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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 11 research projects. These projects dealt with the following topics: (1) weight and density; (2) heat and temperature; (3) scientific theory and methods; (4) hypothesis testing in genetics; (5) geometry; (6) word problems; (7) fractions; (8) programming; (9) applications of computers; (10) videodisc technology; and (11) science teachers' networks. (TW)

EDUCATIONAL TECHNOLOGY CENTER

Third Year Report

The Educational Technology Center is operated
by a consortium comprising

Harvard Graduate School of Education
Educational Collaborative for Greater Boston
Education Development Center
Children's Television Workshop
Educational Testing Service
Interactive Training Systems
Rhode Island/Brown Technology Consortium
Cambridge Public Schools
Newton Public Schools
Ware Public Schools
Watertown Public Schools
WGBH Educational Foundation

November 1986

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INTRODUCTION

The Educational Technology Center (ETC) conducts research on ways of using computers and other information technologies to teach science, mathematics, and computing more effectively at the elementary and secondary levels. Funded by the US Department of Education in 1983, the Center completed its third year of research and associated activities in September of 1986. This report describes the Center and summarizes the third year's work.

ETC is a consortium based at the Harvard Graduate School of Education. Participating with HGSE in the third year's work were 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; and the ETC Rhode Island Satellite, led by researchers at Brown University.

The composition of ETC reflects our interpretation of and approach to the mission we were chartered to pursue. As a research center devoted to formulating and testing fundamental ideas about the use of information technology in science, mathematics, and computer education, it is appropriate that we are based at a major research university and that several of our partners specialize in R&D and in the application of technology in education. But as the central place of school-based organizations in the consortium indicates, we have been committed from the outset to producing ideas that are as useful for the improvement of instruction as they are theoretically powerful.

In choosing the foci for our research, we began by convening groups of subject matter specialists, cognitive psychologists and other educational researchers, teachers, and experts in technology. The groups were charged with the task of identifying topics that were at once intellectually central to the relevant disciplines, hard to learn and hard to teach, and potentially amenable to treatment with the aid of information technology.

The notion was that certain ideas and skills were perennial stumbling blocks for large numbers of students as well as sources of frustration for their teachers. These are the kinds of topics about which many students would later say, "I was all right in mathematics until I got to _________," or "I decided I was no good at science because I just couldn't understand _________." And teachers would say, "For years I've been trying to teach _________, but every year only a few kids really get it."

We think of these key ideas and skills as obstacles that block many students' progress in scientific and quantitative courses of study. Some students drop out of or turn away from these courses; some get through by using recipes, rituals, and rote memorization; only a few achieve real understanding and facility. In effect, then, these intellectual obstacles set limits on the achievement of scientific and quantitative literacy in our society.

Paradoxically, this very fact means that they also represent good targets for research -- strategic research opportunities as well as persistent educational difficulties. Strategic research opportunities because they present persistent difficulties for students and teachers. To suggest the dual nature of these topics, we coined the term "targets of difficulty." By finding ways to break through these difficulties, we hope to contribute to a broad advance in scientific and quantitative literacy nationwide.

Our large collaborative groups of teachers and academics did identify targets of difficulty that appeared central to the disciplines and challenging to teach and learn, and smaller research groups representing all of the same perspectives and backgrounds were assembled. For three years now, these groups have been carrying out close analysis of the subject matter itself; examining students' confusions, misunderstandings, and progress in grasping the subject matter; developing and testing teaching interventions to improve their grasp; and devising ways to use technology to support teaching and learning.

As the project-by-project summaries in the next three sections of this report reflect, research groups have placed differing emphases upon these four interrelated foci of our work (subject matter, students' thinking and learning, teaching, and technology). In general, however, our research has evolved from an initial emphasis on clarifying the essence of the difficult subject matter itself and on understanding children's confusions about it, toward development of technology-based or technology-supported teaching interventions.

Our investigation of students' thinking and learning stands within the constructivist tradition of cognitive psychology, a tradition that views learning as a process of building upon or reconstructing ideas already in place. Thus, to achieve genuine understanding in science, students must undergo conceptual revolutions analogous to those which characterize the history of science. The development of understanding as well as facility in mathematics and computing requires similar construction and reconstruction.

The experimental teaching units developed by different projects vary in significant ways, but beneath the variation, most share an image of teaching not as telling, but as the creation and management of environments that promote such construction and reconstruction of knowledge -- an approach which we refer to as guided exploration. Guided exploration is a teaching style that blends ideas and techniques from the traditions of direct instruction and inquiry-based teaching, balancing structure and openness, straightforward instruction and relatively autonomous but "scaffolded" inquiry by students.

The structure is provided in several ways, including the posing of problems; explicit instruction in the methods and/or mental models to be employed in addressing problems; providing software tools with a flexible but still limited set of capabilities for representing the problem, manipulating the representations, and/or taking experimental data related to the problem; building stepwise instructions into curricular materials;

giving assistance as requested during the period of problem solving, exploration, or experimentation, frequently in the form of Socratic questioning to help students resolve puzzles or answer questions for themselves; orchestrating follow-up discussions to help students articulate and interpret what can be learned from their experience in addressing the problem; and a number of other means.

Within this framework, students' exploration or inquiry takes various forms. In science, they perform experiments and work with computer-based models of the phenomena they are investigating. In mathematics, they use a software tool to carry out geometric constructions easily and rapidly, thus developing an inductive understanding of important geometric relationships; in solving word problems, they use a software tool that permits the formulation and examination of problem situations in several different systems of representation simultaneously (iconic, graphic, tabular, symbolic); in understanding fractions, they perform a diverse set of exercises with number line representations. In computing, students attack traditional programming problems with the use of new "mindware" -- mental models, heuristics, self-monitoring techniques -- learned in special "meta-lessons."

In a guided exploration approach, both the teacher and the technology play very different roles from the roles they play in the context of conventional CAI applications. The teacher's role is to provide the kind of structure, "scaffolding," and support described above. The computer is generally employed as a tool for the student -- a tool for taking and displaying data on physical and biological phenomena; constructing and/or manipulating models of such phenomena; performing geometric constructions, taking data on the resulting figures, and testing conjectures about the generality of observed relationships; representing and solving word problems; and writing, testing, and debugging programs. It is not used as a tutor, drillmaster, test administrator, or instructional manager.

As the foregoing suggests, our technology-supported guided exploration approach to instruction differs substantially from the common instructional approach in many classrooms, and the introduction of computers is by itself far from the greatest of the differences between our approach and current practice. For many teachers, adopting and implementing a guided exploration approach involves significant changes in assumptions about the nature of knowledge and learning (constructed rather than given), the role of the teacher (stimulating and guiding inquiry rather than telling), the role of the student (active inquirer rather than passive recipient of knowledge), as well as about the role of technology (tool for the student rather than tutor and drillmaster).

Such changes in beliefs, to say nothing of the corresponding changes in behavior, do not come easily. If we hope to affect practice, we therefore face a major dissemination and implementation challenge. In addressing this challenge, our first step is to find answers to the question, "What does it take to get a technology-supported guided exploration approach into practice in regular classrooms, and what does the implementation process look like?"

Late in the third year of our operation, we laid the groundwork for a set of five "laboratory sites" designed to answer these questions. During the summer of 1986, we negotiated to set up lab sites in the four ETC consortium school districts plus Boston. We provided orientation and initial training in three experimental units -- one each in science, mathematics, and computing -- to volunteer teachers from each of the sites. In the fall of 1986, Apple Computer, IBM, and Hewlett-Packard provided the necessary equipment for the effort; Sunburst Communications supplied the mathematics software; and Technical Education Research Centers contributed the science lab peripherals and software. Throughout the 1986-87 school year, we are continuing to provide consultation and technical assistance, and we are examining the implementation process in detail. The lab site effort and the continuing work by the research projects summarized below should put us in a good position to make our research pay off for practice and policy audiences as well as the research community during the fifth and final year of our present contract, which begins in October of 1987.

RESEARCH PROJECTS

Each of ETC's research projects in science, mathematics, and computing education addresses a particular target of difficulty in the K-12 curriculum. Each group has analyzed the subject matter in which its target is embedded, analyzed students' difficulties with the subject matter, and developed teaching strategies to help students through those difficulties. Much of work in the Center's third year involved testing of these teaching strategies, which typically combine technology-based lessons with traditional materials. Two of the research projects focus not on a target of difficulty but on the educational potential of emerging technologies that are not yet widely available in schools.

RESEARCH PROJECTS IN SCIENCE EDUCATION

The study of matter and the study of energy make up a substantial part of the elementary and secondary science curriculum. The Weight and Density Project is developing a computer simulation and accompanying teaching activities that increase students' perceptual access to the concept of density by modeling particular properties of matter. A second project, Heat and Temperature Project, focuses on energy and uses microcomputer-based laboratory equipment to help students learn to differentiate heat from temperature, a conceptual reorganization that is the key to an understanding of other thermal phenomena encountered later in the science curriculum.

Two other science projects explore ways to teach students about methods of scienctific inquiry. The Scientific Theory and Methods Project concentrates on hypothesis formation and testing within the larger context of students' understanding of the nature of science. The Hypothesis Testing in Genetics Project has investigated students' learning of the scientific method within the more limited context of computer simulations of genetics experiments.

WEIGHT AND DENSITY

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The notion of density of materials is in many ways a conceptual watershed in the pre-college science curriculum. It is the first intensive physical quantity a student encounters that can be understood in terms of an underlying model, the particulate theory of matter. This theory holds that matter is composed of a finite number of discrete and uniform "bits", each of which weighs something; that the weight of an object is a function of the number of bits; and that the density of an object is a function of how closely packed the bits are. Further, the bits themselves are arranged into different kinds of fundamental building blocks or "atoms". Different kinds of materials are composed of different atoms, which vary in the number and arrangement of these bits. For solids and liquids, the density differences of different material kinds stem primarily from the differences in number of bits packed into an atom (and hence the overall weight of the atom); differences in the spacing of atoms explain less of their difference in density. This model is a major theoretical achievement -- built on both observable and unobservable properties and entities -- and its construction is a matter of doing real science.

By junior high school, students are expected to have distinct concepts of weight and density, and are taught how to measure the densities of different substances in grams per cubic centimeter. The notions of density and specific gravity are central to the earth sciences units commonly taught in the seventh grade, but teachers commonly report that students have difficulty understanding how to measure density. Later, the notion of density is a conceptual prerequisite for understanding the periodic table and more advanced topics in high school chemistry, biology, and physics. At this point, teachers expect that students can not only measure density but also understand density within the particulate theory of matter. However, teachers and researchers alike consistently note that students have difficulty internalizing this theory of matter from formal instruction.

In earlier work, the Weight and Density Group sought to understand more clearly the reasons that density was a difficult concept for children. Clinical work reported in ETC Technical Report 85-15 showed that students have a qualitative precursor of a concept of density -- the notion that objects made of certain materials are <u>heavier for their size</u> than objects made of other materials. This notion enables them to understand that objects which are the same size but made of different materials may differ in weight and that objects made of different materials may have the same weight even though one is larger than the other. However, this is an imprecise notion (not yet <u>weight per unit volume</u>) which does not lend itself to ready quantification. Because students have no clear notion of a unit size, heavy for size cannot define a quantity which is distinct from weight -- it remains a more qualitative notion. Further, because the density of objects is not directly perceptible but must be inferred by relating the weights and sizes of objects, density is a less salient quantity than either size or weight. Thus, in problems which call for students to think about density quantitatively, they confuse density with weight. For example, they do not realize that the density of aluminum is a constant, under standard conditions, which does not vary with the size and weight of the object. Rather, they think that a big heavy piece of aluminum is denser than a small piece of aluminum.

Rationale for Teaching Approach and Overall Significance of Project

The group's earlier work also suggested that a computer modeling teaching strategy might be a highly effective way of developing a clear concept of density in children. The group had developed a computer program in which quantities analogous to size, weight, and density were all directly visible (see ETC Technical Report No. 85-15 for details), and had found that children could understand and reason quantitatively about the visual analog of density depicted in computer displays. The work suggested that teaching activities which involved students in building and working with concrete models of density would form a bridge between their qualitative precursor density concept and a more formal scientific density concept.

In addition to promoting a clearer understanding of density, the group expected more general benefits from taking a computer modeling approach with this topic: the computer models could aid students in developing an understanding of the mathematics of intensive quantities; teaching activities involving computer modeling provide an opportunity for students to learn about the nature of models in science. The group planned to begin with a simple computer model representing only three quantities -- the size of objects, the weight of objects, and the density of the materials the objects are made of -- and constructing only objects of uniform density and rectilinear shape to avoid the problems of introducing objects of mixed density at this time (for example, objects with holes in the middle, objects made of different materials). The idea was to begin with a model for which students would be able to see direct empirical support and which shows in a simple and clear way the basic distinction between intensive and extensive quantities. Gradually the model can be complicated so that it can account for a wider range of situations (objects of mixed as well as uniform density; density changes in materials with thermal expansion, and so on) and so that it relates to an atomistic theory of matter. Changes in the model will create the explicit need for children to consider the complex relation between the computer model and the real world and understand models as tools in science rather than as "truth". The group chose not to begin with a full-blown atomistic model since children do not start out by having an atomistic conception of matter. It is more difficult to provide clear-cut experimental support for such a model, since such models are inherently more complex, and since the distinction between weight and density can be understood without such a conception. It is important, however, to link models of density with atomistic conceptions in the context of discussing the nature of scientific models and the experimental considerations which make such a model plausible.

Activities and Results of Work in the Third Year

The work of the Weight and Density Group in the third year centered on developing a classroom-based teaching intervention using these ideas and making a preliminary test of its effectiveness. This involved several types of work.

First, the computer model itself had to be developed in order to make it usable for instruction. The model piloted in the second year had been static, with limited interactive capability. Work at the beginning of the third year concentrated on making decisions about what the model should look like and developing a scheme for the interactive process. Three computer programs were developed. A first computer program allowed children to build objects of different sizes and materials, order the objects, change them, view or hide their structure, and request numerical data about their size, weight, and density. This model portrayed objects with a grid and dots representation (see Figure 1). In this model, size was represented as number of squares in a grid, density as the number of dots per square, and weight as the total number of dots in a grid. Two additional programs were developed which used the basic model to do simulations of sinking and floating experiments (see Figure 2). In both of these programs, the student could alter the density of the material the object and liquid were made of to see how these changes affected sinking and floating; in the second program, the student could vary the size of the object as well.

Second, teaching activities and materials had to be developed to use in conjunction with the programs. In the teaching intervention, the group wanted children to have experience working with real world objects as well as with the microworld, so that they could gain a deeper understanding of the phenomena in question and of the meaning of modeling. For example, materials were selected whose densities were in 1:2, 1:3, and 1:4 ratios, so that children could have experience discovering these ratios and modeling them on the computer. These materials were cut in 1 cm cubes, so that children could have experience building objects of known size in the real world, the way they did with the computer. Also included were numerous sinking and floating demonstration activities, including a "find the fake" task in which children were shown two pieces of clay of identical size, one which sank in water, while the other (stuffed with cork) floated.

Third, the group needed to pilot the teaching activities individually with a group of students to find out how they would relate to the new computer programs and teaching activities and to select an age group for a teaching intervention. Based on the pilot work with fourth, fifth, and sixth graders, the group decided to begin the teaching study with a classroom of sixth graders, who had more relevant knowledge and better developed math skills. The group also realized the importance of using the model first to develop a qualitative understanding of some of the properties of density as an intensive quantity, rather than expecting such understanding to come naturally from dealing with quantitative problems.

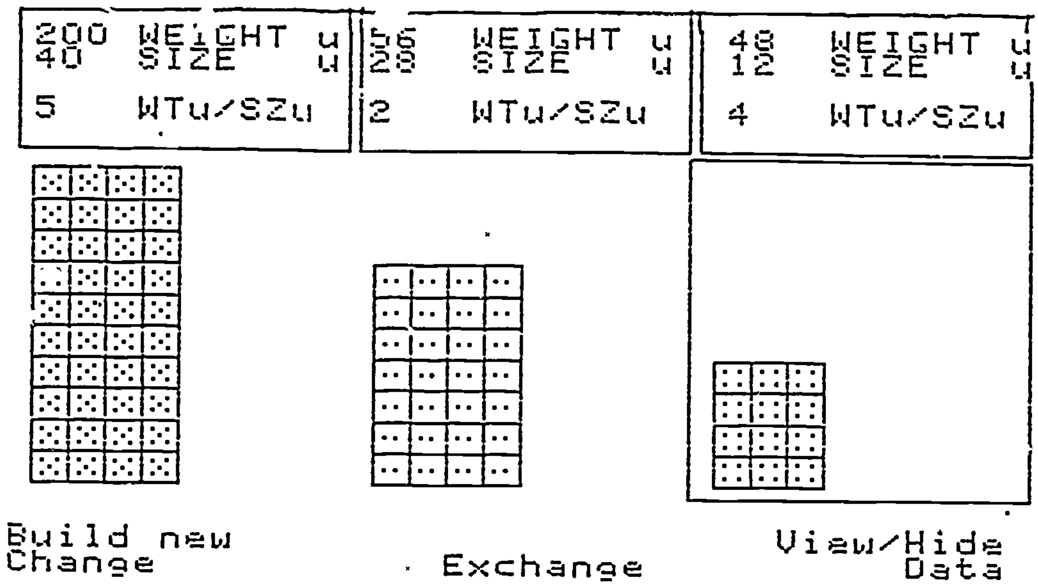

Figure 1. Screen dump of weight and density modeling program.

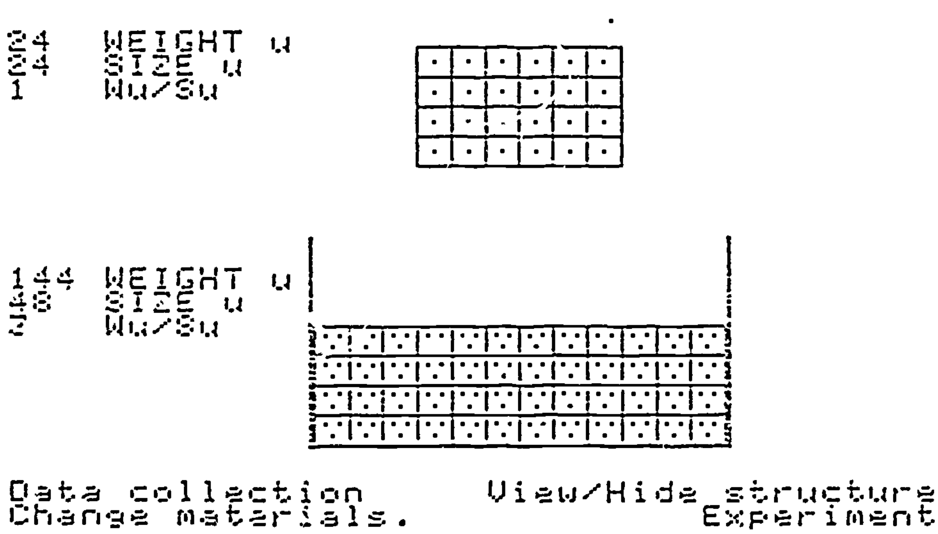

Figure 2. Screen dump of sinking and floating simulation.

Fourth was the teaching study itself, which involved an entire sixth grade class in an elementary school in Watertown, Massachusetts, in eight classroom sessions. Students were asked to invent their own ways of representing the size, weight, and density of a disparate group of objects, and their models were discussed. The teaching also introduced students to the grid and dots computer model of density -- which was ultimately used as a first model in a longer teaching sequence about density -- and the three computer programs which use this model in building objects and in doing sinking and floating experiments. A pre- and post-test assessment showed that the teaching sequence was highly effective in helping children develop a more explicit and integrated concept of density. The experience of teaching also suggested ways to improve the teaching sequence: (1) making more use of a model frequently invented by students, which represents density qualitatively and discussing the contrast between qualitative and quantitative models; and (2) embedding the entire sequence in an exploration of sinking and floating, thus motivating the need for models as a way to resolve puzzles encountered with real world materials. This study is reported in ETC Technical Report No. 86-5.

Finally, a pilot study was conducted with a sixth grade class to investigate the specific ways that the computer program aided the learning process (see ETC Technical Report No. 86-13). At issue were the role of two representational features of the program -- the use of the visual model and the presentation of numerical data -- in helping students understand density. A research assistant conducted a tutorial with individual students and the computer programs, using one or both of these representational features. The data display proved to be the most effective feature of the program in helping students improve their predictions about sinking and floating, while viewing a model of the internal structure of materials helped students to anchor their formal definition of density to a more intuitive understanding. The students who worked with both forms of representation generally achieved the most integrated understanding of density, although those who worked only with the computer programs did not do as well as those who (in the main teaching study reported above) worked with both real world materials and the program. It is important to develop computer programs with multiple forms of representation, and to embed work with simulations in work with hands-on activities.

Directions for Further Work

The group is currently carrying out two studies. The first is a longitudinal classroom-based teaching study (10 sessions) in one sixth and one seventh grade class. In the light of what was learned in year three, the computer program, lesson plans, and teaching activities are being revised and expanded, as are the pre- and post-tests. An individual clinical interview used as pre- and post-test is being expanded to include a wider range of problems about weight and density. A 45-minute written test with a combination of open-ended and multiple choice items has been developed and piloted for use in the current classroom study. In a second study, the group will examine the effects of teaching sequence and the use of computer models in student understanding of density and flotation. The second study will test effects of using computer simulations and of the sequence of teaching activities on children's understanding of density and flotation in an experimental study using four treatment groups and a control group. One hypothesis is that students who study flotation using both a computer simulation and real-world materials will more fully integrate a flotation rule using density than students who use only the real-world materials. A second hypothesis is that students who do experiments to disconfirm a weight rule <u>after</u> they have been introduced to the distinction between weight and density will more fully understand the counter-examples and reject a weight-based rule than those students who do such experiments <u>before</u> density instruction. One group will serve as a control for the effects of taking the pretest and will receive no explicit teaching.

HEAT AND TEMPERATURE

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The target of difficulty of this group's research is students' understanding of basic thermal physics, especially the differentiation of heat and temperature. The group has developed an intervention which uses microcomputers in three different ways: as laboratory tools to collect and summarize real data (Microcomputer Based Laboratories or MBL); as a means to run Laboratory Simulations, which simulate laboratory experiments on the screen; and as a vehicle for presenting molecular models that demonstrate the molecular behavior underlying thermal phenomena.

Underlying the group's pedagogical approach is the view that learning is the interaction between the information presented in class and in textbooks about a domain of knowledge and the pre-existing knowledge a student has about that domain. Consequently the group pursues three interrelated goals: to characterize the initial state of students' knowledge (that is, the ideas and concepts that the students have developed on their own and bring to the classroom); to develop a microcomputer-based curriculum that is optimally adapted to those pre-conceptions; and to monitor the resulting interaction between the students and the curriculum. Research in previous years has concentrated on the first two issues; this year, the group has addressed the third one.

Initially, high school students do not differentiate between heat and temperature; they think of heat as an intensive quality which is measured with a thermometer: the stronger the heat, the higher the level in the thermometer. They have no concept of amount of heat in the extensive sense. Because they think of sources of heat as communicating t[illegible]r heat (that is, heat of a certain degree or intensity) to recipients, concepts such as fixed points, latent heat, and specific heat are impossible for students to understand at this point. The main goal of the group's teaching intervention has been to demonstrate that temperature does not measure heat and to introduce the concepts of unit and amount of heat. In contrast to traditional laboratory methods, the computer hardware and software developed in the course of the research give users direct phenomenological access to those concepts and visually demonstrate that heat and temperature are not always correlated.

In the spring of 1985, the group conducted a study among ninth grade students; half of them received MBL instruction and the other half (the control students) received traditional instruction (see ETC Technical Report No. 85-17). The group further analyzed the results of that study during the third year. These results showed that students taught with MBL were far superior to the control students at solving problems about the quantitative relations among heat, temperature, and quantity of substance, and about latent heat; both advantages are undoubtedly the direct result of the hardware and software the MBL students used. But at the level of reconceptualization, which was probed using a clinical interview, the MBL students were not better than the control students. Overall the number of students who achieved the conceptual differentiation between heat and temperature was extremely small and those who truly understood the concept "amount of heat" even fewer.

Instruction succeeded in instilling the notion that heat and temperature are different, and that mass is relevant to heat measurement, but failed at making students reject the idea that temperature measures heat. Many students learned that "larger amounts of substance have more heat" but concluded either that they must therefore be hotter (because temperature measures heat) or that heat has two different measures, temperature and amount. This concept of amount (amount of heat of a certain degree) is obviously not the physicist's concept. For example, it does not allow one to understand how the same amount of heat put into different masses causes different rises in temperature, nor, conversely, how two different masses at different temperatures may release the same amount of heat.

Students appear very reluctant to give up their own conceptualizations. New information does not replace prior information; rather it is added on, or, most often, it is distorted to fit into their pre-existing frameworks, thus creating further misconceptions. Specific heat is a case in point. What students understood from the Specific Heat Lab was that substances with a higher specific heat absorb more heat than substances with lower specific heat (because they have a lower density), and thus become hotter when exposed to the same source of heat; this in turn forced them to relinquish belief in thermal equilibrium, which is incompatible with this interpretation.

A second trial of the teaching intervention carried out in the spring of 1986 (technical report in preparation) capitalized on the findings of the 1985 study, which showed the need for more diversified lab experiences, and for classroom discussions which address directly the students' preconceptions, the need to take into account possible misassimilations, and the need to help students integrate different aspects of the thermal theory. In order to expose students to more diverse lab experiences, the group used Laboratory Simulations, which take less time (and thus allow presentation of more experiments in a given amount of time) and give more flexibility than real lab experiments.

In assessing learning, the original clinical interview, which is time-consuming because it is conducted individually, was replaced by a written version, administered collectively. Researchers designed a series of multiple choice questions, chosen from those that best revealed the students' concepts. The validity of the "written interview" was tested in a separate study, in which a group of students was administered both the oral and the written versions. The correlation between their answers was sufficient to support use of the written version.

The results of the 1986 study replicate and extend those of the 1985 study. Again, the computer-taught students performed better on problems about the quantitative relation among heat, mass, and temperature and on latent heat questions, especially on the more difficult problems for which students have a strong tendency to revert to their own framework. Performance on the specific heat questions was much better than in the 1985 study, especially in the computer group. The new curriculum, including the Laboratory Simulations, appears to be dealing more efficiently with the students' misconceptions. As in the earlier study, however, the interviews revealed only partial reconceptualization, with no advantage for the computer group. The computer advantage seems to be limited to problem-solving and/or superficial understanding.

The group is presently developing computer-based molecular models that will illustrate various aspects of the basic thermal theory: molecular motion as a function of temperature, increase in molecular motion as dependent on number of molecules and amount of heat given to them, thermal conduction, energy exchange during molecular collisions, and the molecular basis for specific heat. These molecular models may help students with conceptual reorganization. By providing a common explanation for a wide range of phenomena they should help students integrate different pieces of the theory and dispel some of students' misconceptions (for example, that thermal dilation is due to the molecules increasing in size or that heat is an agent that makes molecules move faster and also makes them hotter). Combined with MBL, the molecular models may provide a powerful illustration of the extensivity of heat and of its relation with mass and temperature.

Two pieces of evidence fuel this optimism. In the 1985 study, all of the students who achieved clear differentiation between heat and temperature expressed the difference and relation between heat and temperature in molecular terms. In addition, during class discussions, it became clear that the only way for students to understand specific heat was on a molecular basis; in fact, when specific heat was explained on this basis students seemed to find the notion rather straightforward. This experience suggests that that combining MBL, Laboratory Simulations, and computer molecular models, as well as educating teachers more thoroughly about students' misconceptions, should yield good pedagogical results.

SCIENTIFIC THEORY AND METHODS (STAMPS)

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This group's work proceeds on the assumption that a science curriculum has two legitimate goals: (1) to help students master the ideas in biology, earth science, physics, chemistry, or other fields; and (2) to help students understand the nature of the scientific enterprise itself. STAMPS has focused on the second goal, approaching it in four steps. First, it has identified what it believes students should understand about the scientific enterprise. Second, it has assessed what is currently in the middle school curriculum, by analyzing texts books and widely used tests. Third, it has begun to assess late elementary school-age children's conceptions of science. And finally, it has designed and assembled curricular materials, some of which are microcomputer-based, to be used as a month long unit in the seventh and eighth grades. These materials have now been extensively piloted.

<u>What Should Middle School Students Know About the Nature of Science?</u>

At least since the time of the curricular reforms of the 1960s, one emphasis in science education has been to impart the "process skills" involved in constructing scientific knowledge, as well as to impart the knowledge that scientists have constructed. The process skills that have been the target of instruction are extremely varied, and it is generally agreed that the more complicated and specific skills such as conducting controlled experiments, preparing data tables, and graphing the results of experiments -- called integrated process skills in <u>Science, A Process Approach</u>'s (SAPA) terminology -- should be targeted in the middle school years. The STAMPS group shares with most science educators the commitment to teaching these process skills, but wishes to emphasize more than some educators the use of these skills in theory construction and revision.

One example may make this position clear: some curricular units on the scientific method for junior high school students teach them to identify the independent and dependent variables in an experiment, and to identify cases where two idependent variables have been confounded. Children are not, however, taught the very purpose of the scientific method -- theory building. They are not asked to discuss what makes the effects of some potential variables worth assessing and others not. Existing curricula fail to point out to students that hypothesis formation and testing are always constrained by current understanding of a phenomenon, and that as people begin to explore a phenomenon, they might not conceptualize the relevant variables for understanding that phenomenon. Scientific understanding advances when the investigators discover new variables and concepts that turn out to be useful in describing the phenomenon under question and that generate still other phenomena unanticipated at the beginning.

What's Now in the Curriculum

Texts

During the third year the group began by obtaining 23 currently used junior high school life science, earth science, and general science texts. Twenty-two of the 23 contain introductory chapters on the activity and/or nature of science. The content of these 22 chapters was analyzed in terms of three categories: (1) components of the scientific method; (2) the role of the scientific method in the process of scientific understanding; and (3) the nature of science (see Progress Report 86-11 for details). The texts depict science itself as problem solving; they define the scientific method as a way of solving problems and characterize it as being good for solving problems. They characterize the method very generally as "observe, analyze, synthesize, test." Thus, with regard to Category 1, there is some coverage, but very rarely did the texts discuss the running of controlled experiments. Fewer than half of the texts try to give a feel for the nature of scientific knowledge, scientific explanation, or scientific theories (Category 3) and none try to explain how the scientific method method is useful in constructing scientific knowledge (Category 2). Of the few texts that even try to discuss how hypotheses are chosen, none mentions the fact that the concepts that figure in hypotheses and theories are themselves constructions (for example, force, cell, gene, density, matter, energy).

Tests

The group found five published tests of inquiry skills designed for junior high school aged children: (1) Middle Grades Integrated Process Skills Test (Cronin and Padilla); (2) Test of Logical Thinking (Tobin and Capie); (3) Group Test of Logical Thinking (Roadrangka, Yeany, and Padilla); (4) Test of Enquiry Skills (Fraser); and (5) Test of Understanding Science (Klopfer and Carrier). The first four of these tests are silent on the nature and purpose of science, covering integrated process skills (1), Piagetian concrete and formal operational skills (2 and 3), and an even wider range of inquiry skills, including, for example the use of reference materials (4). The fifth, in contrast, is entirely different in scope and aims from the first four. It assesses what the student knows about science as a human endeavor and social institution. It contains an excellent analaysis of the nature of scientific knowledge and of the purpose of scientific inquiry. This test has been available for 20 years; unfortunately, its analysis is not represented in current junior high science texts or curricular units on the scientific method. This underuse may have two sources. It may be due to educators' acceptance of a narrower conception of teaching process skills. On the other hand, what is good in TOUS, and appropriate for junior high school students, is embedded in a larger context that is not so appropriate. TOUS tests what the student has constructed along the lines of a sociology of science. Children of this age know little of social institutions, and thus lack the knowledge that would make a consideration of science as a social institution of any interest. Questions about personal contacts, professional organizations, funding for science, the education one needs to be a scientist, the existence of pure theoreticians, the relation between science and culture, and so on, are not likely to be meaningful to children of this age. Emphasis on such issues may have led Klopfer's insightful analysis of the construction of scientific knowledge to have had less impact than it deserves.

In sum, with the exception of Klopfer's test, the analysis of available tests confirmed the conclusions of the analyses of the texts. The aspects of the curriculum that concern conceptual change, the constructive nature of theory building, and the reasons for doing science are not represented in the current junior high curriculum.

What Students Already Know

In 1956, Mead and Metreaux published a report in Science of the results of interviews with several thousand high school students from all over the USA. When asked about science itself, students provided a positive view: science is a grand activity, resulting in surprising and powerful knowledge. In contrast, when asked about the life of a scientist, a negative picture emerged. Science was painted as exacting a terrible toll: the scientist toils for years, not guaranteed of making an important discovery, in which case his labor would have been in vain. Male students did not want to become scientists and female students did not want to marry scientists. Mead and Metreaux concluded that what was missing in science education was any feel for the actual day-to-day intellectual activity of the scientist. While it is true that great discoveries or conceptual advances elude most scientists, science is a social activity affording much intellectual satisfaction, even in the short run. The STAMPS group hopes that selected lessons in the month-long curriculum unit it has designed will provide what Mead and Metreaux called for.

The group devised a clinical interview, based on the work of Mead and Metreaux, and administered it to six students entering seventh grade (see Progress Report 86-11 for details of the interviews and their analysis). One student, who had a longstanding interest in science and who came from a special program for gifted children, showed without a doubt that a sophisticated and rich understanding of the nature of science can be achieved by at least some children of this age. Like Mead and Metreaux's senior high school students, the other five students had constructed a negative view of the life of a scientist; they would not want to be one and they do not know any. Their images were more immature (for example, one explained that a scientist cannot have a normal family life because the president is likely to send him away for a year on some important project), but the overall impression is the same. In addition, some students viewed scientists as nerds and science itself as boring.

Not surprisingly, these students, like those of Mead and Metreaux, had no idea about the day-to-day intellectual activities of scientists. They did not understand what experiments are for (to experiment, for them, is to try something new, like putting cream cheese on graham crackers), and had little inkling of the cumulative nature of the enterprise. While two of the six (including the advanced student) understood that theories can be wrong, none expressed a clear understanding of the conceptual advances that characterize the scientific enterprise. Insofar as these students were able to characterize science, they did so in terms of exploration, of gaining new knowledge, and of technological advances. The most sophisticated student, in contrast, also understood quite a bit about the nature of scientific explanation, and he saw science as the search for verifiable explanations of natural phenomena.

The goal of the curricular unit that the group has devised during the past two years is to begin to move the understanding of most seventh graders (which is assumed to resemble that of the five students interviewed) towards that of the sixth student.

The Month-Long Curriculum Unit

ETC Technical Report No. 86-11 contains a full description of the curricular unit that has been devised and extensively piloted. With respect to process skills, it focused on the idea of "the experiment." The emphasis is on stating clear hypotheses, manipulating independent variables, controlling variables, making data tables, and graphing results. What is innovative about the curriculum is its use of computer software to attain these ends and of new "hands-on" units to practice these skills. Each class will practice these process skills in the service of two small pieces of actual theory building, which incorporate discussions of how the process of data collection, stating and testing hypotheses, and so on, contributes to the building of explanatory theories of the world. These materials are receiving field tests in full classrooms during the 1986-1987 school year.

HYPOTHESIS TESTING IN GENETICS

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The Rhode Island/Brown Technology Consortium joined ETC at the beginning of FY 86. Adding RI/BTC was the Center's response to a mandate in the original Request for Proposal to expand the set of school districts served by the Center after the first two years of work. Instead of simply adding another school district, the Center intended to reproduce itself in miniature, with Brown bearing the same relationship to a new set of school districts that ETC bears to the four school districts already in place as members of the consortium. The group was subcontracted to do research on teaching hypothesis testing through the use of computer simulations of genetics experiments.

Plans for the work of this group, led by Brown University in collaboration with the Providence, RI schools, were reviewed in November 1985 by the ETC Agenda Committee and were submitted soon thereafter to OERI. The group was developing software and lesson plans to use its computer simulations of genetics experiments with Biology I students. The simulations allow students to enter data and to examine software-generated data on traits of different size samples and over several generations. Lessons were designed to present the simulations to whole classes with a large screen video projector. Pilot testing occurred in several phases. After completing one round of tests in one classroom, the group revised its software and lessons and conducted further classroom tests. In December, the group reviewed its results from those tests and made further adjustments.

In a third phase of pilot-testing, group members used their experimental lessons and several assessment procedures with classes in two high schools. The experimental intervention consisted of four classes structured around computer-based simulations and instructional sequences. Assessment procedures include a pre- and post-test to assess student learning, a questionnaire to solicit students' reactions to the experimental lessons, videotapes of the experimental classrooms to analyze teacher behaviors and interactions with students, and an interview conducted with teachers after the intervention. Based on results from these classrooms, group members revised four elements of their materials: the software, assessment measures and procedures, teacher preparation methods and materials, and supplementary instructional materials such as homework assignments.

Finally, in May 1986, the group conducted a 7-hour workshop to train five teachers from two public high schools in the use of the revised materials. The teachers learned to use the software and related materials and then conducted the experimental lessons in a series of four classroom sessions with their students. The research group gathered information before and during this teaching experiment. Students were tested before and after the intervention, teachers completed a questionnaire, and about 20 hours of videotape were recorded during the lessons. Teachers also reviewed their experience with the research group after the experimental lessons were completed. These data were analyzed during the summer.

In one of the study's most encouraging findings, analysis of videotaped lessons revealed that teachers in the experimental unit used more higher order questions than the literature on teacher questioning would predict, although they did not spontaneously lengthen the "wait times" after their questions. Students reported that more group discussion occurred during these lessons than in their regular science classes. Findings regarding the effectiveness of the simulations in teaching hypothesis testing were inconclusive, suggesting that a more extended intervention would be needed to see significant change in this area and that measuring student skills in this area is difficult.

Teachers in the teaching experiment reported that they would use the materials again. They did, however, suggest modifications in the software and in the lesson plans, so that activities in the unit could be used more flexibly by both students and teachers. For example, teachers were concerned that lessons in the experimental unit were of varying length and constructed according to a tight linear sequence. If students missed or failed to understand an intermediate step, they tended to lose interest in the remainder of the sequence. In addition, some of the lessons did not fit comfortably into class periods. In general, teacher feedback was helpful in suggesting ways to make the structure of the materials more adaptable to variations in instructional setting.

In September, after considerable discussion as part of the planning and budget process within ETC, the Co-Directors determined that budget reductions necessitated the discontinuation of funding for work on this project. The group presented a full account of its findings in its final report, ETC Technical Report No. 86-6, Teaching Scientific Methodology through Microcomputer Simulations in Genetics.

RESEARCH IN MATHEMATICS EDUCATION

Two of ETC's mathematics projects, Word Problems and Geometry, are exploring ways of harnessing the computer's representational and computational power to give students greater access to meaning in mathematics and to provide software environments in which students can build the critical cognitive links among multiple representations of mathematical phenomena. The Word Problems Group is developing multiple representation software to help students in learning about intensive quantities, while the Geometry Group is exploring the potential of innovative software to enable teachers and students to integrate inductive and deductive reasoning in the teaching and learning of geometry. The third mathematics project, Fractions, has developed hands-on activities and a software environment that approach its target of difficulty using a linear model within the context of measurement.

GEOMETRY

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The traditional geometry curriculum relies heavily on deductive thinking and on memorization of axioms, postulates, and proofs. Students must manipulate the laws and formal representations of geometry without being able to try inventing laws and testing the properties of geometric shapes on their own. The Geometry Group is exploring the educational potential of the Geometric Supposer, a software environment that enables students to make quick, accurate geometric constructions and thus to engage in making and testing their own conjectures. The Group is developing and testing teaching materials that integrate this inductive approach with the more traditional geometry of deductive reasoning and two-column proofs. The group's goals in 1985-86 were to continue to study the development of students' geometric reasoning skills and to investigate issues associated with classroom implementation of its innovative approach to the teaching of a traditional mathematics topic.

The classroom-based research focused on three areas:

(1) How students make the transition from the specific to the general in geometry;

(2) How students formalize their hypotheses and generalizations;

(3) How the roles of and relationships among students, curriculum, and teacher are affected by the new technology (software as well as hardware) in the classroom.

The Geometric Supposer, is a series of software programs that enables users to draw geometric shapes and elements, to make meaurements on those constructions, and most importantly, to repeat those constructions on random shapes of their own construction. During the past year the group has studied three high school geometry classes that used the software throughout the year, aiming to engage students in significant mathematics-building and hypothesis-generating activities.

The three classes studied were located in different Boston area communities. The first, in a middle-class suburban town, had 8 students, was considered a geometry class of low ability, and met in a computer lab with desks in the center of the room and 10 Apple II's around the perimeter. The second, an honors class in a middle class/working-class suburb, was composed of 18 freshmen and met both in a regular classroom and in a lab on different floors. The third class, in a wealthy suburb, was composed of 18 students, was the lowest level geometry class in the school, and met in a regular classroom and in a lab two doors away.

At the beginning of the year, teachers were given a topic outline and problem sets for the year's curriculum. These materials paralleled the traditional content and topics of the regular geometry curriculum. Initially, teachers used all the problems the group wrote for them. Later teachers selected problems and rewrote them for their classes. For the period bracketed by the February and April school vacations, teachers were free to use the software when and how they wished. For the final four to six weeks, students worked on one of a number of Supposer projects -- more open-ended, more complex, multi-stage problems which teachers rewrote for their classes.

In general, when using the Supposer teachers introduced a topic in the classroom and gave students problems related to the topic to work on in the computer lab. Then the data and findings from the lab were reviewed and discussed by the class as a whole. The focus shifted gradually during the year from data collection to the making of conjectures, and eventually, to formal proof. This shift was in part dictated and deliberate, and in part a natural shift prompted by students' evolving sense of what was necessary and important.

Sources of data included: pre and post tests on generalization, biweekly classroom observations, student work, minutes of monthly meetings with the teachers as a group, a year-end test on argument and proof, and interviews with the teachers and a sample of students.

Issues of Implementation

The year's work revealed that the kind of teaching and learning this approach and intervention make possible presents challenges for teachers and for students as well.

Teachers need specific skills for structuring productive student inquiry and investigation. These include:

(1) designing problems and problem-solving experiences that are geared to teach specific geometric content and inductive skills;

(2) knowing how and when to provide structure and assistance without dampening student initiative;

(3) understanding and communicating their own problem-solving strategies as models for students to emulate;

(4) coping with and supporting inquiry in a class that may have branched off in many directions (for example, providing guidance and feedback);

(5) transforming individual student inquiry and findings into a learning experience for the entire class (how to facilitate participation, listening, and learning in a math class discussion);

(6) integrating inquiry learning in the lab with material presented in a traditional manner in the classroom.

Teachers also confront issues of classroom management. These include:

(1) scheduling and coordinating classroom and computer time;

(2) providing students with access to computers for individual work;

(3) finding class time to present material, review homework, model problem-solving strategies, have students investigate in the lab, discuss lab work and provide feedback to individuals on the lab work;

(4) testing for and grading student inquiry;

(5) coping with different questions coming simultaneously from as many as 10 pairs of students in the lab;

(6) pairing students for effective lab work (a subtle matter involving personalities and social relationships as well as ability levels);

(7) meeting departmental and district demands related to curricular objectives and standardized exams.

Taking full advantage of the teaching and learning that environments such as the Supposer promote requires considerable teacher planning and effort on an ongoing basis. Furthermore, this approach demands of students that they take on a larger portion of the responsibility for learning. As one student said in a year-end interview: "It's different. It's like abstract thinking. It's different than anything else you've ever done. ... Maybe a little harder than I expected. We have to think about everything that you learn, instead of just having a teacher to teach you, memorize, and just do it. You have to think about it yourself."

Geometric Reasoning

Preliminary findings about the development of students' reasoning skills suggest several consequences of the approach supported and fostered by the software.

First, students in the classes studied did not view diagrams as static objects or entities. They were willing and able to think about a figure in dynamic terms and to visualize what it means to move a line or change a triangle without actually doing the construction.

In class discussions, students often made convincing arguments using their hands and their bodies to demonstrate the manipulation of shapes and constructions. Students made the transition from working and thinking of drawings as detailed, specific cases to using more general diagrams which represented classes of shapes and phenomena. They were able to make the distinction between a verbal description of a problem and a diagram which exemplified the description.

Seco , students found it more difficult than the group anticipated to make conjectures. In contrast to students from higher level classes studied by group member Yerushalmy in 1984-85, these students often found it difficult to find patterns in their data and to state those patterns in general terms. The group has identified ancillary skills, problems, and strategies that seem to foster and to facilitate conjecture-making.

Third, this research contradicts the general wisdom that students who learn geometry inductively will experience neither an intuitive nor a logical need for proof. On the generalization posttest, treatment students gave significantly more arguments to support their generalizations than non treatment students.

The group's findings will be presented in full detail in an ETC Technical Report to be available i. April 1987.

WORD PROBLEMS

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Students' well-known and pervasive inability to solve word problems, and their distaste for doing so, prompted the selection of word problems as one of ETC's original targets of difficulty. The group's earlier analyses of multiplicative word problems in particular (see ETC Technical Report No. 85-19) agree with many other recent studies that attribute the heart of the difficulty - a lack of appropriately rich and flexible cognitive models of the operations of multiplication, division, and the associated idea of intensive quantity. For the purposes of this discussion, an intensive quantity is a ratio with referents for each of the numbers involved. This definition includes continuous rates (for example, speed in miles/hour), as well as discrete "per quantities" (for example, "3 people shaded per 2 trees"). In this summary, the terms "reasoning with intensive quantities" and "reasoning with ratios and proportions" are used synonymously.

Because intensive quantities seem to be at the nexus of those ideas that students find most difficult, the group's goal has been to link students' concrete understanding of situations involving intensive quantities with more abstract representations in such a way that the linkages would provide the means for students to think flexibly with and about intensive quantities -- a ramp upward from their concrete, situation-bound conceptions to more abstract and powerful ones.

The group has employed three types of representations in several learning environments that can be used over several grade levels: a concrete iconic representation using sets of screen objects, a numerical table of data, and a coordinate graph. A fourth representation is used in new environments under development. All these environments are also intended to lead from thinking with linear quantitative relationships (which is the conceptual context for these mathematical ideas) to thinking with more general quantitative relationships (polynomials, exponentials, and so on) later in the curriculum.

In each activity of each part of the software environments, the student is an active decision maker. The computer's role is to carry out the intentions of the student and render the adequacy of the student's choices and actions visible and salient. In particular, the computer can be used to see the counterparts of actions taken in one representation in any of the others. Thus the learning environments support actions and provide feedback <u>in ways that are intimately tied to the structure of the subject matter itself and that engage and exercise the sense-making power of students to monitor the consequences of their actions across representations</u>. The group maintains that this is a deeper use of the technology than has often been the case previously -- deeper both in the penetration of the subject matter and deeper in the level of cognitive interaction with the student.

Another possible source of the power of multiple representations is that they allow suppression of some aspects of complex ideas and emphasis of others, thereby supporting different forms of learning and reasoning processes. With more than one representation available at any given time, users can "have their cake and eat it too" in the sense of being able to trade on the accessibility and strengths of different representations without being limited by the weakness of any particular one. But, perhaps most importantly, the cognitive linking of representations creates a whole that is more than the sum of its parts in the same sense that binocular vision is more than the simple sum of perspectives. It enables the user to "see" complex ideas in a new way and move about them more effectively. The group contends that appropriately structured experience in a multiple, linked representation environment can provide the webs of meaning missing from much of today's school mathematics, which is centered on the manipulation of formal symbols apart from any meanings they might carry. Such experience will also generate the cognitive control structures required to traverse those webs in order to tap the real power of mathematics as a personal intellectual resource.

The group's curricular objectives also have an historical basis. Historically, it was not until about the time of Newton and Leibniz, when the ancient Greek ideas of ratio and proportion were integrated with the the ideas of rational number, algebraic variable, function, and coordinate graphs, that the real power of mathematical analysis was able to flourish. Until that time ratios remained a very clumsy tool, even in the hands of the most brilliant mathematicians. The group's approach attempts to bring together the same set of ideas and the same representational tools that helped make possible the explosion in mathematical knowledge that occurred in the two centuries after Descartes.

<u>The Software</u>

At the beginning level, the student actively builds the initial iconic representation of an intensive quantity according to his/her concrete conception of a given situation by choosing, grouping, and dragging icons into a model rectangular cell on the screen. The computer then takes the student's model and ties it to a table of data and a coordinate graph which then jointly respond to actions specified by the student. For a variety of reasons (see ETC Technical Reports No. 85-19 and 86-9), the most important of which was the desire for representations that supported long-term curricular coherence, the group decided that tables of data and coordinate graphs were primary representations for the concept of intensive quantity and operations with intensive quantities.

This part of the environment is intended to teach the connections among the representations, although it can also support traditional activities such as missing value-proportional reasoning tasks within and across representations. During the 1985-86 year it was the primary investigatory environment. See Figure 3 below to interpret the description that follows.

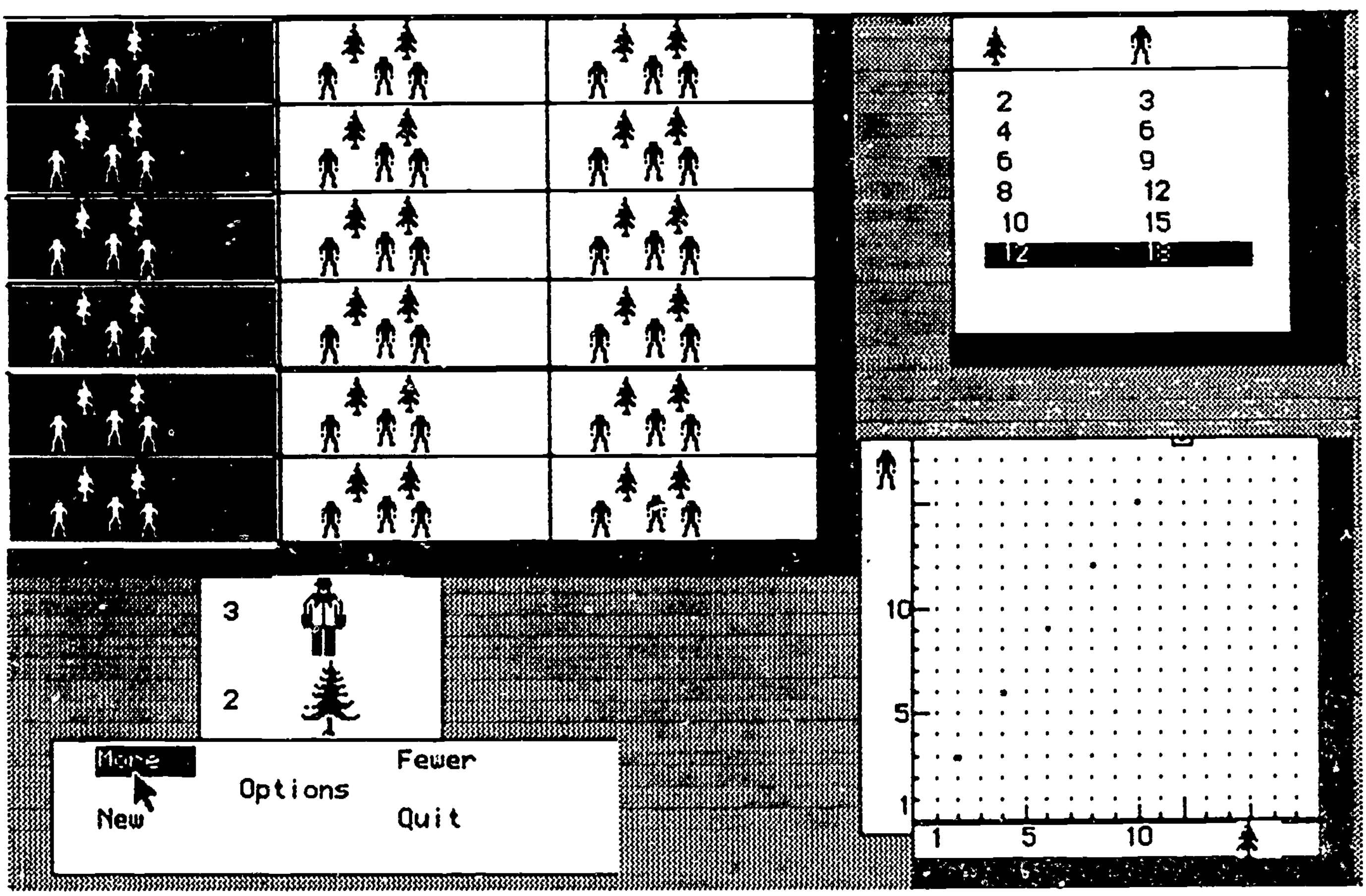

Figure 3. Screen dump from proportional reasoning software.

The icon window consists of rectangular cells, each of which is a duplicate of the initial model cell that the student constructs while specifying an intensive quantity such as 3 "person" icons per 2 "tree" icons. The two trees can be situated so as to "shade" the three people. After the preliminary actions setting up the situation, the screen provides a table of data window where the table of data is labeled by the appropriate icons, and a coordinate graph window, where the axes are correspondingly labeled.

As the student clicks a MORE button, the cells in the icon window are highlighted, corresponding number pairs are entered in the table of data, and the corresponding points are deposited (by the computer) in the coordinate graph. (Thus the intensive quantity is modeled in the coordinate graph as the slope of a line of discrete points.) With each such click, the latest pair and the latest point are highlighted to correspond to the number of icons of each type that are highlighted in the icon window. By clicking on FEWER the highlighting process is reversed, although the previously deposited number pairs in the table and points on the graph remain. By clicking on the boundary of any of the windows, the student can turn off that particular representation, so that prediction tasks are possible. For example, with the table of data turned off one could ask, "What number pair will be highlighted if we clicked on MORE 3 times?"

The objective of the Linking Environment is mainly to introduce the two new representations and to link them with the previously introduced icon representation as well as to link them with each other.

Research Objectives

Preliminary work to prepare students for use of the computer, and the computer-based work that followed during the second half of the year, were intended both to inform the details of elaborating the software environment and to pursue the following wider research objectives -- in particular, to determine:

(1) how the learnability of ratio and proportion ideas is affected by changes in the representational environment in which that learning takes place;

(2) how different representations support different ratio and proportion reasoning processes;

(3) how linkages between these reasoning patterns can be taught, especially linkages between concrete and intuitively acceptable reasoning patterns and more abstract and flexible ones;

(4) whether experience with multiple representations leads to the kind of cognitive flexibility and cognitive control structures that are reflected in an ability to choose and then correctly manipulate the representations appropriate to a particular problem.

The results of these investigations may have important implications regarding a traditional measure of cognitive development -- the ability to do proportional reasoning. They also make it possible to address directly the broader question of whether and how cybernetically linked external representations can be used to build cognitively linked internal representations.

Empirical Research and Software Development Activities

The first half of the year was spent designing and programming the first linked representation environment and testing paper/pencil versions of prototype tasks for that environment, mainly in clinical settings (although two entire classes were also tested for interpretations of coordinate graphs). The goal here was to determine that the particular features of each representation and connections between representations were comprehensible to the students (mostly sixth and seventh graders), and to assess what the best forms for their presentation might be. Additional clinical work prior to the summer helped modify the initial software environment and deepened the group's understanding of the relationships between the representations and various thinking patterns.

The summer was the most empirically productive part of the year because earlier work had provided a robust software environment to work with, and two opportunities were obtained for extended experience with the environment, including a week-long classroom experience with two different groups. Two groups of students were involved in five one-hour sessions combining manipulative activities, paper/pencil work, board work, teacher-centered classroom activities, and time in the microcomputer environment spread over one five-day week of a six-week voluntary summer program in a public school near Boston. One group was comprised of 11 above average students who had completed third grade. These students were in the summer program for enrichment purposes, whereas the second group, comprised of 7 below average mostly seventh grade students, were enrolled in the program by their parents mostly, but not always, because of inadequate performance during the school year. They were considerably less enthusiastic about being in a summer program than their younger counterparts.

Each class had an instructor and at least one assistant with one computer for each pair of students. At least two observers who took notes on the proceedings in each class. A pre-test on ratio reasoning was administered before the first class and a post-test on the Monday after the last class. Activities were similar for the two groups, but were slightly accelerated for the older students and involved more use of non-integral ratios and larger numbers. The approach was to set a conceptual context for ratio reasoning before entering the software environment, and then use the environment in conjunction with off-line activities for the remainder of the week.

The results were extremely encouraging, both in terms of the amenability of the software environment to use in a laboratory class setting and in terms of the rather dramatic post-test gains made by the older group. (The younger group did not receive the post-test). In addition, sessions with seven students who had finished third or fourth grade were held during another summer program at another local public school. For the first time there were students -- two below average students who had just completed third grade -- who could not manage to relate the iconic representation and the table of data. They were unable to count icons reliably and recognize totals in the table of data. This episode was significant in identifying the bottom level competence in counting necessary to understand the most elementary linkage as it then existed. Previously, all students seemed to have little difficulty with the iconic representation, the table of data, and their connection. These teaching sessions and results are reported in more detail in ETC Technical Report No. 86-19.

In addition to confirming the viability of the software approach taken, the year's empirical work deepened the group's understanding of the relationships between the forms of representation and the reasoning patterns supported. In particular, finding that some students used the icon model of intensive quantity in a very natural way in concretely based strategies influenced further development of the software.

During the summer months, software development continued, producing two forms of an intensive quantity sampling environment that address the issue of intensive quantity as a descriptor of a homogeneous intensive property of a substance, object, or situation. Work also continued on an environment centered on the coordinate graph representation that addresses the order properties of intensive quantities.

A Look Ahead

The 1985-86 year's work helped clarify the three fundamental aspects of intensive quantity: its multiplicative structure (best seen in missing value problems), its "intensivity" descriptor aspect (involving sampling), and its order aspect. Development and testing of environments that involve students in each aspect continues apace. The icon representation is being expanded to support actual calculations on-screen via grouping, dragging and counting, including single icon sets that involve only multiplication and division, precursors to the cognitive actions involved in ratio reasoning. In the other direction, a link to an equations-based representation is being designed in such a way as to effect a smooth transition to the more formal algebraic environment that most teachers regard as the "goal state" in teaching ratio and proportional reasoning. In addition, the extension of the discrete environments to cover the continuous case are likewise being planned. Together with the several prototype learning environments already built, those under construction and design will provide the basis for strong and coherent curricular strands across grades 3-8 that teach substantive thinking about quantitative relationships. Moreover, these results suggest that this innovative and powerful application of technology may render these deeper concepts accessible at considerably earlier grade levels than was formerly the case.

FRACTIONS

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The work of the ETC Fractions Group has focused on ways of increasing students' understanding of and ability to use fractions. Based on its earlier review of existing materials and prior research, the group had determined that its teaching approach should use a linear model within a measurement context and should incorporate both hands-on experience and computer-based activities. Accordingly, the group developed prototype software, hands-on materials, and lessons for grades five through seven.

In the early part of FY 86, the group revised its lessons based on analysis of the data collected in pilot tests held the previous spring, and it began developing clinical interviewing procedures and pre- and post-tests for another round of testing during the spring of 1986. A software numberlines environment was written which allows the student to enter parameters and view the equivalence, order, and betweenness properties of fractions on different numberlines. Specific classroom activities for the numberlines environment were developed, incorporated into the lessons, and pilot-tested later in the spring.

In January, the interviewing and assessment procedures were pilot-tested on eight students who had participated in the previous spring's testing. Based on the results of these sessions the group consolidated the pre- and post-test activities into one oral section and one written section. These sessions also served as a long-term follow-up to the previous spring's teaching experiments. In this respect the results indicated that the lessons should engage students more actively in estimating fractions and using numberlines to measure fractional distances. Using procedures based on the scaffolding model used by David Perkins and the ETC Programming Group, the group also conducted clinical interviews as students interacted with two pieces of software.

The pre-test was revised on the basis of this pilot-testing and was also checked for reliability through two administrations (four days apart) to one class of fifth and one class of seventh graders who had no other contact with the teaching unit. In the subsequent research study the oral portion of the pre-test was conducted in the style of a clinical interview.

Having completed the revisions indicated by these January tests, the group began their teaching experiment with groups of fifth and seventh graders in two school systems. The pre-test was administered in mid-March, and the teaching sequence ended in mid-April and was followed by the expanded clinical interviewing process and post-test. The remainder of the study consisted of approximately ten lessons focused on the properties of equivalence, order, and betweenness taught through a linear model and in a measurement context; clinical interviews as the students interacted with two pieces of software; the written and oral post-test; and an attitudinal questionnaire asking the students to rate how much they enjoyed each activity and how much they felt they had learned. Expanded versions of the "hands-on" numberlines activities were used, but the software numberlines environment was in too early a stage of development to be included in the research project. All sessions had an observer who took notes on students' responses, comments, and strategies. The oral tests and clinical interviews were also audiotaped to provide further documentation.

The Fractions Group did not propose to continue its work into FY 87. In May and June group members compiled and analyzed their data in preparation for writing a final report. This report is expected to be available in April 1987.

RESEARCH IN COMPUTING EDUCATION

One of ETC's research projects in computing education has studied the difficulties of beginning programming students and developed a "metacourse" teaching intervention to help these students overcome some of the initial difficulties in learning to program. The second project has studied the use of applications software and its potential uses across the curriculum.

PROGRAMMING

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During the 1985-86 school year the Programming Group continued to investigate the difficulties encountered by novice programmers. It also began a series of experiments to test the effects of the metacourse, an instructional intervention the group designed to equip students with thinking and learning heuristics that may help to moderate the problem of "fragile knowledge" identified in its earlier research.

Studies of Novice Programmers

At the beginning of the year, the group completed the data analysis and wrote technical reports on two earlier studies. "Loci of Difficulty in Learning to Program" (ETC Technical Report No. 86-6) discusses the results and implications of a quantitative analysis of the clinical interviews of the BASIC study conducted in the spring of 1985. The analysis strove to determine the extent to which students suffered from inadequacies of their BASIC "database" versus higher order difficulties. The analysis of the data provided information about loci of difficulty in three aspects of students' programming behavior: attitudes, knowledge base, and problem-solving strategies. The results argue that novice programmers' difficulties are far from monolithic, and give evidence of loci of difficulty in attributes and mastery of the relevant knowledge base as well as in elementary problem- solving strategies. In addition, it appears that, at least in programming, shortfalls in knowledge and strategies much simpler than those usually discussed in the literature on mathematical problem solving heuristics may considerably impair novice's efforts.

A second study conducted in the summer of 1985 on children learning Logo also supported this hypothesis (see ETC TEchnical Report No. 86-7, "Nontrivial Pursuit: The Hidden Complexity of Elementary Logo Programming"). The data suggest that "trivial" elements of Logo programming are not so trivial as they may seem. Four aspects of programming that might at first appear trivial were found to be possible sources of significant conceptual difficulty:

(1) close discrimination problems, which make certain concepts hard to grasp. These difficulties occur with solution elements that require careful discrimination, for example, left and right turns in Logo;

(2) domain and domain-operation problems, for example, difficulty in understanding geometry and the Logo commands for making geometric moves;

(3) the conjunctivity effect, as in tasks such as arithmetic and Euclidean geometry where a correct response depends on the correctness of each individual response element. In a high-precision endeavor like programming the conjunctivity effect escalates difficulties that in isolation may merely be matters of "knowing it" into major challenges; and

(4) a shortfall in elementary problem-solving strategies, which prevents students from making the most of their somewhat fragile knowledge bases.

Development and Testing of the Metacourse

This clinical work led the group to focus on the problem of a fragile knowledge base among novice programmers. The term "fragile" draws a contrast between knowledge that is missing and knowledge that is present in some sense, but not easily accessed, or garbled, or retrieved for inappropriate uses. The metacourse instructional intervention was designed to address the following areas in particular:

(1) a fragile knowledge-base, impoverished knowledge of commands, ability to read back code to see what it does, and so on;

(2) a shortfall in problem-solving strategies, especially a failure to deploy elementary problem-solving tactics such as simple

self-prompts (for example, "what am I trying to do now," "do I know a command that might help," or "what will this line of code really do?");

(3) problems of confidence and control, exepmlified by "stoppers" and "movers." "Stoppers" refer to those students who, on experiencing difficulty in a programming activity, disengage from the task and make little or no further attempt to solve the problem. With some encouragement, however, stoppers can often reach a solution. "Movers", on the other hand, keep trying to work toward a solution, but often fail because they proceed in a haphazard way.

In the fall the group piloted a preliminary version of the metacourse in two classrooms. Research assistants taught the lessons in two classes, and a formative evaluation was made. The eight-lesson metacourse is designed to enhance what students learn from normal first-semester instruction in BASIC. As the name suggests, the metacourse stands above the content of the normal instruction, providing programming-specific skills and a conceptual framework that guide the exploratory thinking of the novice programmer.

Specifically, the metacourse taught this year incorporates the following components: (1) the "paper computer", a visual model of what happens inside the computer (at a functional level of operation) to help students interpret exactly what commands do, (2) an analytic scheme for understanding commands and command lines in terms of the purpose, command, syntax, and action of a command in the computer world, depicted by the paper computer, (3) an easy-access "minimanual" that includes the key BASIC commands organized according to the purpose, syntax, and action framework, (4) attention to computer-user interactions as a top-level planning strategy, and (5) the introduction of "patterns," recurrent schema such as counter variables or certain compound conditional branches that provide an intermediate level of analysis between the whole program and individual command lines. In addition to piloting the metacourse, the group developed and piloted a cognitive skills pre- and posttest as well as an achievement test in BASIC programming.

As planned, in the spring the group carried out a controlled teaching experiment with the metacourse, using five experimental and five control classrooms in the Boston area. Sites was chosen even though it was clear that teachers in some sites might not be able to provide all the data needed. Teachers conducted the metacourse lessons, interspersing them throughout their regular instruction. Complete data were obtained from three treatment and three control sites, including pre- and post- cognitive skills tests, the BASIC programming achievement test, and classroom observations concerning the fidelity of the teaching to the metacourse lessons and teacher-student interactions. During the summer and fall the group began analyzing these data.

During the current year the group is continuing its efforts to develop and test the effects of the metacourse. Expansion of the metacourse lessons has begun based on teacher reports and classroom observations from the Spring 1986 experiment. For optimal impact, the ideas from the metacourse may need to be infused throughout instruction in BASIC. ETC's new laboratory sites provide settings where this can be tried. The group is working with teachers in the lab sites to implement the eight existing metacourse lessons and to infiltrate the BASIC courses with the metacourse themes. Since the extension of the metacourse will have begun during the same period, ideas from the extension can also be incorporated into the infusion experiment. The students at the infusion sites will receive pretests and posttests similar to those used to evaluate the results from the Spring 1986 intervention.

During the spring of 1987, the group plans to conduct a summative evaluation of the extended metacourse. This experiment will take place in regular classrooms as opposed to the lab sites of the fall study in order to approach conditions more nearly approximating those of a real classroom. The group will update versions of the cognitive skills and BASIC instruments.

APPLICATIONS

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- Chip Morrison, ETC
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- Debbie Ross, Cambridge Public Schools, Cambridge, MA
- Joe Walters, Porject Zero, Harvard Graduate School of Education
- Martha Stone Wiske, ETC

This group completed its final project, a study of students learning to use a database. The fall was spent analyzing the data on seventh-grade students in a Brookline, Massachusetts school who were systematically observed as they learned to use the TC Filer program in a required computer literacy course. A report was drafted and is currently in revision.

In addition, the group completed a paper on the school and student variables predicting student computer use, based on analysis of items from the 1984 National Assessment of Educational Progress (NAEP). Further revisions of the paper were in progress at the end of the third year.

RESEARCH IN NEW TECHNOLOGIES

Two research projects have been exploring the educational promise of new technologies that are not yet widely available in schools. The Videodisc Group has investigated the usefulness of videodisc to teach scientific inquiry skills, and the Computer-based Conferencing Group has studied the potential of electronic conferencing to promote collegial exchange among science teachers.

VIDEODISC

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The Videodisc Group's research during 1985-86 focused on completing production of a prototype disc, Seeing the Unseen and subsequent testing of the disc.

Seeing the Unseen was produced to achieve three objectives: 1) to investigate the design choices and compromises entailed in creating the disc by retrofitting existing video materials through the use of an authoring system; 2) to explore the promise of videodisc as a medium for illustrating and eliciting science process skills; and 3) to examine videodisc use patterns and user-machine interactions. The videodisc was created using existing video segments from NOVA and 3-2-1 CONTACT and an authoring system, Authority (TM), developed by Interactive Training Systems, Inc.

Through the design of the research videodisc the group investigated the potentials and constraints of videodisc creation through retrofitting. Conclusions regarding this process are described in ETC Technical Report No. 85-18, The ETC Science Videodisc Project: A Report of Research in Progress.

The disc was designed to incorporate an inquiry approach to science education, an approach in which students explore and inquire as scientists do, rather then simply being presented with information. Through this design, the disc provides an environment in which students carry out scientific investigations and make discoveries. Through their interactions with the disc, either alone or in groups, students hone their science process skills. The inquiry skills include making observations; collecting, recording, and classifying data; seeking patterns; forming and refining hypotheses; conducting experiments; and making predictions. Inquiry skills are not practiced independently of each other and are not viewed as separate or linear steps in a problem solving process. Some, but not all, of these skills are required for each of the disc's four lessons.

Each of the lessons poses a different problem. While the lessons present topical information (plants and light, animal camouflage and mimicry, time and motion, and the geometry of shapes), the value of each lesson is derived from using scientific process skills to examine the subject matter. The problem-solving methods required vary from lesson to lesson depending on the teaching strategy employed and the mode of inquiry elicited.

The lessons take advantage of the many forms of interactivity available with Level 3 videodisc technology. Computer control of the videodisc permits branching based on student responses, use of two audio channels, random access to visuals and automatic search, and the presentation of text screens as well as text and graphic overlays. Specific modes of interaction built into the lessons include: video pause (freeze-frame), video replay (forward or backward), redo (return to an earlier activity), menu (go back to the last menu), and go ahead (go to next menu, screen, or activity). In some lessons, students can also choose to view charts, lists of thought questions, or additional information. The user controls the system primarily by touching the screen, although keyboard input is required in some instances.

The four lessons that have resulted from the videodisc design and development process are briefly described below.

<u>How Does Light Affect Plants?</u>

This lesson is composed of several related activities that promote increasingly sophisticated ways of thinking about a single question: How do plants respond to light? The activities include an introduction to the role of light in plant growth, three experiments designed to lead students to formulate and test hypotheses about the interaction of light and plants, 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 interactivity include manipulating variables, replaying video to observe events more than once, and recording data on a chart.

<u>What Disguises Do Animals Use?</u>

This lesson consists of four activities that provide the tools and subject matter for an investigation into forms of animal mimicry. The activities include an introduction to animal disguises, a sorting exercise in which students identity different classifications of animal disguises, and an observation game. Critical observation and the subsequent formation of hypotheses is the process skill emphasis of this lesson. The classification exercises use video clips to furnish observable data in which students seek patterns to successfully complete the exercise. Students form hypotheses to be tested, revised, and extended. Modes of interactivity include playing and replaying the clips, recording observations using pencil and paper, and group discussion of the process and result. The games encourage trial and error experimentation while taking full advantage of the technology's ability to produce appealing touch-screen interactions.

<u>What Happens When Time Is Altered?</u>

This lesson is open-ended and exploratory in nature. It includes an introduction and three exercises that illustrate how altering the perception of speed and motion can reveal new information about everyday events. Although the lesson can be enjoyed by students working alone or in small groups, it is designed as a teacher-directed activity that will generate discussions about differences in perception and hypotheses about formerly undiscernable observations. In this lesson, students use their observation skills to investigate the nature of time and the underlying characteristics of common events. Students learn to recognize patterns in phenomena and make predictions based on the similarities they notice. The lesson encourages students to consider different frames of reference, explore new data, and form hypotheses from observations.

<u>How Do Scientists Study Things They Can't See</u>?

This lesson contains an introduction, an interactive tutorial, and a computer simulation that lead students to consider how scientists study phenomena they cannot readily observe. The lesson presents Linus Pauling figuring out the shape of a three-dimensional block hidden inside a small covered box and then invites students to solve a similar problem in a computer game. The process of approaching a "hidden" phenomenon or problem, making indirect but systematic observations, and reasoning logically about these observations to reach a conclusion is the focus of this lesson.

In January of 1986, after production of SEEING THE UNSEEN was completed, research began to explore the use of the disc in use in middle school science classrooms. Three questions formed the basis of the research:

(1) What did users like and dislike about the system?

(2) How was the system used? How did students and teachers respond to different use modes?

(3) How did students interpret and understand the material presented?

Research was conducted in middle school classrooms in two Boston area schools. Students and teachers were observed using the videodisc in three different use modes: individual (student without a teacher), pair (two students without a teacher) and entire class (teacher-directed). Data was gathered by means of observations, interviews, and questionnaires.

The latter part of the year was spent interpreting the collected data. The group identified several prevalent trends worthy of discussion. These include the importance of user control in navigating through the lessons and the appeal of the disc's interactive features and the user participation it affords. Findings also include use-mode preferences and an overriding appreciation for the quality of the visual presentations of the disc. An in-depth and detailed report of the results of this study is forthcoming in April 1987.

SCIENCE TEACHERS' NETWORK

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The Science Teachers' Network was established to explore the potential of computer-based conferencing to promote collegial exchange among high school science teachers. The project sprang from a problem identified in recent papers and discussions on the state of science education in secondary schools -- the isolation of science teachers both from ongoing developments in science and from colleagues with whom they might exchange ideas about the teaching of science. Although computer conferencing on mainframe computers had served for over a decade as a medium to support substantive discussion and a sense of professional community among geographically dispersed groups, the size and expense of these computers had limited conferencing to the worlds of business and technology. The increased availability of microcomputers and concern for the isolation of science teachers led naturally to the question of whether a conferencing facility would be of help.

The conception of conferencing for teachers included both "information sharing" and "discussion". Regarding the latter notion, proponents hoped that conferencing might prove a vehicle for staff development. Teachers might be led, through the increased opportunity for interaction with colleagues, to share not only simple practical information, but also their reflections on their practice. These interactions might in turn enliven their existing practice or create a fertile environment for changes in practice to develop in the future.

A review of existing conferencing systems found them to lack certain important features, so the decision was made for ETC to develop one. Common Ground was designed to have several characteristics that facilitate discussion: it limits enrolled membership; it is easy to use for regular members, discussion managers, and system operators; it enables easy identification of discussion topics; and it allows messages to appear as private messages, public messages, or both. Furthermore, it runs on a microcomputer so that educational institutions can run conferences without purchasing more expensive computers. In Common Ground, the facilities are organized around a spatial metaphor which compares the entire conferencing system to a building with many rooms in it. Some rooms are private offices, where participants receive their private mail; other rooms are publicly accessible and serve as "forums" for discussions of particular topics.

Research Goals and Network Operation

Research on the network pursued three goals: (1) to determine the extent to which the network succeeded in promoting collegial exchange about science and science teaching; (2) to identify the variables that influenced the extent and nature of use; and (3) drawing upon these findings, to develop recommendations about the best uses and management of computer-based conferencing among science teachers, among teachers generally and, to the extent possible, for other educational applications.

While the research approach to these goals was a broad descriptive one in keeping with the lack of previous research from which to predict how teachers might use such a system, mainframe conferencing research pointed to several issues that deserve attention. First, accounts from EIES and COsy mainframe networks indicated that computer-based conferencing might disinhibit communication, perhaps facilitating the kind of dialogue among teachers that was a goal of the project. A second issue was access to and distribution of information. Although the medium seemed to promise equal access of all members to information, since interactions can occur in public among large numbers of people, a question was raised as to whether this potential is illusory. People reading a message addressed to a group in a large conference may feel less obligation to respond than in face-to-face interactions. If the probability of a response is increased where a member knows or has heard of the questionner, then information does not derive from the total membership and may follow channels of pre-existing relationships. A final issue was which discussion topics would best produce extended interactions or reflective thinking in a group of teachers such as these, who were mostly unacquainted with each other.

During the fall of 1985, science teachers from eastern Massachusetts were invited to join the network for purposes of "collegial exchange", as were several scientists and science educators who were suggested by member surveys. Teachers provided their own equipment and phone costs. About one-third had a computer at home and had no significant phone costs; the remainder had less convenient access. About 40 percent used a school computer; for many of these, it was hard to schedule time to log in during the school day.

The network was managed by two psychologists, including an experienced staff development specialist, and four teachers. Initial topics for discussion ("forums") were established by suggestions of an advisory group of science department heads during an earlier pilot network; others were added by staff in December 1985 so that there was a forum for each teaching area, and for special guests. Each forum had a facilitator ("moderator") -- one of the teachers, staff, or guests. The forums were: Notice Board (for notices of general interest); Software (about educational software); System (for technical information on computer conferencing); Teaching (concerning general issues of teaching); PBSEarth (for guest Victor Schmidt about the PBS series Planet Earth); TERC (for guest Robert Tinker of TERC, Inc., developer of microcomputer-based laboratory hardware and software); and each of the main teaching areas, including Physics, Chemistry, Biology and Earth Science. Two additional guests participated "at large": James Kaufman, consultant on school lab safety; and Ralph Lutts of the Trailside Museum, specialist on environmental education.

Technical assistance included two training meetings, telephone assistance provided by staff, sharing of information among members in network exchanges, the software "help" command, a participant's manual and quick reference card.

Findings regarding Network Participation

The network membership grew continuously from December to June 1986, reaching [illegible]5 teachers, 60 percent of whom became continuing users. About a quarter of all users, or about half of the continuing users, logged in at the rate of once a week or more often. Examination of patterns of use reveals that some members lost interest, others logged in occasionally, and others logged in regularly and frequently. Data on message reading show that half of the continuing users read all forums; 60 percent read all messages in their own teaching area and 80 percent read at least half of these.

Amount of writing varied, but averaged one message per week among continuing users. Writing behavior showed that disinhibition did not occur in this group; rather there were signs of reticence. Teachers initially posed questions in private mail that would have been of interest to the entire group. In interviews teachers mentioned feelings of discomfort such as embarrassment at spelling mistakes. Some said that by the end of the term, they felt they were "just getting started." There was also evidence of shyness in the content of messages. Only some of the teachers, and only after using the medium for a while, offered messages with more personal content in the form of thoughts, opinions, or stories about themselves. Thus several kinds of evidence suggest that it may take more time for such a group of teachers to feel comfortable using the medium. Since teachers logged in on average less than once a week, they may not have had enough experience to become more comfortable with the medium (or with each other). Some other researchers report similar reactions to computer conferencing among new users.

The data also showed that (1) lack of previous acquaintanceship was not a barrier to interactions or flow of information in the conference; and (2) the network reached and especially appealed to teachers who were more professionally isolated. When asked, "do you feel that you really gotto know anyone by interacting with them on the network or by just reading their messages?" 36 percent answered yes, and these members tended to engage in more writing relative to reading. Furthermore, the channeling of information was not limited to pre-existing relationships. The majority of teachers addressed messages more or less equally to known and unknown individuals. Further, the conference succeeded in eliciting responses to inquiries. That is, when messages were classified according to the social acts performed (for example, seeking information, offering unsolicited information, offering a response to an inquiry or idea, and others), the most frequent of these was responding to a question or idea. Many of the messages written to unknown persons were answers to their specific questions. Thus, although acquaintanceship was associated with more writing on the network, the conference encouraged interactions among participants according to common interests, and the specific topic appeared responsible for the initiation of an interaction.

On the second point, the network succeeded in reaching professionally isolated teachers who, in fact, used it more often than less isolated teachers. Teachers with fewer contacts with colleagues outside of their own school logged in and read more, and did relatively more public writing. In addition, those who mentioned in the interview that lack of colleagues was a difficulty of the profession tended to engage in more public writing.

Convenient access to the computer, and lack of burdensome phone costs, were found through both interviews and correlational analyses of participation to be a very important influence on participation. Teachers without easy access logged in less frequently, read more selectively, and wrote less. The software Common Ground proved easy to use; however, teachers used their own communications software (needed to dial in to Common Ground or any computer network), and this software was often difficult to use.

Recommendations and Future Directions

The work leads to recommendations in four areas for computer-based conferences that aim to promote information-sharing and discussion as a support for teachers: hardware and software; applications; changes in Common Ground; and user training. First, convenient access to the computer and modem, and use of the same hardware and software, are the ideal conditions for a network because the entire group can more quickly learn the technical skills for uploading and downloading messages. Uploading and downloading, in turn, allow the writer/reader to spend more time thinking about the content of the message, while composing it or reading it.

Second, network planners should consider that membership size, topic, and log-in frequency are probably interrelated. A small membership with diverse interests and a broad network topic is likely to fail because the probability of members' finding messages on their specific interests is too low. A larger such network may succeed, but since the frequency of log-ins will probably vary, this network cannot be used for information that is needed urgently. For discussion purposes, on the other hand, a small membership may be ideal because members can get to know each other and feel more comfortable offering personal views. Finally, the strongest means to pull members into interactions would be a common task which cannot be carried out except over the network. Here the task itself would structure log-in pattern and content of discussions. Therefore, where a network aims to promote interactions among unacquainted persons, the data suggest maximizing the degree of common interests among participants by either limiting topical focus or introducing collaborative activities. In addition, since a network discussion evolves in pieces, and each member may read a different segment of the discussion at one time, moderators need to summarize, weave themes, and re-raise unanswered questions.

The group recommended several minor changes in Common Ground to allow more options for management of topic, including forum descriptions and optional topic line revision, as well as user training in uploading and downloading and in topic line composition and retrieval of messages by topic lines.

The current year's research efforts are designed to examine several natural experiments that will help sort out social and topical influences in network discussions and allow the drawing of firmer guidelines for educational applications of computer conferencing for small groups.

DISSEMINATION AND TRAINING

During FY 86 ETC expanded the range of materials that document its work and present its results to the educational community. These products are now available to wider and wider audiences. In line with the Center's ongoing policy of wholesale dissemination, ETC has created opportunities to market its products through existing channels and networks as well as directly from the Center itself, and it has joined with other research and educational technology organizations to cosponsor training activities.

DISSEMINATION

During FY 86 ETC has enlarged the array of print and other materials through which it communicates its findings on technology and education and presents the results of its research.

Newsletter

The Center's newsletter, Targets, is published three times per year. It describes ETC's research and related activities to a broad audience of practioners and researchers. The readership for Targets expanded from 8,000 at the beginning of FY 86 to 16,000 at the close of the year. This national and international audience includes school superintendents across the country as well as state computer coordinators and curriculum coordinators in science and mathematics. Each issue contains an insert that lists technical reports and other products and provides an order form.

Technical Reports and Other ETC Reports

This year ETC has continued to make available the technical reports produced by research projects as deliverables under the Center's contract with OERI. Although intended mainly for other researchers, these reports also discuss the practical classroom implications of ETC's work and thus are of interest to school people as well. The reports are available to anyone who requests them; fees are low, covering only the costs of reproduction, binding, and mailing.

In addition to technical reports, the Center also produces and disseminates reports on certain of the conferences that it sponsors. Lastly, ETC makes available topical papers written by ETC associates; although not emerging directly from the Center's own research, these papers cover topics that complement the Center's research agenda.

In all, the Center distributed 2,409 reports in FY 86.

Videotapes

The Center continued dissemination of New Tools for Learning: Using Computers in Science Education, a videotape produced by Education Development Center in collaboration with ETC. Intended primarily for in-service training for high school science teachers, the tape is also ideal for use with school administrators, parents, and other audiences. ETC sells the videotape at cost. In addition, it is now available through two software publishers, Sunburst Communications and HRM Software, who sell New Tools at cost through their catalogues. The Center is pleased to join forces with these two organizations that reach virtually every science teacher in the country.

Also in FY 86, EDC, in collaboration with ETC, produced a second videotape called Image, Graph, Symbol: Representation and Invention in the Learning of Mathematics. This 29-minute tape is intended primarily for the in-service training of upper-elementary and high school mathematics teachers. Image, Graph, Symbol makes the case for the use of multiple representations in mathematics education. It suggests that when students have the opportunity to work with concrete as well as abstract representations of mathematical concepts, and to move at will among a variety of representations, their understanding of and facility with mathematical ideas improves.

Image, Graph, Symbol demonstrates the use of multiple representations in a variety of classroom settings. A seventh grade class uses geoboards to learn about the Pythagorean Theorem. Fifth and sixth graders try out an experimental computer program designed to help children improve their proportional reasoning. An eighth grade teacher with only a single computer at her disposal uses the program Green Globs to review with her students the relationship between graphs and equations. High school students working with the program Guess My Rule learn to derive equations from tabular and visual data. Another high school class uses the Geometric Supposer to investigate the properties of and make conjectures about similar triangles. The videotape also includes interviews with two mathematics educators -- Judah Schwartz, professor at MIT and Co-Director of the Educational Technology Center, and Robert Davis, professor at the University of Illinois.

EDC is currently producing a 3-4 page brochure to accompany Image, Graph, Symbol. The brochure will suggest ways for using the tape in a teacher workshop: how to set up computer-based activities, what questions to ask in a discussion. It will also provide information about how to order the software demonstated in the videotape.

Image, Graph, Symbol is being distributed by ETC as a product of the Center. In addition, Sunburst Communications has agreed to make the tape available at cost through its software and videotape catalogues, as it does New Tools. The Center is also exploring distribution of the tape with a second major software publisher.

Software

This year ETC also made available two pieces of software that have come out of the Center's research. The first is Common Ground, a microcomputer-based conferencing system, which was developed for the ETC Science Teachers' Network. The December 1985 issue of BYTE magazine featured an article on Common Ground, which generated interest in the software and boosted dissemination.

The second piece of software now available through ETC is Immigrants, a social studies unit in which students use an integrated software package, AppleWorks, to explore Irish immigrant experience in Boston from 1840-1860.

To date, the Center has sold 165 copies of Common Ground and 237 copies of Immigrant.

Other Dissemination of Work in Progress

ETC has continued to submit monthly research summaries for dissemination on Edline, the OERI-sponsored electronic newsletter disseminated through the Source.

TRAINING

ETC also communicates the results of its work by sponsoring or cosponsoring a variety of events. Some present only the results of the Center's own research. Others create a forum for broader discussion of technology and education.

Conferences

Evaluating Computer Use in Schools

On October 17-19, 1985, ETC co-sponsored an institute with the Programs in Professional Education at the Harvard Graduate School of Education. Entitled "Evaluating the Uses of Computers in Schools," the institute was addressed to planners and administrators responsible for designing and evaluating the use of educational technology in school systems. Sessions covered models for conducting evaluations, research on the effects of using computers in education, current and future trends in school-based evaluations, and the need for careful attention to the fundamental purposes for using computers in schools. Tthe institute was attended by approximately 130 school administrators and others from across the nation.

Educational Technology and Educational Equity

In November, ETC was one of several co-sponsors of a conference entitled "Computers, Technology, and Issues of Equity." The conference was designed to bring local (Boston area) community leaders together with local and national policy analysts, educators, corporate representatives, and economists to investigate issues associated with technology and equity. The conference represented the initial meeting of what has become a series of work groups in the areas of: educational practice, education and labor policy, appropriate and humane use of technology, corporate/community initiatives, and entrepreneurial activities. The conference was attended by 75 invited guests. A conference report entitled Computers, Equity, and Urban Schools was prepared by ETC with funds from the Ford foundation.

ETC Coordinator of External Affairs Ceasar McDowell followed up on this effort by serving on an ongoing planning committee. In an effort to enhance dissemination of the conference report, McDowell and Charles Thompson traveled to Washington, DC, to consult with various organizations concerned with education of minority and other at-risk students.

Southwest Regional Conference

From June 23-26, ETC and New Mexico Highland University cosponsored a southwest regional conference on computers and education. ETC was asked to assist with the portion of the conference which focused on the use of technology to improve science and mathematics education.

The conference, which was attended by about 85 people from the southwest region of the country, featured an all-day workshop on evaluation techniques, along with sessions on implementation, the use of comuters to teach thinking skills, computers and writing, the use of application programs, technology and bilingual education, and in-service training.

The conference presenters included ETC Co-Directors Judah Schwartz and Charles Thompson, ETC Programming Project Leader David Perkins, members of the Highland University faculty, representatives from the Colorado, New Mexico, and Arizona Departments of Education, and practitioners from various school districts in the southwest.

Laboratory Sites Training Conference

Although the ETC Laboratory Sites Project did not officially begin until FY87, a great deal of preparation took place during the last half of FY86. Part of that preparation was a conference to acquaint lab site participants with ETC's approach to the use of educational technology and familiarize them in the specific innovations they would be using in their classrooms.

On June 30 and July 1 ETC held a two-day conference to provide an overview of the project for all participants. The first day of the conference was open to the public and was attended by about 100 educators. This day included a summary of the background and purpose of the laboratory sites followed by an introduction to each of the ETC research projects whose findings and materials will be used in lab sites: Geometry, Heat and Temperature, and Programming. Members of these projects first described the conceptual framework guiding their work and then the materials and activities included in their classroom interventions. A final presentation by the ETC Computer Conferencing Project explained the goals and approach of this project and the ways in which the conferencing system Common Ground will be used to connect lab site participants.

The second day, open only to lab site participants from schools and ETC, gave these 25 school people and 20 ETC associates an opportunity to learn more about the particular innovation they will carry out. Each of four groups--Geometry, Science, Programming, and Liaisons--met simultaneously. Each group included the relevant people from the different lab sites and several members of the corresponding ETC research group. These sessions expanded on the information provided the previous day and gave teachers an opportunity to work with the hardware and software they will use in their classrooms next year.

During the afternoon, all lab site participants met together to begin training in use of Common Ground. After learning about the structure of this conferencing software, people gathered with colleagues from their school to try logging in.

A fuller description of this conference is contained in a report entitled Teaching with Technology through Guided Exploration: A Conference on Implementation, submitted to OERI.

Seminars

This year ETC continued its seminar series, an ongoing effort to convey and extend the findings of ETC research and to explore other issues associated with educational technology. These sessions are attended by ETC associates and others from the greater Boston area who are interested in education and technology. In FY 86, ten presentations were made by researchers, technology specialists, and school practitioners. A list of the entire series can be found on page 45.

Courses

As faculty members of the Harvard Graduate School of Education, both ETC Co-Directors offer course on topics related to the Center's work. During FY 86, Charles Thompson offered a course entitled, "The Use of Information Technology in Science, Mathematics, and Computing Education," which focused mainly on the Center's research efforts. In addition, Thompson conducted a seminar on the computer as an educational innovation. Judah Schwartz taught a project laboratory in the design of educational software for grades K-12.

Presentations

Throughout ETC's existence members of the staff have represented the Center by participating in conferences, serving on committees, and giving talks at professional events. Among these presentations are the following:

Judah Schwartz

"Recent Research in Mathematics Education at ETC" and "On the Intellectual Symbiosis of Learner and Computer". Addresses to the National Council of Teachers of Mathematics, Washington, D.C., April 1-4, 1986.

Testimony. National Governors' Conference. April 8, 1986.

Plenary Address. World Congress on Technology and Education. Vancouver, B.C. May 23, 1986.

Presentation on recent research results. Soviet Academy of Sciences, Moscow. May 26-31, 1986.

"On the Intellectual Stimulation of the Intellectual Stimulator". University of Wisconsin, Madison. June 16, 1986.

Presentation on recent research results. Apple/UCAL/Berkeley Conference for Educators. Monterey, CA. August 8, 1986.

David Perkins

"Fragile Knowledge and Neglected Strategies in Novice Programmers." Paper presented at the Workshop on Empirical Studies of Programmers, Washington, D.C. June 5-6, 1986.

James Kaput

"Students as Builders Rather Than Reciters of Mathematical Knowledge: Examples Made Possible by Technology." National Council of Teachers of Mathematics, Washington, D.C. April, 1986.

Marianne Wiser

"Learning about Heat and Temperature: A Content-based, Historically Inspired Approach to the Novice-expert Shift". NSF conference, "The Psychology of Physics Problem-solving: Theory and Practice". Bank Street College, N.Y. July 21-23, 1986.

Michal Yerushalmy and members of the Geometry group

"Microcomputer-centered Plane Geometry Teaching." Paper presented at the conference of the Group for Psychology of Mathematics Education, East Lansing, Michigan. September 25-27, 1986.

EDUCATIONAL TECHNOLOGY CENTER

FY 86 SEMINAR SERIES

September 24: Henry Olds, Learningways, Inc., "Imaginative Software as New Tools for New Curriculum"

October 15: Robert Tinker, Technical Education Research Centers, "Software Tools for Learning Science"

October 29: Jeanne Bamberger, Massachusetts Institute of Technology (MIT), "Mind and Hand: Moving between Symbolic and Sensory Knowledge"

November 5: Betty Bjork, Education Collaborative for Greater Boston (EdCo), "Getting Teachers and Computers to Talk to One Another"

November 26: Christopher Hancock, ETC, and Eileen McSwiney, ETC and EdCo, "Common Ground: A Teacher-oriented Microcomputer-based Network"

December 17: Judah Schwartz, ETC and MIT, "How to Use Videodiscs in Education: An Iconoclast's View of Learning from Images"

March 25: Wallace Feuerzeig, Bolt, Beranek, and Newman, "Logo-based Algebra"

April 8: James E. Dezell, IBM Educational Systems, "Educational Technology and National Needs in Education"

April 22: Daniel and Molly Watt, Educational Consultants, "Barriers to Innovation in Education: The Case of Microcomputers"

May 13: Phil Smith, IBM Fellow, "A Programming Language for Thoughts and Dreams"