated that students might benefit from explicit teaching of controlled exploration as part of their instruction in beginning programming. This conjecture led the Programming Project to design a teaching experiment which they conducted over a four-week period during the summer of 1985. The experiment was designed to address two goals. The first goal was to explore the teachability of the controlled exploration concept and to assess the effects of explicitly teaching these behaviors. The second goal was to test the group's conjecture that the heavy use of LOGO's immediate mode, which is customary in most LOGO classes, may hamper the development of certain skills, such as close tracking, that require the student to have an internalized mental model of the effect of LOGO commands.

For this study the Programming Group designed a curriculum to teach beginning LOGO with explicit instruction on controlled exploration strategies. The subjects were 25 students from nine to twelve years of age enrolled in a LOGO class at a summer day camp. They were divided into two groups. Both received identical instruction except that one group was allowed to make extensive use of immediate mode while the other was required to plan their programs on paper. Students in both groups were given pre- and post-tests to measure their progress in various aspects of controlled exploration as well as their progress in general LOGO programming ability. Unfortunately, summer holidays and other factors caused such attrition of the original sample that intergroup contrasts seem unlikely, although pooled-group effects will be analyzable. Data from this study are currently being analyzed and will be presented in a report that will be available in March, 1986.

Based on their findings to date and on continuing analysis of their data, members of the Programming Project are designing an experimental set of lessons for beginning BASIC students. The lessons will be designed to teach controlled exploration strategies such as applying an accurate critical filter, providing oneself with general, strategic prompts, and striving for precision in tracking code. The Programming Group will pilot-test the lessons and research instruments during the fall of 1985. The curriculum will then be assessed in a controlled teaching experiment during the spring of 1986.

The Programming Group's work is described in detail in ETC Technical Report No. 85-13, Conditions of Learning in Novice Programmers, April 1985, and in ETC Technical Report No. 85-22, Fragile Knowledge and Neglected Strategies in Novice Programmers, October 1985.

7.3.2 Applications

Group Members:
Marlaine Lockheed, Educational Testing Service, Project Leader
Betty Bjork, Educational Collaborative for Greater Boston
Charlotte Fogarty, Ware High School
Joan Gulovsen, ETC, Research Assistant
Jane Manzelli, Brookline High School
Carolee Matsumoto, Concord Public Schools
Chip Morrison, ETC, Research Assistant
Frances K. Morse, Newton Public Schools
Timothy Reed, Watertown Public Schools
Debbie Ross, Cambridge Public Schools
Joe Walters, ETC, Research Assistant

The overall purpose of the Applications Project has been to investigate the educational potential of applications software and the problems that students and teachers encounter as they explore this potential. A survey conducted by the project revealed that very few teachers use applications software as a tool for teaching topics in the regular school curriculum. In light of these findings the ETC Applications Project pursued two complementary lines of investigation during the past year. One of them was a series of studies involving close observation in a few classrooms where students were being taught to use application or tool software. A second line of work was the creation of an experimental curriculum unit as a model with which to analyze the educational potential of tool software.

7.2.3.1 Observations. The Applications Group's observational research took two different forms during the 1984-85 school year. The first set of observations used an ethnographic approach, while the second set of observations used a more structured form of data collection, reduction, and analysis.

During the fall of 1984, two Applications Group researchers conducted ethnographic observations in four classrooms -- two at the high school level, one eighth grade, and one fifth grade -- where teachers were using applications software the availability of microcomputers varied widely among the classes: the high school classes were sections of a "Computers in Society" course that was taught in a computer resource center containing five microcomputers; the eighth grade class was taught in a computer center containing 15 microcomputers; the fifth grade classroom contained no computers on a regular basis. In all four classes, the teachers were using database managers as part of their instructional program.

The researchers collected twenty-five observation protocols in the four classes: four in one high school class, thirteen in the second high school class, three in the eighth grade class, and five in the fifth grade class. The results of the high school observations were summarized in an unpublished paper by this group.

The purpose of the observations was to identify further the difficulties students encountered while using database management systems. Once identified, these difficulties were to serve as "targets of difficulty" for further research and development activities. The primary difficulties encountered in the classroom, however, were not those of learning and using the software. Rather, the observed difficulties centered around technical problems with implementing the innovation in the classroom. Thus, the observers noted machine failure, hardware-software incompatibility, and other symptoms of an inadequately implemented curriculum. While a great deal was learned about difficulties in introducing an innovation such as microcomputer database managers into the curriculum, these observations did little to shed light on recurrent "targets of difficulty" in applications software use. For this, the group turned to a more formal observations strategy.

During the spring of 1985, the Applications Group identified a former programmer who was teaching five sections of a seventh grade computer education course focused on applications software: word processing, simulations, and database managers. Unlike the other classes the researchers had observed, these classes were taught in a computer resource center containing 23 microcomputers networked with a hard disc, which allowed a 1:1 student-to-computer ratio.

Three researchers observed in the five classrooms once a week for five weeks, for a total of 25 observation visits. They used an observation procedure that employed natural language recording of discrete behavioral events associated with selected target students. These students were selected by the teacher to include equal numbers of males and females, and expert and novice programmers. Each observer followed four students per class, and each class was observed by two observers simultaneously, resulting in data on 40 students.

In addition, all students in the five classes (N = 99) were surveyed regarding their experience with computers and their attitudes toward computers; the survey instrument used items from the National Assessment of Educational Progress and from an instrument developed by Collis in 1984 from children's own statements regarding computers. Student work samples, quiz scores, and teacher grades were also collected.

A total of 1399 observation records were gathered. These were coded into 64 categories of behavior according to a detailed lexicon developed during the first year of the project. The lexicon comprised thirteen superordinate categories of behavior related to database managers. Codes also indicated whether or not the observed behavior (a) represented a student difficulty, and (b) was performed under the immediate direction of the teacher or another student.

Behaviors that represented fewer than 5 percent of the observations were collapsed into related categories, and records of students for whom fewer than 20 observations were made were excluded, leaving 1282 records for analysis. The most commonly observed behaviors and the percentage of occasions on which students had difficulty with them were:

Design of record form: planning space and length in form as required	38.1%
Data analysis: interpreting data	26.6%
Data analysis: counting or ordering records	26.3%
Data analysis: selecting records on a single variable or using logical relationships	21.2%
Data entry: proofreading and/or correcting spelling and/or typographical errors; using appropriate and/or consistent spelling; ing unit of measure consistent with variable name or description; choosing correct field; typing in new or different data for each field; saving changes or record	20.2%
Knowledge of screen message: paying attention to status line and following instructions when appropriate	19.8%
Design of record form: naming the unit of analysis; choosing variables/field names consistent with unit of analysis; distinguishing variables from variable names; typing in field names	12.4%
Knowledge of implicit commands: using return key after typing command or information when appropriate	11.8%
Data analysis: choosing variables for analysis	11.3%
File and disk management: making proper selection at menu	10.8%
Knowledge of implicit commands: using program-specific implicit commands; locating cursor; using arrow keys correctly to move cursor; choosing variables/fields to be printed; choosing print location	10.6%
File and disk management: giving password correctly; changing from one file to another; returning to menu if incorrect choice is made; calling up file; naming file	10.1%

During the summer, preliminary analyses of performance grade, use, and attitude data were also undertaken. Significant differences were found between expert and novice students, between girls and boys, and between computer owners and non-owners. In comparison with novices, experts demonstrated greater proficiency with the database manager and received higher grades, but did not use computers more outside of school or have more positive attitudes towards computers. In comparison with boys, girls demonstrated equal proficiency, received higher grades, but used computers less and had less positive attitudes towards computers. In comparison with non-owners, computer owners (40 percent of the sample) demonstrated comparable proficiency, received comparable grades, had comparable attitudes, but used computers more. A final report for this study will be available in January, 1986.

<u>7.3.2.2 Experimental Curriculum</u>. The creation of the experimental curriculum unit was undertaken by a group including a cognitive research psychologist, experienced trainers, and computer specialists from two school systems. Several shared assumptions shaped their activities. First, the group believed that applications software should be introduced to teachers and students as a tool for investigating particular problems embedded in the regular curriculum of a classroom. They saw this approach in contrast to a staff development or teaching strategy focused primarily on the structure or general function of the software. Second, after reviewing available materials, they concluded that they would have to develop both an instructional unit and the teacher training activities needed to explore the first assumption. Third, they concluded that <u>Appleworks</u> was the most appropriate software to use because it provided a flexible, powerful, but relatively simple integrated package including a data manager, a spreadsheet, and a word processor. Finally, they believed that the development of the unit should be a collaborative endeavor involving people with experience in using applications software as a problem-solving tool and in training teachers to use computers in their classrooms.

After polling interested teachers about possible topics, the group chose to develop a social studies unit on the experience of Irish immigrants to Boston. This topic was particularly feasible given easy access to extensive data on the Boston immigrant experience. The group decided to organize the model unit to show students how to use <u>Appleworks</u> to examine realistic data in exploring the socio-economic experience of a particular Irish immigrant family from 1840 to 1860.

Several kinds of materials, both software and traditional, were prepared. Three data sets were created with the <u>Appleworks</u> data manager: passenger lists for two immigrant ships including the name, age, sex, and occupation of each passenger; a list of housing opportunities in the Boston area during the years 1840 and 1850 including cost of rental, location, and number of rooms; and a job list describing representative jobs from the same years including wages, location of job, and experience required. In addition two spreadsheet templates were constructed. One, called "market basket", allows students to calculate a family's food and clothing expenses. The other, a household accounts template, permits calculation of total family income and expenditures for up to a ten-year period. Other materials include maps, transportation information, and information about the Appleworks package.

These materials provide the basis for a simulation in which each student (or a small group of students) "adopts" an immigrant family and then explores the world of the early Boston Irish by following this particular family's experience. In the simulation students decide where the family will live, what jobs its members will take, and what food they will eat. Students record their decisions and experiences using the Appleworks word processor. The computer assists, but does not direct, the decision-making process. The goal of the unit is to engage students in active historical inquiry using the computer as a tool to support the simulation of the immigrant experience.

Members of the Applications Group presented a three-day workshop during the summer to area junior high school teachers interested in considering the unit for their classrooms. The workshop participants were briefly introduced to the purpose of the unit and of the workshop. Then, taking the role of students, they divided themselves into teams and worked through the unit. They selected a family, found housing and jobs using the data manager, determined household budgets using the spreadsheet templates, and maintained a diary of their experiences, using the word processor. The workshop focused primarily on the simulation itself and provided little direct instruction in Appleworks.

Although some teachers at the workshop were bothered by the lack of explicit instruction about the software, most appeared able to master the skills necessary to use Appleworks with ease. More importantly, most participants became deeply engaged in the subject matter of the unit and thought carefully about how it could best be presented to students.

The workshop experience prompted the group to revise the software and the other materials in light of workshop participants' reactions and to prepare a Teacher's Manual describing the limitations of the simulation and suggestions for extending its use with students. The materials and the guide are now available through ETC.

This project suggests a promising model of one way to train teachers and introduce students to the educational uses of applications software. Tool software can be used profitably if objectives -- either for learning about the applications program or learning of particular content -- are clear, and if the features of the software are suited to the curriculum objectives.

Given the clear promise of this curriculum unit and the complex considerations necessary to develop or assess such a unit, the ETC plans to undertake a careful analysis before designing further research in this area. During the fall of 1985, the ETC Co-Directors will form a group to undertake such an analysis, focusing on the use of data managers and perhaps other application software in teaching science. The group will include experienced educators, subject matter specialists, researchers, and specialists in the structure and use of applications programs.

A full despription of the Applications Group's observational research will be available early in 1986; a report on the experimental curriculum appears as an article by Donald M. Morrison and Joseph Walters, "IMMIGRANT: A Social Studies Simulation for AppleWorks," in Charles Thompson and Larry Vaughan (Eds.), 1986, Computers in the Classroom: Experiences Teaching with Flexible Tools, Chelmsford, MA: Northeast Regional Exchange.

7.4 RESEARCH PROJECTS IN NEW TECHNOLOGIES

These projects focus on emerging technologies not yet widely available in schools but rich with educational promise. The Videodisc, Computers and Television, Speech Technology, and Science Teachers' Network Projects have been exploring the potential of these new technologies and attempting to foresee the issues that will require attention as they enter the schoolroom and the curriculum.

7.4.1 Videodisc

Group Members:
- Kim Storey, WGBH, Project Leader
- Ed Atkins, Children's Television Workshop
- Idit Harel, MIT, Research Assistant
- Gregory Hood, Newton South High School
- Karen Janszen, WGBH, Research Assistant
- Linda Koretsky, Interactive Technology Systems
- Harry Lasker, Interactive Technology Systems
- Rob Lippincott, WGBH
- Carol Sauerhaft, Children's Television Workshop

The Videodisc Group is researching the effectiveness of videodiscs for teaching inquiry processes in science, and studying the process of videodisc creation. The group spent the year planning a research videodisc that presents science subject matter to middle school students in a manner that both illustrates and elicits the application of scientific modes of inquiry.

The group has designed an enriching supplementary resource which will serve as an environment for thinking about and solving problems scientifically. The instructional strategy underlying the design of the research videodisc--active engagement in learning through discovery--is consistent with the strengths of the videodisc medium as a teaching tool. Students will interact with the videodisc on two levels: 1) they will explore content by carrying out investigations and making discoveries using the same methods as scientists; and 2) they will regulate their own learning pace by choosing alternative branching patterns and activities.

Since production costs for creating original video software are prohibitively high, the group opted to experiment with an alternative means of videodisc development: using existing video segments and an authoring system. The video included on the research videodisc is derived from two award-winning television science series: NOVA, produced by the WGBH Educational Foundation, and 3-2-1 CONTACT, produced by the Children's Television Workshop. During video selection, the group looked for segments with the following characteristics: visual and/or dramatic appeal; features or variables than can be investigated with a variety of outcomes or are amenable to replay or alterations in speed or direction; comprehensive treatment of a concept or topic; and good fit with current middle school science curricula. The videodisc is being produced using Authority (TM), a software authoring system developed by Interactive Training Systems.

Designing the videodisc provided group members with first-hand experience and information about the opportunities and limitations of creating retrofitted videodiscs. Their efforts demonstrated the trade-off between the time and money saved by the use of existing video and an authoring system and the constraints of developing lessons within established parameters. Design work did not progress from an ideal concept to a concrete realization. Instead, it started with the concrete--visual images from science television programs taped for linear viewing--and progressed as these images were fashioned into interactive lessons within the capabilities of the authoring system. The group found that this process usually resulted in the use of video segments as visual databases for illustrating content.

The group explored this promising use for existing visuals--the creation of visual databases--by designing five lessons which lead students to formulate and test hypotheses through the observation, manipulation, and recording of visual data. The lessons are on diverse topics: the role of light in plant growth; forms of camouflage and mimicry among animals; alterations in time and the nature of everyday events; the study of phenomena that cannot be readily observed; and the relationship between temperature and color. Each lesson is built around a central question and contains activities that allow students to investigate the question using evidence in video segments.

The plant growth lesson, for example, poses the question, "How do plants respond to light?" The activities include an introduction to the role of light in plant growth, three experiments for investigating the effects of light on plant growth, and a prediction quiz. The lesson is designed to give students practice in identifying variables, conducting controlled experiments, making and recording observations, and forming predictions. Modes of interaction include altering variables, replaying video to observe events more than once, and recording data on a chart.

The group will test the videodisc in both laboratory and classroom settings during the winter and spring of 1986. The study will focus on patterns of use by students and the kinds of inquiries students make in response to the videodisc. More information about the past year's work can be found in ETC Technical Report No. 85-18, The ETC Science Videodisc Project: A Report of Research in Progress, July 1985.

7.4.2 Computers and Television

Group Members:
Kim Storey, WGBH, Project Leader
Cornelia Carey, WGBH
Marja Brandon Drevitch, Harvard Graduate School of Education
Candace Julyan, ETC, Senior Researcher
Catherine Wolinsky, Buckingham, Browne and Nichols School

The Computers and Television Project conducted research on new multimedia educational packages that combine video, software, and print materials. Educational television and microcomputers offer different but complementary pedagogical strengths. As a medium which displays real-life, moving visual images, television brings the "real" world directly to the learner and can portray much of the color, excitement, and immediacy of actual experiences. Microcomputers, on the other hand, have the ability to provide interactive opportunities and to store and retrieve data. As most schools now have access to both computers and television, it is important to explore how computers and television can be effectively combined for instructional use.

Two multimedia educational packages introduced into the educational market in 1984-85, Bank Street College's The Voyage of the Mimi and the Agency for Instructional Technology's (AIT) Solutions Unlimited, provided the opportunity to explore the design and implementation of these types of packages.

The Voyage of the Mimi, developed for teaching scientific and mathematical concepts in grades four through six, consists of a television series with accompanying software and print materials. Each of the 13 television programs includes a 15-minute dramatic episode based upon whale research which takes place on board the Mimi, a ship chartered for a summer expedition, and a 15-minute "expedition" which features one of the cast members out-of-character visiting scientists involved in research projects. The software and print materials are incorporated into learning modules which encourage application and further exploration of the program concepts.

Solutions Unlimited, developed to teach problem-solving skills in grades six through eight, consists of video segments selected from an existing AIT television program and new software and print materials created specifically for the package. Eight units were designed to increase students' abilities to solve problems encountered in everyday life. Each of the units includes a 7-10 minute video program which, through dramatization, sets up a problem, demonstrates problem-solving skills, and provides a stimulus for engaging in the computer activity. The computer materials are designed to guide students through problem-solving situations.

The goal of examining these two educational packages was to understand both the designers' goals and teachers' experiences using the packages in their classrooms. Specifically, the research examined the assumptions and principles that guided the designers in their development of the packages, the strategies that teachers reported using in their implementation, and the teaching and learning opportunities that teachers reported finding in the design and implementation of the packages. In-depth interviews were conducted with the package designers and with teachers who used the packages.

The interviews with designers indicated that, for both packages, designers were interested in creating a new type of curricular material which would use the immediacy of television to enhance educational software. Each group viewed the television component as providing a vital stimulus for the package but the emphasis given to this aspect of the package differed. Although both groups saw the television component as the lead-in from which the other material would develop, Bank Street considered it the centerpiece of the package, while AIT was interested in developing computer materials which would have video support.

Interviews with the designers further revealed that this difference in emphasis affected the integration of the components within the package, the evaluation procedures, the utilization concerns, and the designer's reflections about continuing to produce this type of curricular material.

For example, the designers of the two packages had different views of how the materials should fit into the regular teaching schedule. Bank Street's modules provided teachers with an abundance of material that required a substantial number of classroom periods. Although Mimi's dramatic adventure episodes followed in sequential order, the related documentaries could be viewed independently, the topical units were only loosely joined to one another, and the designers did not envision that all components would or should be used within a set number of class periods. The Mimi designers emphasized the development of a new curriculum unit that went beyond current teaching practices, rather than a unit that could be easily integrated in the classroom.

In contrast, the AIT package was carefully designed so that each multimedia unit could fit into the confines of one or two class periods and be integrated into a classroom curriculum. AIT's goal was to combine the television and computer technologies in the most accessible way possible. To achieve this goal, AIT decided to design the software so that students could use it without ever seeing the video segment. Anticipating problems of accessibility to both television and computers, each computer program contains a review of the important aspects of the video. Although AIT designers hoped that the TV component would be used, they did not feel that it was realistic to assume that it would be.

Thus, although both packages offer teachers a new approach to teaching involving a combination of technologies, the underlying assumptions of the two groups differed. Bank Street's primary interest was in expanding the ways teachers viewed the content area, while AIT was primarily interested in working within the existing classroom conditions to develop a package that could be widely used.

In order to investigate teachers' experiences in using the package, interviews were conducted with 21 teachers using The Voyage of the Mimi in

Massachusetts and 11 teachers using Solutions Unlimited in Wisconsin. These two states, according to the packages' distributors, had a relatively large number of schools that had purchased the package; no state could be found that had a wide distribution of both packages.

Most of the teachers interviewed were homeroom teachers and had been teaching for more than ten years. The majority of Mimi teachers taught the fifth grade; the majority of Solutions teachers taught the sixth grade. A substantial number of the Mimi teachers taught science; the Solutions teachers taught a range of subject areas. Most teachers had access to television and video recorders as well as to computers; however, more Solutions teachers than Mimi teachers had regularly used television in the classroom. All teachers were either experienced or moderately experienced computer users.

Teacher reports confirmed the designers' predictions that the packages would appeal strongly to students and engage their interest more than other curricula. Many teachers found high levels of student participation and eagerness. Although most teachers believed that the package made their teaching more fun, they did not report that it made their job easier or more efficient.

The teachers were most enthusiastic about the particular component which designers had made the centerpiece of the package -- for Mimi, the video; for Solutions, the computer software. This occurred despite the fact that Solutions teachers had more experience with classroom television than Mimi teachers.

AIT's attention to details of logistics appeared to pay off. Teachers using Solutions were pleased with the review of the video in the software material and with the ability to copy as many disks as they needed. Most Solutions teachers commented that the package fit well into the framework of their classes. Both Solutions and Mimi teachers reported receiving effective support from school staff and inservice workshops. Logistical difficulties, however, were the major complaints from teachers using Mimi. Many teachers commented on the inconvenience of not being able to boot up more than one machine with the software program. In addition, some teachers reported that the sheer volume of material provided in the Mimi package was initially intimidating. Yet, in spite of these problems, Mimi teachers all praised the package, particularly the television drama.

Although teachers responded favorably to AIT's logistical support, the interviews revealed that AIT's logistical strategy of designing the computer material to be used without the television was not warranted. Furthermore, AIT's prediction that the video would not be critical to the appeal and teaching value of the package was the largest discrepancy between the views of the AIT designers and the teachers using Solutions. Unlike the designers, the teachers believed that the video was not only important but vital to the package for both motivation and learning.

Although the majority of teachers, when asked directly, noted "no change" in how students related to them, some believed that using the package changed their role from lecturer to facilitator, while others reported a closer, more collaborative relationship between teacher and student.

The designers did not provide for assessments of learning within the package materials and most teachers did not directly assess learning. Many teachers felt that tests were not appropriate for this type of material and turned to class discussions for a measure of students' understanding. The teachers discussed the learning benefits of the packages in two ways: first, teachers believed that multimedia packages are an important shift in curriculum development and noted that students are eager to apply themselves in this new learning situation; second, teachers reported that the different package modalities were important to student learning, especially for students who normally had difficulty with written classroom work. Teachers, for the first time in some cases, found that all of their students, including those who had been slow to learn or reluctant to participate, were able to join in class activities.

Further detail on this study may be found in ETC Technical Report No. 85-20, The integrated design and use of computers and television in education, July 1985.

7.4.3 Speech Technology

Group Members:

Charles L. Thompson, Education Development Center, Project Leader
Ilene Kantrov, Education Development Center
Beth Wilson, Education Development Center
Philip Zodhiates, Education Development Center

Speech synthesizers--devices that can produce spoken language from digital code--have become familiar adjuncts to microcomputers and have been built into some computers intended for educational use. Speech recognizers--devices that can distinguish among spoken words--are a more recent phenomenon. The first speech recognizers were either too expensive or too unreliable to support widespread educational use, but lately, the price-performance picture has changed. Dragon Systems, a Newton, Massachusetts-based speech technology research and development firm, has introduced low-cost speech recognition software that places this technology within the reach of developers of educational software.

The Speech Technology Project conducted a study of the educational potential of speech recognition technology in early reading instruction. The study used the Dragon Systems Mark II Isolated Word Speech Recognizer to investigate two principal questions:

-- Does an inexpensive, microcomputer-based speech recognizer perform reliably enough on young children's speech to permit application to reading instruction?
-- What are the main human factors attending such use?

The Mark II is mainly in software form. It is speaker-dependent, requiring each user to train the recognizer by giving a few samples of his or her pronunciation of each word to be recognized. The Mark II analyzes these samples and constructs templates against which to compare subsequent utterances. In some applications speaker dependence is considered a disadvantage, but preliminary research has suggested that speaker dependence might in fact be an asset with the highly variable pronunciation of young children's speech.

Because beginning readers cannot be expected to rely on text display as the sole or even primary mode of computer output, the system makes heavy use of graphics, music, and speech output. Prototype versions of software under development by the Education Development Center (EDC) were used in the study to provide the reading tasks and the graphics and computer-generated music used to prompt and reward reading performance. This study also experimented with two different methods of producing high quality speech output from digital code.

Field testing of the prototype speech recognition system was carried out in four phases between June 1984 and August 1985 in two elementary schools in the Boston area. The participants -- a total of forty-eight kindergarten and first-grade students -- were nominated by their teachers to represent a range of ability levels.

Students were tested in pairs outside their regular classrooms. Seated together in front of an Apple IIe microcomputer equipped with an inexpensive commercially available microphone, they were first pretested on the ten words to be learned in the prototype program. Next, students had to "train" the system to recognize their voices by giving four samples of their pronunciation of each of the words to be recognized. These templates were then used during the latter portions of the experiment.

The test of the speech recognition system continued with the reading of a story. The computer produced speech output for the text as it appeared on the screen, accompanied by graphic illustrations. Target words were shown in large letters, and the speech output instructed the child to read the words. If the child supplied the correct word, he or she was rewarded with a graphic display and a musical phrase. If the child made a mistake, the computer provided assistance.

The final component of the prototype software was a series of games. One game, for example, was composed of a 3x3 matrix containing eight words and an empty center square. By reading the word from a box that bordered the empty square children were able to move that word into the empty box. The objective was to move the word which began in the lower left-hand corner to the upper right-hand corner.

At the conclusion of the session, students were posttested to determine how many words they had learned. They were also asked about their experience with the system. In addition, data were collected on three types of recognizer error: rejection (a valid utterance of a trained vocabulary word is not recognized as such), substitution (one word is recognized for another), and insertion (background or extraneous speaker noise is recognized as a valid utterance).

Data collection also focused on human factors associated with the educational use of speech technology: prompting, microphone handling, and response to recognizer error. Observations noted whether children were able to comprehend and respond to the synthesized speech output and whether they were able to use the microphone appropriately and modulate their voices effectively enough to train the machine. Videotapes of all testing sessions and interviews provided simple documentation and are now available for possible future use in a tape designed to introduce speech recognition applications and issues to educators.

Microphone quality and handling posed problems. When a hand-held microphone was used, many children had a tendency to hold the microphone too close or too far from their mouths or to wave it around, making it difficult for the recognizer to construct usable templates of their speech or to match subsequent utterances once the templates were stored. Use of a microphone stand reduced these problems, and an adjustment of the amplification improved performance even more, especially during training. The use of headset microphones required the least conscious attention from participants. A problem with the headset microphones, however, was that they were designed for adult heads and adjusted poorly to fit young children.

Not all recognizer errors were related to microphone quality and handling. Some were due to extraneous verbalizations by participants or their partners. This was particularly true in the games; because many children needed assistance with the rules of the games and with strategy, as well as with reading the words, there was a great deal more conversation back and forth between the experimenter and the children and between the children and their partners. The recognizer at times accepted this background conversation as a valid utterance.

Still others recognizer errors may have been due to variability among the utterances of particular children as they tried to accommodate to the system. For example, if children were initially shy and spoke softly to the computer, the recognizer may have formed templates from only the portions of their utterances that were loud enough to hear. Later, as students became more confident and talked more loudly, the recognizer may have produced errors because their utterances did not match well against the templates formed earlier.

Another human factor of interest was children's ability to understand the speech output needed to deliver prompts, directions, and rewards. In fact, the speech output proved to work very well. Even in the training segment, when single words were initially presented without context, most children had no difficulty understanding the words. In certain places it was necessary to modify or add speech output prompts to guide students toward patterns of use that would make the recognizer work more reliably or would make the student's experience more satisfying and rewarding.

The study also looked at the level of adult support and supervision required to keep students moving along in the program activities. With initially sparse prompts and directions, students tended to rely on the experimenter to tell them when and how to respond. By the final phase of testing the number of prompts, directions, and demonstrations had increased in all segments, lessening the need for adult supervision. Even then, however, adult supervision was clearly required, not only to make sure children understood what they were expected to do, but also to provide encouragement for them to try again when the recognizer rejected their correct responses or did not respond to them.

Finally, regarding the instructional potential of speech technology for beginning reading, the data indicate that such potential does exist: forty-four out of the forty-eight children who participated learned to read new words. Findings suggest that high and average ability readers tend to benefit more from this particular educational application of speech recognition than low ability readers.

This exploratory study suggests that speech recognition technology holds potential for such educational applications as beginning reading instruction. Perhaps the most significant contribution is the identification of human factors as cruc' to the successful application of speech recognition technology in education.

No further exploration of these issues is currently contemplated by the Center. A fuller description of this research is contained in ETC Technical Report No. 85-24, Speech Recognition Technology: An Application to Beginning Reading Instruction, October, 1985.

7.4.4 Science Teachers' Network

Group Members:

Eileen McSwiney, Education Collaborative for Greater Boston, Project Leader
Bram Arnold, Lincoln-Sudbury Regional High School
William Barnes, Concord Public Schools
Frank Finigan, Winchester Public Schools
Chris Hancock, ETC, Research Assistant
Candace Julyan, Harvard Graduate School of Education
Mary Maxwell Katz, ETC
Richard McKnight, Waltham Public Schools
David Parfitt, Brookline Public Schools
Julie Rabschnuk, Ware Public Schools
Stuart Rist, Newton Public Schools
Judah Schwartz, ETC
Martha Stone Wiske, ETC

Professional isola :s a key problem for most science teachers--isolation b an the ongoing process of science and from people with whom they m . discuss the teaching of science. Especially in rural areas, science teac are unlikely to have nearby colleagues with similar interests. In-service courses and professional conferences offer only a partial solution. Difficulties of traveling, compounded by the teachers' busy and often inflexible schedule, put these opportunities for professional growth out of the practical reach of many teachers.

Computer conferencing appears to be a promising remedy for this problem. It seizes the logistical bull by both horns: participants need not meet in one place, nor participate at the same time. Using any terminal or microcomputer equipped with a modem, a participant can connect with the "host" computer on which the conference resides. He or she can exchange messages with other participants via the host computer. Messages can be sent privately to a specific recipient, sent to a small group with an identified interest, or publicly posted for all conference participants to read.

During the past decade, computer conferencing has served as a medium for substantive discussion, supporting professional communities among geographically dispersed groups. Most examples of this come from the worlds of buisness and technology, partly because of the expense of the computers on which conferences typically operate. A handful of institutions, primarily universities, have pioneered the use of computer conferencing for educators. Participants have noted two major problems: a lack of access to equipment and a feeling of intimidation by computers. A system originally envisioned as a mechanism for substantive discussion among teachers has frequently deteriorated to a channel for trivial exchanges among students.

The Science Teachers' Network at ETC is a project to test the potential of computer conferencing as an effective means of stimulating intellectual growth and professional collegiality for high school science teachers. The process of introducing and supporting network participants is being carefully developed in light of prior research and experience with the human factors affecting computer conferences. The software for the network has been designed at ETC to enable easy, flexible access to the conference facilities, specifically tailored to the needs of educators. This conferencing program, called <u>Common Ground</u>, is also carefully structured to make intuitive sense to an inexperienced user. It is organized around a spatial metaphor that likens the entire conferencing system to a building with multiple rooms. Some rooms are private offices where participants can receive their personal mail; others are publicly accessible rooms where participants can convene forums to discuss particular topics, such as advanced placement physics, Halley's comet, or curriculum and software exchanges. The system runs on a microcomputer equipped with a hard disk, making it easily usable by other networks of school-based participants.

An advisory board made up of secondary science teachers from the Boston area was introduced to the ETC conferencing program in Spring, 1985. They were given modems with communication software and a short training session in the use of <u>Common Ground</u>. These teachers, along with several other ETC associates interested in science education, used the conference on a pilot basis for several months.

Several themes emerged from their experiences. First, access to the necessary hardware, software, and phone lines was a significant hurdle for many school people. Second, even after these logistical barriers were surmounted, several participants needed assistance to overcome their hesitation about using the technology. Third, users frequently wanted to trap and print messages from the network, making this a desirable feature of the participants' own communication software. Fourth, although a few modifications were indicated, Common Ground proved to be easy to learn and effective for this project's purposes. Finally, none of the potential forums proposed at the introductory meeting for pilot users ever materialized and few other suggestions were made by the teachers on the network. Thus, very careful attention to the recruitment of participants and the cultivation of interesting ideas seems necessary (though not sufficient) if a network is to be a vehicle for vibrant, substantive discussion.

In light of these experiences members of the project met during the summer and fall of 1985 to design an action research project that will begin in late fall 1985. The project will be shaped by both research and service objectives. The service objective is to establish a network that successfully reduces professional isolation of participating secondary science teachers. The overall research questions to be investigated are: (1) Does the ETC Science Teachers' Network alleviate the isolation of participating science teachers from developments in both science and the teaching of science? (2) If so, how much? (3) In what ways? Project members are balancing the requirements of these objectives as they develop criteria and methods for selecting participants, designing network activities, and studying the process and results of operating the network. ETC is also recruiting staff members to help design and carry out this project during the coming year.

A fuller discussion of the Science Teachers' Network is contained in ETC's Computer Conferencing for Science Teachers: A Proposal for Research, August, 1985. The first technical report on this work will be available in September, 1986.

7.5 RESEARCH PROJECTS: CONCLUSION

With some exceptions in the New Technologies area, ETC research groups have concerned themselves with four elements: (1) theoretical and/or procedural knowledge within subject matter domains, (2) student difficulties in mastering subject matter (naive theories, confusions, misconceptions, recurrent lapses), (3) teaching strategies (interventions based on a more or less explicit theory of the mechanisms through which students' theoretical grasp or procedural facility advance), and (4) the special contribution which information technology can make in helping teachers advance students' knowledge.

The allocation of attention among the elements has been far from uniform across groups, and the paths among the elements have been complicated and meandering--not linear--within each group. A fairly common pattern has been alternation among, or even simultaneous consideration of the subject matter itself, children's difficulties with it, and some technology-based treatment of it--examination of each serving to clarify the others as well. In the coming year, each group will be encouraged to complete the picture: to identify those elements which have been left relatively inexplicit, to develop their understanding of these elements, and to concentrate on articulating the relationships among the elements in a rigorously theoretical way. Spelling out the pedagogical strategies that underlie emerging teaching experiments will be a special focus.

8.0 TRAINING AND DISSEMINATION

8.1 Overview

Training and dissemination activities for Fiscal Year 1985 (FY85) continue to reflect the basic assumptions that have shaped these activities from the beginning. First, training and dissemination activities provide opportunities to establish dialogue with the various audiences who shape as well as learn from ETC work. Second, dissemination is best achieved through a predominantly wholesale approach, rather than through attempts to reach end-users directly.

8.2 Dissemination

8.2.1 Newsletter

ETC, in conjunction with the Educational Testing Service (ETS), produced two issues of Targets during FY85. Targets, which reports ETC activities, plans, and related information, is sent to approximately 8,000 people in this country and abroad. Publication of the newsletter away from the ETC central office proved difficult, however, even with the coordinated efforts of both the Center and ETS, which handled production and distribution. As a result, beginning with the Fall 1985 issue, Targets will be produced soley by ETC under the direction of the Administrative Assistant.

ETCetera, a newsletter for members of the ETC consortium, was published once during FY85. Now, with the production of Targets based solely at ETC, the purposes previously served by the two separate newsletters will be fulfilled by Targets alone.

8.2.2 Technical Reports and Other ETC Reports

Each ETC research project is required to prepare at least one technical report each year, as a deliverable under the Center's contract with NIE. These technical reports are available to individuals or groups who request them from ETC. With the goal of wide dissemination of its findings, ETC had distributed these documents free of charge. Recently, however, the U.S. Department of Education Publications and Audiovisual Advisory Council (PAVAC) ruled that the duplication and distribution costs of all reports except those required to meet NIE contract obligations must be covered with non-NIE funds. As a result, small fees have been initiated to cover the costs of meeting other requests for ETC documents.

In addition to technical reports from each ETC research project, several other kinds of reports were produced during FY85. These include conference reports and a summary of the past year's activities. A report on the proceedings of a conference funded by the Ford Foundation on computers and urban schools was prepared from the conference funds. This report was distributed to a small number of individuals and organizations who serve as nodes in the networks of audiences to which the particular conference is of interest. Additional copies were made available at cost to parties who requested them. A list of reports published by ETC was included in Targets along with information regarding cost and ordering procedure.

Attempts continue to make ETC reports available through ERIC, but success has been limited. To date, only one of the several documents sent to ERIC has been made available to ERIC users.

Finally, as the Center's research progresses from pilot work to more formal studies, reports suitable for distribution through regular professional channels are being produced. A number of ETC projects -- Computers and Television, Word Problems, Programming, for example -- have successfully submitted papers to juried professional journals and conferences. Reports of these papers and presentation were sent to NIE.

8.2.3 Videotape on the Uses of the Computer in Science Education

As part of its dissemination activities in connection with the Educational Technology Center, Education Development Center has produced a 27-minute videotape on the uses of the computer in science education at the secondary level. The videotape is intended primarily for use in in-service training of high school science teachers; secondary target audiences include educational officials at the local, state, and federal levels.

The videotape is organized around a theoretical framework similar to the one guiding ETC's research program. This conceptual scheme distinguishes among five different uses of the computer: as a medium for tutorials, for drill and practice, and for simulations and games; and as a tool for the measurement and analysis of data, and for programming. The videotape provides illustrations of each of these educational applications, and discusses their appropriateness for teaching different kinds of scientific knowledge -- theoretical, procedural, factual.

The tape also includes interviews with technology experts, software developers, and teachers: Adeline Neiman of HRM Software, Robert Tinker of Technical Education Research Centers, Judah Schwartz, professor at MIT and the Harvard Graduate School of Education and Co-Director of ETC, and several science teachers from high schools in the Boston area.

8.2.4 Other Summaries of Work in Progress

During the year ETC prepared research summaries for dissemination in Edline, the NIE-sponsored electronic newsletter disseminated through the Source.

8.3 Training

ETC sponosors or co-sponsors a variety of events designed to communicate the results of its work or to explore topics related to the Center's efforts. For the most part, these activities are funded from sources other than NIE. Travel costs and paper commissions are sometimes defrayed with NIE funds. Training activities for FY85 were similar to those of the previous year except that beginning in the fall of 1985 the Center discontinued the off-site institutes. These are more appropriately convened by other organizations in our region, such as the newly funded New England Laboratory. ETC will, however, assist in these institutes when requested to do so.

8.3.1 Off-site Institutes

During the spring of 1985, the center held the last of the off-site events, "Institutes On Computing and Schools" in Maine, New Hampshire, and Western Massachusetts. The Institutes were graduate level non-credit programs for educators concerned about the quality and effects of computer-based education. The aim, in a one-day program, was to provide participants with a series of experiences which would help them think about these issues, and thereby make more effective, confident decisions about this burgeoning field.

The Institute's curriculum focused on three aspects of the impact of computers in schools.

(1) Subject Application. This section looked at applicable software and discussed the promise and problems of such software in math/science and language arts instruction.

(2) Staff Development. This portion of the Institute familiarized participants with the range of staff and organizational issues associated with the use of computers in schools.

(3) Decision Making. The third area emphasized the integral link between application and effect, as examined in the previous sessions, and the importance of that interrelationship to effective decision making.

To encourage participation, and in line with ETC's collaborative approach, the institutes were sponsored jointly by the Center's individual state departments of education. Registration fees were kept below $50 to make it easy for individuals to enroll on their own. Enrollment was limited to 50.

8.3.2 Conferences and Seminars

ETC sponsored or co-sponsored three conferences this year. The first, funded and co-sponsored by the Ford Foundation was entitled "Computers, Equity, and Urban Schools". The two-day event brought together a small group of educators, scholars, and community advocates to examine vigorously several questions from educational, economic, political, and philosphical prespectives. Among the questions were: How should urban schools respond to the technical change that is transforming the workplace? How can they best use the computer to increase educational opportunities for urban students? How can they find material resources and develop human resources to match those of their surburban counterparts?

Proceedings from this conference were summarized in a publication Computers, Equity, and Urban Schools which has been distributed, with funds from Ford, to instituions and organizations concerned with urban education. Copies are also available for purchase directly from ETC.

In January of 1985, ETC sponsored "Microworlds and Expert Systems: Is It Either or Can It Be Both?" This conference was attended by nearly 150 elementary and secondary teachers and other educators, as well as researchers and software developers from New England, other states, and Canada.

"Microworlds" was devoted to an exploration of two questions: what is presently possible in the building of intelligent tutoring programs for education; and what are the likely effects on children, teachers, schools, and society of any particular allocation of authority and responsibility among students, teachers, and computers? Speakers from the research community represented differing positions on these questions and used the conference to illustrate their views with software that embodied their approach to the general questions.

In June 1985 ETC sponsored a one-day conference entitled, "Teacher As Learner: The Impact of Technology." Over 150 educators gathered to consider how computers touch the intellectual lives of teachers and affect the way they perform their role in schools. The keynote address by Patricia Albjerg Graham, Dean of the Harvard Graduate School of Education, emphasized the importance of teachers in any educational innovation and called for efforts to support their creativity and resourcefulness.

Two panel presentations then developed the conference's main themes. The first focused on teachers as learners--how they become interested in learning about technological innovations and how the use of new technologies enlarges their understanding of their subject matter, reshapes the organization of their classrooms, and stimulates discussion about the purpose, content, and process of education. The second panel explored the ways that school systems can provide the time and resources needed to support teachers'learning and can benefit from teachers' knowledge of their craft to discover the best educational uses of new technologies.

The bi-weekly seminar series for FY85 provided another forum to convey, enrich, and extend the findings from ETC research and analysis in educational technology. Fourteen presentations were made by researchers, writers, school practitioners, and others during this year's series. A detailed list of the seminars is attached.

8.3.3 Courses

Both ETC Co-Directors are members of the faculty at the Harvard graduate School of Education, where they offer courses on topics related to the Center's work. During the spring of 1985 Judah Schwartz offered a laboratory on "Educational Software Design." Greg Jackson served as a faculty advisor for a group designing a videodisc database.

8.3.4 Presentations

The ETC Co-Directors and other central staff made presentations at various major conferences throughout the year. Among those conference attended by a member of the ETC staff were: (1) annual meeting of "The Council of Great City Schools"; (2) "Meadow Brook Research Symposium on Collaborative Action Research," sponsored by Oakland University; (3) National Rural Education Forum; (4) National Task Force on Educational Technology; (5) Conference for Science Teachers of Ontario; (6) AERA national convention; (7) National Council of Teachers of Mathamatics; (8) Bank Street Conference on Computers in Education, and; (9) "Computer Conferencing and Electronic Messaging" at the University of Guelph.

FY85 SEMINAR SCHEDULE

DATE	PRESENTER	TITLE
October 2, 1984	HERBERT GINSBURG UNIVERSITY OF ROCHESTER	CHILDREN'S MATHEMATICAL THINKING: A VIDEOTAPE WORKSHOP FOR EDUCATORS
October 16, 1984	ANDREA diSESSA MASSACHUSETTS INSTITUTE OF TECHNOLOGY	DESIGN CONSIDERATIONS FOR COMPUTER LANGUAGES
October 30, 1984	COLETTE DAIUTE HARVARD UNIVERSITY	USING COMPUTERS TO DEVELOP WRITING IN THE ELEMENTARY GRADES
November 6, 1984	SHERRY TURKLE MASSACHUSETTS INSTITUTE OF TECHNOLOGY	THE SECOND SELF: COMPUTERS AND THE HUMAN SPIRIT
NOVEMBER 13, 1984	BRAM ARNOLD PAUL LYONS DAVID OLNEY	COMPUTER APLLICATIONS FOR THE HIGH SCHOOL CONTENT AREAS: MATH AND SCIENCE
NOVEMBER 20, 1984	JANET BAKER DRAGON SYSTEMC, INC.	TALKING TO YOUR COMPUTER: PROSPECTS FOR SPEECH RECOGNITION IN EDUCATION
NOVEMBER 27, 1984	SHELDON H. WHITE HARVARD UNIVERSITY	HOW CHILDREN FILE USEFUL INFORMATION
JANUARY 22, 1985	DAVID PERKINS HARVARD UNIVERSITY	THE FINGERTIP EFFECT: HOW INFORMATION PROCESSING TECHNOLOGY SHAPES THINKING
FEBRUARY 12, 1985	KAREN SHEINGOLD BANK STREET COLLEGE OF EDUCATION	CHILDREN & COMPUTERS: WHAT RESEARCH SHOWS
FEBRUARY 26, 1985	GEORGE BRACKETT BRACKETT ASSOCIATES	THE WORLD OF SOFTWARE THROUGH THE EYES OF AN INDEPENDENT DEVELOPER
MARCH 19, 1985	WALTER KOETKE SCHOLASTIC	THE WORLD OF SOFTWARE THROUGH THE EYES OF A PUBLISHER
APRIL 16, 1985	PAUL EVANS IBM	THE WORLD OF SOFTWARE THROUGH THE EYES OF A HARDWARE MANUFACTURER

APRIL 30, 1985	SAM GIBBON BANK STREET COLLEGE OF EDUCATION	TEACHING AND LEARNING SCIENCE USING TV AND ASSOCIATED MATERIALS
SEPTEMBER 24, 1985	HENRY OLDS LEARNINGS, INC.	IMAGINATIVE SOFT- WARE AS NEW TOOLS FOR NEW CURRICULUM