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ABSTRACT

The six chapters in this report focus on: (1) a basic orientation for a focused research agenda; (2) research on reasoning (considering the development of competence and the search for generality in reasoning skills); (3) research on instruction (examining research on teachers, curricula and curricular materials, and testing); (4) research on settings (discussing research on classroom settings, the political and social context of science and mathematics education, the home as a setting for education, and out-of-classroom settings); (5) research on new learning systems (discussing research on interactive computer software, research on microsystems, and research on developing a systems approach to improving mathematics and science education); and (6) a summary of a research agenda (considering separately, research on reasoning, instruction, settings, and new learning systems). A list of background papers is included in an appendix. The report neither describes nor endorses a program for educational reform. The intent is simply to suggest a strategy for research and development that would provide somewhat better answers to such practical questions of educational change as how to design and teach new courses to ensure student achievement and what makes an effective teacher or a good school. (JN)

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Mathematics, Science, and Technology Education:

A Research Agenda

Committee on Research in Mathematics,
Science, and Technology Education

Commission on Behavioral and
Social Sciences and Education

National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, The National Academy of Engineering, and the Institute of Medicine.

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Preface

This is a report to the National Institute of Education from the National Research Council Committee on Research in Mathematics, Science, and Technology Education. The report is based on a review of current work in relevant fields, several papers commissioned by the committee, and our understanding of existing knowledge and promising directions for research (see Appendix A for titles and authors and Appendix B for biographical sketches of committee members). It reflects our assessment of where we are and where we might go and outlines some strategies for extending and utilizing research to improve precollegiate education in mathematics, science, and technology.

The background for the report can be read in any contemporary newspaper. Concerns about the quality of mathematics, science, and technology education have become commonplace in the United States. Unflattering comparisons between the performance of American youth and youth in other countries, and between the current ineffectiveness of schools and their traditional quality, are regular topics for journals, legislatures, and street corners. The educational system has responded by raising requirements for high school graduation, by stiffening standards for teacher certification, by developing incentives for attracting able teachers, by exploring new technologies for instruction, and by challenging the validity of the critiques.

Our report neither describes nor endorses a program for educational reform. Judgments about the allocation of resources to education and their utilization are the province of political leaders and educators. Our intention is simply to suggest a strategy for research and development that would provide somewhat better answers to the practical questions of educational change: How should new courses be designed and taught to ensure student achievement? What makes an effective teacher? Or a good school? How can modern information technology contribute? How can parents and the public assess the extent to which educational goals are being reached?

This volume is the result of the efforts of many people. We have drawn gratefully on the assistance of our colleagues and would like to acknowledge particularly the contributions of the National Council of Teachers of Mathematics, especially Joseph Crosswhite and Sigrid Wagner, who provided an extensive bibliography and other materials on research in mathematics education, and of the National Association for Research in Science Teaching, especially David Butts. We want to thank the National Institute of Education for its support of this project and the National Science Foundation for support of the committee. We also want to express admination and thanks to the National Research Council staff, who made our work possible. Senta Raizen, study director, made a major contribution to the substance and organization of this report. Rolf Blank, research associate, was very helpful in the later stages of its preparation. Christine McShane, editor for the Commission on Behavioral and Social Sciences and Education, added to the clarity of the report and managed its production.

JAMES G. MARCH, Chair
Committee on Research in
Mathematics, Science, and
Technology Education

1

Introduction: A Basic Orientation for a Focused Research Agenda

Contemporary problems in American scientific education are well documented and extensively bemoaned (see, for example, National Commission on Excellence in Education, 1983; National Science Foundation, 1983; Task Force on Education for Economic Growth, 1983; Twentieth Century Fund Task Force, 1983). Although the United States continues to make substantial contributions to science and technology and has a population able to function comparatively successfully within modern technologies, the mathematical competencies of American students appear to be inferior to those of comparable student groups in several other modern societies (Walberg et al., no date; Stevenson, 1983; Travers, 1984), and achievement scores in science and mathematics have declined for 17-year-olds during the 1970s and 1980s (Hueftle et al., 1983; National Assessment of Educational Progress, 1983b). Moreover, variation among Americans in scientific and mathematical competence is high, with some minority groups particularly underrepresented among the scientifically literate (Holmes, 1980; Hueftle et al., 1983; National Assessment of Educational Progress, 1983a; National Center for Education Statistics, 1984). These disadvantages and disparities pose significant risks for American society.

This report suggests some investments in research and development that would contribute to understanding the causes of and ameliorating our present deficiencies in education for mathematics, science, and technology. At the outset, however, we should observe that many of the inadequacies of scientific education are the consequences of choices, not ignorance. A country with a market economy that accords low status to science teachers and pays them poorly should not be surprised if the teaching of science is found wanting. A university that requires little mathematics for entry should not be surprised at having to remediate student deficiencies. A society that does not encourage women to pursue technical careers should not be surprised at large gender differences in technical knowledge. Desires for scientific literacy and excellence compete with other social values, and Americans have not been willing to resolve these conflicts in favor of improving American capabilities in mathematics, science, and technology or reducing disparities among groups.

The members of this committee share an unusually strong commitment to the importance of education and particularly mathematics, science, and technology education. That commitment predisposes us to see considerable danger to our society in the choices reflected in our present educational course, and we would be disingenuous to pretend neutrality. Our report, however, is intended not as an argument for the unconditional importance of science education but as an outline of a research and development agenda that will allow this society to make choices more intelligently and to do what it chooses to do more effectively and efficiently.

Education research has profited from variety, from a long tradition of having a relatively loose structure, multiple sponsors, and multiple agendas. Without rejecting that basic strategy, we commend a somewhat more focused research agenda in this instance. We believe there is room for significant improvement in the knowledge and experience base in mathematical, scientific, and technological learning in the United States. Previous research in education has addressed a wide array of issues and has been synthesized for use in educational policy and practice (Kiesler and Turner, 1977; Shumway, 1980; Driscoll, 1982; Fey, 1982; Resnick, 1983; Shymansky, 1983; Glaser, 1984; Holdzkom and Lutz, 1984). A coherent, persistent, and broad-gauged research and development effort built on that base would facilitate a serious, nonfaddish improvement of American scientific education.

Effective education in mathematics, science, and technology requires the development of reasoning ability. We contrast reasoning with recalling facts in essentially the same form as they were learned. Reasoning involves making inferences from organized facts or using them to solve problems. It includes the ability to apply scientific concepts usefully. Learning to reason is therefore central to learning mathematics, science, and technology. But reasoning is hard to teach, and current efforts are often not successful. Although the curricula of the 1960s in mathematics and science led to some improvement in the learning of inferential skills and critical thinking skills (Shymansky et al., 1983), the effects have not been maintained as these curricula have been replaced. Current studies on the outcomes of schooling show gains in elementary knowledge and skills by younger students--the "basics" that the schools have been stressing--but higher-level processes are being acquired less well (Champagne and Klopfer, 1977; National Assessment of Educational Progress, 1983a).

Although other factors enter importantly into an effective education, a powerful factor influencing school learning is the amount of class time devoted to active teaching and learning of relevant skills--called "quality learning time" in this report. The importance of quality learning time is reflected in a core set of findings about the effectiveness of alternative learning conditions. More concentration on a subject leads to higher student performance (National Center for Education Statistics, 1981; Hilton et al., 1984; Jones, 1984; Coleman, 1985). Greater amounts of time spent by students on active learning lead to higher achievement (Stallings, 1975; Fisher et al., 1980). Given the curriculum materials in current use and the usual procedure of teacher-led group instruction, supervised learning activities involving substantive interaction between teacher and students is more effective than unsupervised instruction (Brophy and Evertson, 1976; Good and Grouws, 1977; Fisher et al., 1980). These findings do not deal specifically with the learning of reasoning, since the pertinent research is limited by the tests used to assess student learning and by the nature of classroom instruction, neither of which emphasizes the acquisition of reasoning skills. There is no a priori reason to suppose, however, that the general relationship between quality learning time and student learning does not hold as well for the learning of reasoning. The issue of turning instructional time into active learning time is particularly serious for students who come to school with motivations, aptitudes, and preparation that differ from those assumed by the teacher, the curriculum, and the school.

Expanding the capabilities of the educational system to increase the amount of quality learning time--that is, time devoted to effective teaching in contexts that engage the learner--should therefore be a primary objective of a research agenda. Quality learning time is seen to affect the development of reasoning ability through basic psychological processes occurring within the context of lessons. The learning of concepts or skills from lessons is mediated by instructors, peers, curricula, and equipment in a learning situation. Learning situations, in turn, are embedded in larger contexts of schools, school systems, families, social norms, communication systems, and political institutions. Understanding the ways in which students learn, or fail to learn, mathematics, science, and technology involves an appreciation of how these factors and their nested interactions affect quality learning time.

Therefore, we recommend research in four broad categories:

- Research on the development of reasoning;
- Research that facilitates increasing the amount of quality learning time through better instruction;
- Research that facilitates increasing the amount of quality learning time through better settings for learning; and
- Research that facilitates increasing the amount of quality learning time through the development of new learning systems.

Each of these categories includes projects that range from manifestly basic research to manifestly applied research. Historically, developments in the understanding and improvement of education have confounded simple distinctions along such lines--basic research feeds application and applications provide essential material for basic research.

The four categories of research are taken up in each of the succeeding chapters of the report. Chapter 6 summarizes our recommended research agenda.

2
Research on Reasoning

Much fruitful research on reasoning has been generated by the contradistinction between general reasoning skills and knowledge of specific subject matter as instructional goals. Some investigators have concentrated on identifying the substantive knowledge needed for problem solving in a particular area, others on the strategies used by good problem solvers, and still others on impediments to the use of reasoning skills.

An understanding of how a particular reasoning skill operates in a specific substantive context can lead to improved ability to teach the skill. For example, Larkin and Reif (1976) analyzed what information a learner should acquire while reading a description of a scientific relation and used their findings to design special training. In this training, students reading scientific text practiced finding particular kinds of information, e.g., units and symbols for quantities, typical values, scaling properties, and features distinguishing them from other quantities. After they had practiced answering such questions for a variety of passages over a period of six weeks in a physics course, the number of students who were able to learn how to use a scientific relation from its written descriptions increased from 40 to 80 percent. As another example, Anderson (1981) has developed a computer model that solves problems in geometry. Anderson's system is based on a model of how experts solve geometry problems. This model also can "understand" a student's proposed solution and give flexible advice when the student executes steps that are either wrong or unproductive. Because the model itself has an understanding of high school geometry, it does not rigidly constrain the learner to particular solution paths, but gives advice only when the student does something entirely incorrect or unproductive. Although it has not yet been proven, Anderson estimates that an instructional system based on this model may improve the efficiency of teaching geometry by a factor of two.

Knowledge required to solve arithmetic word problems has been studied in detail. Being skilled at such problems appears to be associated with being skilled not merely in the basic arithmetical operations, but also in categorizing problems according to the relationships they involve. Riley et al. (1983) have categorized word problems according to the implicit problem structure. In "change problems," a quantity (Jane's three marbles) is increased or decreased (by Tom giving Jane two more or taking two away). In "equalizing problems," two quantities must be considered and made the same (three of Jane's seven marbles have to be taken away and added to Tom's one marble). In "combine problems," two separate quantities have to be considered in combination (Jane's marbles and Tom's marbles). In "compare problems," again, the quantities remain the same but have to be compared (how many more marbles than Tom does Jane have?). To solve such problems, students must recognize distinct patterns that involve the ways in which quantities are related. This research has been used to provide explanations of the different levels of problem-solving skill that are observed among elementary school children.

Schoenfeld (1979) has developed a theory of problem-solving competence in mathematics that describes the "executive" knowledge good problem solvers use to make efficient use of their resources. The theory also deals with attitudes of students about problem-solving techniques that prevent them from using methods they have mastered. Schoenfeld presented general heuristic strategies (shown in Figure 1) that could facilitate problem solving in mathematics to a group of college science and mathematics majors and a control group. He concluded that the likelihood of students' picking up such strategies from experience is small and that problem-solving strategies must be taught explicitly as are other mathematical techniques. He also found that, even when students master problem-solving techniques, there is no guarantee that they will use them. Although experts find these strategies easy to use, students must be taught not only how to use them, but also when. When students do use them, the impact on their problem solving is substantial. However, much more research is required

(1) Draw a diagram if at all possible.

Even if you finally solve the problem by algebraic or other means, a diagram can help give you a "feel" for the problem. It may suggest ideas or plausible answers. You may even solve a problem graphically.

(2) If there is an integer parameter, look for an inductive argument.

Is there an "n" or other parameter in the problem that takes on integer values? If you need to find a formula for f(n), you might try one of these:

(A) Calculate f(1), f(2), f(3), f(4), f(5); list them in order, and see if there's a pattern. If there is, you might verify it by induction.

(B) See what happens as you pass from n objects to n + 1. If you can tell how to pass from f(n) to f(n + 1), you may build up f(n) inductively.

(3) Consider arguing by contradiction or contrapositive.

Contrapositive: instead of proving the statement "If X is true then Y is true," you can prove the equivalent statement "If Y is false then X must be false."

Contradiction: assume, for the sake of argument, that the statement you would like to prove is false. Using this assumption, go on to prove either that one of the given conditions in the problem is false, that something you know to be true is false, or that what you wish to prove is true. If you can do any of these, you have proved what you want.

Both of these techniques are especially useful when you find it difficult to begin a direct argument because you have little to work with. If negating a statement gives you something solid to manipulate, this may be the technique to use.

(4) Consider a similar problem with fewer variables.

If the problem has a large number of variables and is too confusing to deal with comfortably, construct and solve a similar problem with fewer variables. You may then be able to

(A) Adapt the method of solution to the more complex problem.

(B) Take the result of the simpler problem and build up from there.

(5) Try to establish subgoals.

Can you obtain part of the answer, and perhaps go on from there? Can you decompose the problem so that a number of easier results can be combined to give you the total result you want?

FIGURE 1 The five problem-solving strategies.
Source: Schoenfeld (1979)

to identify truly useful strategies, how experts learn how and when to apply them, and efficient means of passing this knowledge on to students.

A number of studies have identified obstacles to learning reasoning that lie in the preconceptions students bring to school. For example, Champagne et al. (1980), Clement (1982), and McCloskey (in press) have shown that college students have preconceived notions about common physical situations that run counter to and can interfere with learning the principles of physics taught in the classroom. Even after instruction, naive pre-Newtonian beliefs about basic mechanics interfere with students' understanding of the physical world. Various strong convictions, which are often reinforced by unaided commonsense perception (as in naive accounts of forces acting on the movement of objects on an inclined plane), become intertwined with new learning and inhibit its progress. Alternative learning experiences can connect these tendencies. By presenting computer simulations of events (for example, objects falling in accordance both with Newtonian principles and commonsense perceptions), experimental instruction in this area has been shown to influence strongly held beliefs and deepen understanding of the power of scientific accounts (Champagne et al., 1980; diSessa, 1982; White, 1984). Such results are examples only, but they portend a deeper understanding of the mechanisms underlying reasoning skills in science, mathematics, and technology, and the development of effective instructional strategies to teach these skills.

DEVELOPING COMPETENCE

To understand the mechanisms of reasoning skill, it has proven useful to compare and contrast the performance of more and less skilled individuals. Much more work needs to be done, but good examples of such research include that of Chase and Simon (1973), Egan and Schwartz (1979), Chi et al. (1981), Jeffries et al. (1981), Clement (1982), Lesgold (1983), and Voss et al. (1983). These studies are concerned both with how a reasoning skill operates and with the difficulties and limitations of students who have not acquired this skill. The studies indicate that problem solving proceeds on the basis of the solver's representation of the problem. Students with less skill tend to represent problems through recognition of literal surface features and not by inferences from abstracted principles in the domain of knowledge pertinent to a problem. Yet investigations in radiology, architecture, electronics, chess playing, and physics show that experts categorize problems according to principles--this is a Newton's-second-law problem, a conservation-of-energy problem, etc.--rather than according to the specific set of factors and conditions presented by the problem. The relations between a structured body of knowledge about the pertinent domain and the problem-solving process is mediated through the quality of the solver's representation. Both the scope and depth of the solver's domain-related knowledge and its organization--its completeness and its coherence--determine the efficiency of progress toward the solution. In addition, experts' knowledge includes information about conditions of applicability for various procedures. Average performers in a field often know enough about the domain to construct an efficient initial representation of a problem, but they lack knowledge of the conditions for applying certain procedures.

A major research challenge is to understand better the dynamic process through which reasoning skills are acquired, to develop a rich theory of learning particularly targeted toward reasoning skills that are difficult to acquire. Such a theory would facilitate the development of more effective interventions to help learners acquire these skills more efficiently and reliably. Productive work in this area includes that of Greeno (1980), Anderson (1981), Larkin et al. (1983), and Riley et al. (1983). Anderson's instructional system for geometry, mentioned earlier, not only includes sufficient knowledge to solve a wide range of geometry problems, but it can also adjust the nature of this knowledge to match the state of the learner. For example, for a beginner, the system might break up the recognition of congruent angles into several substeps. For a more advanced learner, the system might expect the learner to recognize congruent angles in a single step. Larkin has noted that experts and novices solving textbook physics problems use a very different set of subgoals. A typical novice, however, exhibits a strategy that shows a few expert features as well as a predominantly novice structure. Thus it seems that learners gradually acquire the system of subgoals that experts use productively. As another example, Riley et al. have developed a model of how children's knowledge for solving simple word problems changes over time. Primitive versions of the model are based on extremely simple mental structures, while more powerful versions can take advantage of more elaborate structures.

In studies contrasting more and less skilled individuals, the more skilled individuals are often much easier to understand. They have well-formed processes and models of knowledge that correspond accurately to the discipline. In contrast, less skilled individuals often have processes and organizations of knowledge that are rich and complex, unstable, and do not correspond accurately to the discipline. Current research (McCloskey et al., 1980; Clement, 1982; McCloskey and Kohl, 1982) suggests that learners do not simply discard these processes when they are instructed. Instead, their initial reasoning processes interact with instruction in complex ways. Research efforts should be targeted toward understanding those initial processes and showing how they can be addressed through instruction (Glaser, 1984). One approach might be through confrontation so that new, more effective processes can replace old. Another approach might be through incorporation, where useful aspects of initial processes can be incorporated into more accurate and effective processes.

Cognitive studies use the notion of prototypical knowledge structures or schemata to account for various phenomena in memory, comprehension, problem solving, and understanding. Schema theory attempts to describe how acquired knowledge is organized and represented and how such cognitive structures facilitate the use of knowledge in particular ways. This theoretical construct has particular utility for devising approaches to instruction as individuals attempt to interpret new information on the basis of prior knowledge. Modes of instruction that demand interrogation of the learner's knowledge and thinking and that demand confrontation with new knowledge are being investigated by a number of researchers. For example, Collins and Stevens (1982) have studied effective teachers' procedures for teaching students domain-specific rules and theories. The procedures involve shaping a line of inquiry that helps students articulate their naive initial conception of facts and principles and then accept, modify, or reject them in the light of their predictive power, congruence with new facts, and the like. This inquiry approach both enables the student to assimilate new information efficiently and provides practice in deriving rules or theories for related knowledge. An important feature of the approach is the selection of cases and questions that enable students to use extant knowledge as a framework for new learning.

Research toward better understanding of children's developing capabilities for scientific reasoning is needed, including more detail on the capabilities of children at varying ages and on the kinds of scientific experiences that aid the development of those capabilities. Work on understanding scientific reasoning in young children has illustrated that they are capable of using quite intricate thought processes (Carey, 1985). The nature of mathematical concepts on which young children build their learning is beginning to be described. Pervasive changes in children's reasoning and learning abilities appear as they gain knowledge in various domains. Researchers need to study what children can do as well as what they cannot do. As Gelman and Gallistel (1978:242) note: "the discoveries we have made about development would not have been possible if we had followed the trend of considering preschoolers merely as beings who lacked the capacity of their older siblings. Our hypothesis of more capacity than meets the eye has served us well. We expect that researchers who keep their eyes open will find still more unexpected ability in young children."

The committee recommends research on how competence in reasoning skills is acquired, including the mechanisms of reasoning skills, particularly as evidenced in the differences between novice and experienced learners; the dynamic processes through which reasoning skills are acquired in the context of specific domains of knowledge; and the scientific reasoning skills of children.

THE SEARCH FOR GENERALITY IN REASONING SKILLS

Despite many efforts to understand and teach "general" reasoning skills, success has been unclear. For example, Polya (1957) outlined some general help for solving problems. He divided problem solving into four phases--understanding, planning, executing, and looking back--and formulated heuristics such as thinking of a simpler problem that is similar to the difficult problem at hand. While almost everyone finds these formulations appealing, success in improving problem solving behavior based on such general advice remains to be demonstrated. Early computer models of problem solving were also quite general. Ernst and Newell (1969), for example, developed a "general problem solver" with computer codes for solving problems that could be applied to a variety of specific task domains, including algebra, geometry, several puzzles, and logic. Again the example is appealing, but this line of work has not developed into truly powerful general problem solvers. One explanation may be that effective reasoning requires a large amount of domain-specific knowledge, as illustrated by the work cited in the previous section, and relatively little general-purpose knowledge. This conclusion is further supported by considerable recent work on modeling and simulating experts in various fields. The models generally do require a large amount of domain-specific knowledge and relatively little general-purpose knowledge (Davis et al., 1977; Duda et al., 1978). Studies of problem solving by cognitive scientists have indicated a strong influence of specific knowledge structures on effective performance in a discipline (Lesgold, 1983; Voss et al., 1983).

Studies in the social sciences, particularly protocol analyses of expert and novice political scientists, indicate that problem solving in these fields generally proceeds through an analysis of the historical background of the problem, the positing of a solution, and its consideration in the light of the subproblems it would generate. For example, experts who were asked to consider the Soviet agricultural situation laid out the problem first either in terms of its actual history or in terms of long-standing ideological factors influencing agricultural policy. Their solutions consisted of lines of intersecting argumentation on subproblems such as technological capacity, transportation, supply and demand, and agricultural education. In this instance, experts were differentiated from novices not only by the range of subproblems they uncovered in examining the implications of their solutions, but also in the quality and depth of the knowledge they incorporated into their lines of argument (Voss et al., 1983). The latter is important in the social sciences, in which the test of a solution is the strength of the argument since hypotheses can seldom be experimentally validated.

It appears that problem solving and comprehension are based on knowledge, and that people continually try to understand and think about the new in terms of what they already know. If this is indeed the case, then it seems best to teach reasoning skills--e.g., skills needed for solving problems and for correcting errors of understanding--in terms of knowledge domains in which individuals are attempting to become competent.

To further such teaching, the committee recommends research on reasoning in particular disciplines, aimed at understanding how abilities to make inferences, to reason, and to generate new information can be fostered by ensuring contact with prior knowledge that can be restructured and further developed as learning takes place.

There is, however, research that suggests how particular general-purpose reasoning skills may operate (Larkin and Reif, 1976; Schoenfeld, 1980; Larkin et al., 1983; Palincsar and Brown, 1984). In these studies, researchers have specified the skills to be taught in detail and applied them to a focused set of related domains. For example, in an integrated set of training studies, Palincsar and Brown have shown that instruction based on a system of inquiry can greatly increase children's skills in understanding what they read--from 20 percent to 60 percent correct scores on reading comprehension tests. The training sessions they designed focus on encouraging children to internalize skills that foster comprehension. These skills are modeled bythe instructor, who leads dialogues involving paraphrasing main ideas, questioning ambiguities, predicting questions that are implicit in a given passage, and hypothesizing the array of themes of a reading passage. The aim of the sessions is to enable the children to lead such dialogues and eventually develop techniques of self-criticism. An important aspect of the instruction is keeping students fully aware of the purpose of the activity, its utilities for comprehension, how it improves their deficiencies, how and when to use the various interrogative techniques, and the expectation that they will eventually internalize the techniques in their own performance.

Currently, significant effort is being devoted to thinking and reasoning courses in secondary and postsecondary education; the effectiveness of such instruction requires careful analysis and evaluation (Chipman et al., in press; Segal et al., in press). Of particular interest are the self-regulatory or metacognitive capabilities present in mature learners. Examples of these abilities include knowing what one does and does not know, predicting the outcomes of one's performance, planning ahead, efficiently apportioning time and cognitive resources, and monitoring and tailoring one's efforts to solve a problem or to learn (Brown, 1978). These skills vary widely. Although individuals can be taught knowledge of subject-matter rules and procedures or appropriate theories, if transfer of learning to new situations is a criterion, then they need to know how to monitor the use of this knowledge. Self-regulatory activities thus become important candidates for instruction, and their presence may predict student abilities to solve problems and to learn successfully.

Hence, the committee recommends focused research on self-regulatory or metacognitive capabilities--what they are, how they develop, and how learners can be helped to acquire them. We also recommend systematic tracking of outcomes resulting from efforts to teach generalized thinking and reasoning skills.

3
Research on Instruction

Whatever is known about the acquisition of reasoning skills in mathematics and science, such knowledge needs to be translated into classroom instruction. Teachers and curriculum are key to the amount and quality of time spent on instruction; testing assesses the outcomes of instruction. This chapter discusses research on each of these three elements.

RESEARCH ON TEACHERS

To use time given to instruction effectively, teachers must be competent and willing to exert sufficient effort. (See Levin, 1980, for a cogent discussion of teacher inputs to educational productivity.) Teacher competence involves adequate cognitive mastery of the subject matter to be taught and, in the case of science especially, proficiency in handling experimental materials that can lead students to form new concepts from observation and evidence. For example, Arons (1981) argues that even the best curricula will be ineffective unless teachers are trained to deal with various modes of abstract logical reasoning, for example, the logic of arithmetic involved in ratios and division, the logic of control of variables, dealing with propositional statements, recognizing gaps in available information, making inferences and predictions from mental models, doing hypothetico-deductive reasoning, and the like. In fact, the processes and problems involved in educating teachers to acquire these capacities are not very different from those involved for any other learners. But, Arons (1983) also argues, subject-matter courses taken by prospective teachers--usually the standard courses offered by science departments--often cover too much content at too rapid a pace and seldom pay explicit heed to developing reasoning capacities. Hence, prospective and practicing teachers often lack a genuine understanding of concepts and lines of reasoning that characterize the subject(s) they are teaching and, having missed effective training themselves, are unable to cultivate and enhance the basic abstract reasoning capacity of their students.

The shortcomings in his or her college courses may be one of the reasons a teacher's background in science (as well as preparation in professional education) shows relatively low correlations with student outcomes (Druva and Anderson, 1983). However, there may be other possible explanations for these low correlations, including lack of significant variations in teacher training, low correspondence between subject matter taught and the content of tests (Freeman et al., 1983), and such other factors as teacher motivation and energy level.

Whatever its effect, little is known about the subject matter preparation of the 2.37 million teachers in the current pool (Raizen and Jones, 1985), much less about their competence for teaching science and mathematics. Two ongoing surveys, one by the National Center for Education Statistics and one by Research Triangle Institute, will provide some relevant information, but it will be limited in scope. Much general information on teachers is also being collected in connection with the National Assessment of Educational Progress; assessments in mathematics and science and concomitant teacher surveys are scheduled for 1986. Meanwhile, in the absence of sufficient knowledge about the nature of teacher preparation programs, assessment of teacher quality has been based on reviewing SAT scores of college freshmen planning to be teachers (Weaver, 1979; Schlechty and Vance, 1983) and increasingly on the scores of newly entering teachers on the National Teacher Examination or on state-constructed teacher tests.

Over the last five years, states have made various policy changes intended to increase the quality of teachers: 32 states have changed teacher certification requirements; 28 states have changed teacher education curricula, and 20 states have raised entrance requirements for teacher education programs (Goertz et al., 1984). Other policies that have been proposed include salary increases and structural changes in compensation for teachers, requiring liberal arts majors for all teachers and possibly a five-year rather than a four-year degree program (Scannell and Guenther, 1981; Boyer, 1983; National Commission for Excellence in Teacher Education, 1984), and ensuring teacher competence through a nationally recognized licensing examination (Albert Shanker, as reported in the Chronicle of Higher Education, 1985a). With respect to increasing the quality of science and mathematics teaching specifically, monies have been appropriated by Congress and by a number of states to provide loans and scholarships for students preparing to enter these fields (U.S. Department of Education, 1984), and a program for developing models for teacher education has been established by the National Science Foundation.

Few of these policy changes are based on research evidence that relates the proposed interventions to observed responses on the part of individuals who might enter teaching (Murnane, 1985) or to the acquisition of knowledge and skills deemed necessary for science and mathematics teaching. Indeed, there are indications that some of the new policies may prove ineffective or have some undesirable consequences. For example, Summers and Wolfe (1977) found a statistically significant negative correlation between teachers' scores on the National Teachers Exam and their students' test score gains. Increases in credentialing requirements may rob local districts of the flexibility to hire individuals who exhibit the capacities for teaching mathematics and science but lack the credentials; abolishing traditional credentials, as New Jersey has done and other states are considering, may have the perverse effect of setting lower rather than higher standards (Chronicle of Higher Education, 1985b). Moreover, simply raising requirements to enter teacher education programs is likely to reduce the socioeconomic and racial and ethnic diversity of the nation's teaching force at a time when schools will be educating a larger number of minority students (Goertz et al., 1984). Systems of compensation such as merit pay that require evaluating teacher performance are hampered by the difficulties of developing and implementing such evaluations (Wise et al., 1984) and, perhaps for that reason, historically have had a short life span (Educational Research Service, 1979).

The current experimentation with incentives, teacher education programs, and credentialing sharpens the need to understand better (a) who gets access to teacher preparation programs under various conditions, (b) the content of these programs, and (c) the regulation of access to teaching positions. These factors are poorly understood even for the current pool of teachers. The unplanned variations resulting from current policy changes provide a rich opportunity for assessing the effects of various alternatives.

Therefore, the committee recommends the development of a national data base on teacher preparation and qualifications sufficiently detailed and appropriately stratified to reflect conditions in different types of school districts and for varying student populations. We recommend a research program to develop improved understanding of: (1) the response to various monetary incentives designed to attract able individuals to mathematics and science teaching and keep them in these fields; (2) how to improve the subject-matter education of both pre- and inservice teachers, including optimal volume and pace of subject-matter coverage in different sciences and experiences that develop and enhance abstract reasoning capacity; and (3) the effects of alternative requirements for entering and being certified in the profession, particularly with respect to developing an adequate pool of teachers competent to teach mathematics and science.

Effective use of instructional time involves not only the teacher's capacity, but also the teacher's effort (Levin, 1980). Direct measures of the quantity of teacher effort in the classroom (e.g., the amount of time spent by the teacher on direct instruction or active teaching) and indirect measures (e.g., the amount of time students are "on-task" or engaged in learning) show positive correlations with student performance (Brophy and Evertson, 1976; Good and Grouws, 1977; Fisher et al., 1980). Particular aspects of active teaching have also been investigated as to their effectiveness--for example, strategies for giving information (Rosenshine, 1968; Armento, 1977; Smith and Sanders, 1981) and reacting to their responses (Clark et al., 1979; Evertson et al., 1980) and for assigning and checking homework (Good and Grouws, 1977; Walberg and Rasher, 1985). However, attempts to assess teacher behavior have been limited to specific instructional settings (Gage, 1978), and no consistent pattern of success across subject areas or specific groups of students has emerged (Brophy and Evertson, 1976; Medley, 1979). The exception is work on the assignment of and feedback on homework--apparently an effective way of extending learning time through teacher effort.

Teacher effort is not solely a consequence of individual attributes; it is also influenced by the organizational characteristics of schools: the degree of autonomy allowed teachers in their own classrooms and their contribution to school practices and policies (Levin, 1980; Lightfoot, 1983), opportunities for professional interaction and encouragement of innovation (Grant, 1981; Little, 1981; Lipsitz, no date), explicit and tacit reward structures and sanctions (Lortie, 1975; Sykes, 1983), and the general values and attitudes of teachers, for example, consensus on academic goals and norms for behavior (Brookover et al., 1979; Rutter, 1979). Unfortunately, assessing the effects of such factors on teacher effort is even more difficult than measuring teacher capacity or teacher behavior in the classroom. Nevertheless, it is important to conduct research on how societal pressures, school organization, and educational policies affect the effort teachers are able and willing to invest in instructing their students.

RESEARCH ON CURRICULA AND CURRICULAR MATERIALS

Advanced scholarship in a subject is based on theories and concepts that serve to make a domain accessible to subject-matter experts. However, a theory for the expert may not be good pedagogical theory for the novice. As already noted, recent work in cognitive psychology has described how acquired knowledge is organized and represented, and how cognitive models can facilitate reasoning and thinking as students use and test these models to solve problems and revise what they already know (Estes et al., 1982; Rumelhart and Norman, 1981). Such research has had little influence, however, on the rigidly hierarchical conception of science and mathematics that undergirds most classroom instruction. Nevertheless, effective teachers use their experience of how students learn to shape the subject matter they present. This craft knowledge provides a second source for developing pedagogical theory for teaching science and mathematics to students at different levels of competence and education. Still a third source is the current experimentation with computer systems for intelligent tutoring, based on models of how successful students perform various cognitive tasks (Sleeman and Brown, 1982; Anderson et al., 1985).

Based on work from these sources, the committee recommends research directed toward effective instructional strategies based on explorations of: (1) the design of pedagogical theories that students can test, evaluate, and modify; (2) the techniques of ingenious teachers who are able to devise such temporary models or pedagogical theories; and (3) the design of intelligent computer-assisted instruction that incorporates interrogation and exploration.

In addition to these general research issues on curriculum, there are specific questions surrounding the subject matter of technology. Unlike the more traditional domains of science and mathematics, technology and computer science do not have well-established curricula. Many schools are now introducing "computer literacy" courses. Often, such courses focus on teaching programming in a particular computer language. In other instances, computer literacy courses deal with the capabilities and functioning of computers, either with or without hands-on experience, and may include topics on the effects of computers on the workplace and society. At more advanced levels, science and mathematics courses may devote some class time to illustrating changes in these fields that have come about because of the availability of poweful computational tools.

In the committee's view, there is insufficient knowledge about the age and grade levels at which the computer and programming should be introduced and about the effects of alternative curricula in computer literacy. Systematic attention must also be given to how the knowledge structures and the processes of the sciences and mathematics have changed as a result of readily available computation and what these changes imply about the school curriculum. For example, the advent of calculators made traditional drill in using logarithm tables superfluous. Similar issues need to be explored regarding the advent of more powerful computers for all the science and mathematics courses taught in school.

The committee recommends research targeted at providing characterizations of the cognitive skills and knowledge needed for understanding of and successful performance in technological systems; based on such characterizations, development of usable school curricula in computer literacy; and investigating the effects of computers on the knowledge structure of mathematics and various sciences and the changes implied for the school curriculum.

Recent research with preschool children suggests that changing the context of the learning task, or "recontextualizing," can help students acquire some basic cognitive skills (holding information in memory, building structural representations for later use, comparing perspectives) essential to achievement in science. Istomina (1975) compared the performance of preschool children on a test-like version of a free recall task and the same task embedded in a role-playing game of being sent to a make-believe store for a list of items. Activation of the four- to five-year-olds' still-crude memorizing operations was greatly facilitated by the play situation.

Similarly, Margaret Donaldson (1978) and her students addressed the presumed inability of children younger than 10 to 11 years of age to take account of another person's visual point of view (Piaget and Inhelder, 1975). They demonstrated that perspective-taking ability is present in very young children in the right circumstances. Donaldson arranged for the problem to involve toy children hiding from a toy policeman. Only by taking the policeman's point of view could the child subjects know where the toy children should hide. Four- to five-year-olds succeeded at this problem even when they had to coordinate the points of view of two policemen, whose view of the scene was different from their own.

As a final example, decades of research on "delayed responses," in which an object is hidden in one of several boxes and children are required to search for it several seconds or a few minutes later, has shown children to be deficient in their ability to keep the location of objects in mind. DeLoache and Brown (1979) repeated this experiment with two- to three-year-olds in their homes. Instead of hiding a piece of candy, children's favorite toys were hidden under a piece of furniture. Under these conditions, children would remember the location of the hidden object for 24 hours, the longest intervals tested.

This research suggests that a fundamental way of changing how much time is needed for a particular task is to change the context of the task as presented to and understood by the learner. The cognitive task was more successfully completed when it was embedded in some larger activity involving familiar scripts and human intentions.

These examples from research on young children are not intended to suggest that recontextualization for older learners must always strive for simplification or that it should only involve making materials more familiar and obviously utilitarian. Knowledge is unavailable on how the insights gained from the work with young children can be applied at higher levels of the curriculum in the areas of science, mathematics, and technology. However, there is evidence that science curricula combining activity-based instruction with appropriate text materials are more effective than traditional curricula in teaching higher-order skills (Shymansky et al., 1983; Holdzkom and Lutz, 1984).

On the basis of such research, it has been argued that programs and school curricula in science and mathematics should stress utility and practical applications rather than heavy reliance on theory (Harms and Yager, 1981). Hands-on, laboratory, and activity-oriented are accurate descriptions of most programs identified in recent surveys as exemplary, especially at the elementary level (Penick, 1983). However, activity-based teaching is notoriously difficult to carry out and appears at times to be in conflict with the high level of control of the teacher over classroom activities advocated by some proponents of research results on effective teaching (Stallings, 1975; Hunter, 1984; Brophy and Good, 1985). Moreover, a broad conclusion rejecting more abstract curricular forms is clearly premature. For example, a trademark of the SEED program (Johntz, no date) is demonstrating the success of minority students in performing highly theoretical mathematical manipulations with little focus on applications or ties to anything concrete. At least in the hands of an extremely competent and knowledgeable instructor--usually a scientist or mathematician in the case of the SEED model--theoretical training works.

Because of the great importance of curricular orientation and context to learning, particularly to the learning of mathematics, science, and technology, the committee urges special emphasis on this research area. Priorities include research on how important tasks can be embedded in contexts that reduce the time needed for learning; under what circumstances and in what ways activity systems using physical objects and "real" events (whether hands-on experience, models based on systematic laws, or story lines that mirror common experiences) can be used to enhance learning; and what makes theory-oriented instruction work, especially with individuals from some minority groups and women generally said to require a more pragmatic, utilitarian approach.

Curricula depend on and are built around educational materials. Textbooks and, to an increasing degree, educational computer software are central factors in determining what is learned on what time schedule (Stake and Easley, 1978). The content of textbooks is influenced by the authors' sense of appropriate learning goals, the publishers' perception of the demands of the education market, and state and local district priorities and procedures for textbook approval and selection. There is some information on choice of textbooks, but it dates back to a 1977 survey (Weiss, 1978). This survey will be repeated in 1985, but even though it may yield information on what texts are used, there is no systematic effort under way to analyze the content of these texts.

During the development of reform curricula in the 1960s, much attention was paid to the balance between emphasis on facts and emphasis on concepts and learning how to learn. Students using the reform curricula did appear to make greater gains than their counterparts on reasoning and problem-solving skills as well as on general achievement measures (Shymansky et al., 1983). There is no equivalent current information on textbook content (Walker, 1981), although analysis of the structure and language of science textbooks has documented that the learning of special or technical vocabulary, i.e., rote memorization, is a central feature of these texts (Yager, 1983).

The increasing use of standardized tests to assess student achievement assumes that a curriculum covers the material on the test. Based on a detailed analysis of fourth-grade mathematics texts and tests, Freeman et al. (1983) found (p. 511) "the proportion of topics covered on a standardized test that received more than cursory treatment in a textbook was never more than 50%." Limited as it is, such evidence indicates possible inaccuracies in general assumptions about the curricular content of educational materials in current use. Further evidence on disparities between the assumed ("intended") and actual ("implemented") curriculum comes from several large-scale studies on student achievement. For example, the studies conducted by the International Association for the Evaluation of Educational Achievement (IEA) have attempted to relate the items on student achievement tests to the opportunity students had to learn the material through asking their teachers whether pertinent instruction had been provided. The opportunity to learn the material turned out to be highly correlated with student test scores (Husén, 1967; Wolf, 1977; Crosswhite et al., 1985). The National Assessment of Educational Progress (1985) also includes measures of the implemented curriculum, such as asking teachers of students taking the mathematics tests what topics are included in mathematics instruction in grades 6-8.

Differences in implemented curricula presented to different sorts of students affect their opportunity to learn (Alexander and McDill, 1976; Entwisle and Hayduk, 1982; Barr and Dreeben, 1983). Thus, the effects of ability grouping and tracking on learning are realized not only through differences in instructional strategies and peer influences but also through differences in the curriculum to which different groups of students are exposed (Rosenbaum, 1976; Cicourel and Kitsuse, 1983; Hallinan and Sorensen, 1984).

The committee recommends a concerted research effort on how educational curricula and materials are created, their content, and how they are used, specifically, on (1) whether and how the treatment of substantive content in current textbooks and software supports the learning of reasoning, thinking, and problem-solving skills as well as lower-order recall and memorization tasks; (2) the exploration of new content areas within various fields and at various grade levels that might be productive additions to promoting higher-order skills; (3) the abilities, skills, and perspectives of those who write textbooks and software (for example, to what extent do they understand the importance of curricular context, as discussed above) and the means for attracting better prepared individuals to those fields; (4) the development of consensus on appropriate subgoals, content, and sequencing by grade level to facilitate greater emphasis on higher-order skills; (5) the effects of state approval processes on content issues; and (6) further studies on the relation between what is tested and what is included in textbooks and software and between the intended and the implemented curriculum.

RESEARCH ON TESTING

The testing of cognitive achievement and aptitude plays a powerful role in American schools. Tests are used to group and track pupils, resulting in the differentiation of pupil experiences. Tests are used to diagnose current knowledge and skill prior to instruction. Tests are used to assess mastery of instructional objectives. Tests are used to evaluate teaching and instruction. There is a widespread consensus among cognitive scientists that many of these procedures are inadequate, particularly in the assessment of higher-order thinking skills (Frederiksen, 1984).

Assessing reasoning ability is not easy. Traditionally, it has best been done by open-ended tests requiring problem solving and free-form answers (e.g., essay and problem tests). Such tests are difficult to administer and to grade, particularly for large numbers of individuals. There is a long and productive line of research within the field of psychometrics on the practical measurement of a variety of intellectual skills. There is a new and promising line of research that links traditional psychometrics to the growing understanding of reasoning skills described above (Hunt et al., 1973; Glaser, 1981; Sternberg, 1977, 1984). Inexpensive, powerful computers provide a new possibility for more effective interactive testing. Using current microcomputers to test students could be more accurate and less time-consuming for those taking tests as well as less labor-intensive for those administering tests (Weiss, 1983), but further research is required to substantiate that possibility.

Tests also play a role in the learning process itself. They tell students what in the curriculum is important and shape the teaching and learning process (Frederiksen, 1984). If, for example, testing is confined to memorizable end results, students will concentrate on these end results, ignoring the more sophisticated levels of understanding and reasoning to which teachers and text materials may be rendering lip service. Teachers and school administrators also use tests as a guide to curriculum emphasis, especially when student performance on given tests is used as a measure of teacher and school performance.

The committee recommends a program of research on testing, including: (1) the development of practical tests that reliably assess reasoning ability, perhaps using interactive testing made possible by microcomputers; (2) improving the testing of mathematics and science achievement to reflect important instructional goals and objectives; and (3) techniques for educating teachers to become better writers of test questions, particularly of questions that test for the higher-order intellectual skills and levels of learning.

4

Research on Settings

Formal instruction takes place in the classroom, but the classroom is not isolated from the rest of society. Classrooms are subject to school policies and explicit and implicit educational goals. Schools, in turn, are shaped by the political and social context in which they operate. Moreover, school is not the only seting for learning: children come to class shaped by their homes and by informal learning done outside school.

RESEARCH ON CLASSROOM SETTINGS

Repeatedly in the history of American education the prevalence of routine instruction has been criticized, attempts to change the situation have been undertaken, and those attempts have failed. Perhaps the problem is more fundamental than previously conceived. The roots of the problem may go deep into the ecology of everyday teaching practice.

Descriptive studies suggest that the organization of American classrooms is largely based on teacher-led whole groups (Dunkin and Biddle, 1974). Teacher-led small groups tend to occur primarily in early grades, particularly in reading instruction (Cazden, 1983). Small groups of students working together cooperatively are infrequent in today's school--limited to 2 percent of students, according to one study of 129 elementary school classrooms (Sirotnik, 1981)--and are more common in social studies and science than in other subject areas (Stodolsky, 1984). Promising classroom strategies can take hold only where the wider school setting provides a favorable climate. Considerable work has been done on the relationship of alternative strategies of classroom organization to student achievement through the production of active learning time. An extensive study describing the teaching and learning of mathematics and reading in grades 2 and 5 (Fisher et al., 1980) found that more substantive interaction between students and an instructor is associated with higher levels of student engagements, and that class lessons depending on seat work do not permit the right kind of substantial interchanges crucial to effective learning time. Some strategies based on behaviorist principles have been developed for improving student engagement during seat-work lessons and appear to have been effective for learning simple skills. (See, for example, Rosenshine, 1979, and Gersten, 1984, for syntheses of findings from the models tested in the "Follow-Through" program.) The solution more generally adopted by teachers is to break the class into smaller groups for instruction. This solution, however, is fraught with problems.

A large body of research on the organization of classroom activities focuses on the effects of different principles of grouping for instructional purposes. Group placement based on ability is common to reduce heterogeneity and match instruction more effectively to learners' skills. Such placement has been shown to be stable over time (once in the low group, it is hard to get out) and to have differential impact on high- and low-group students. Studies consistently and robustly document that ability grouping has detrimental effects within classrooms on average and low-ability groups. Persell (1977:92), in a review of 217 studies, found that "there is a slight trend toward improving the achievement of high-ability groups but that is offset by substantial losses by the average and low groups." Differences in instruction across high and low reading groups, with respect to both content and the quality of interaction, have been found to "sustain the poor performance of slower students and to increase the disparity between the two groups" (Good and Marshall, 1984:18). Inappropriate grouping may amplify relatively minor differences at the beginning of first grade into major differences in later grades (Hallinan and Sorensen, 1984).

Both the literature on teacher-student ratio (e.g., Glass et al., 1982) and that on effective learning time (e.g., Denham and Lieberman, 1980) urge a reduction in the size of the instructional group representing the primary teaching unit. But neither of these research traditions motivates any particular principle of grouping. On the basis of a review of relevant studies of children organized to work in peer groups, Stodolsky (1984) concludes that "children working together produced problem solutions characterized by higher cognitive levels of response than individual children could produce." There is also evidence that peer work groups need not be homogeneous, that cooperative, mixed-ability group processes seem genuinely to enhance learning and cognitive development in some circumstances (Sharan et al., 1984; Slavin, 1978.)

Evidence about the proper mix of circumstances is sparse, but some principles have emerged. First, the school principal and school administration must support alternative classroom behavior that does not fit the stereotype of quiet children obviously controlled by the teacher. Second, the care with which tasks are designed and materials prepared is even more important in peer work groups than in teacher-led groups precisely because the teacher is only intermittently available. Third, the learning of curriculum content in a peer work group is positively related to the frequency of interaction within the group, and that in turn is correlated with social status in the classroom (Cohen, 1984). Thus, it appears that cooperative groups do not necessarily ensure equal exposure to learning. Differential treatment can come as readily from peers as from a teacher. However, some experimental evidence indicates that, by manipulating the activities of the individuals involved in activity groups, it is possible to change their perceived status evaluations and bring about positive educational outcomes (Kagan et al., in press; Cole, 1985).

Constructing effective learning groups in the classroom holds great promise for increasing quality learning time devoted to higher-order skills. Therefore, the committee urges research on how to make student activity groups successful in multi-ethnic classrooms for a range of mathematics and science tasks, including improved understanding of the ideological and pragmatic reasons teachers group their students by ability and prefer teacher-led groups to cooperative student-led groups; investigating systemic factors relating to societal and institutional pressures on schools and teachers to arrange their classrooms and instruction so as to produce easily measurable performance results; and developing kinds of teacher training that facilitate widespread adoption of activity-centered curricula when this approach is appropriate.

Linguistic and cultural factors can serve as resources for changing contextual and motivational factors that promote educational excellence. For example, Erickson and Mohatt (1982), working among the Odawa in Canada, found that Odawa teachers were spontaneously and intuitively adapting instruction in culturally responsive ways by using discourse modes prevalent in the children's community. The phenomenon that Erickson and Mohatt addressed was the apparent passivity and silence of Native American students in regular classrooms (Phillips, 1972). Erickson and Mohatt showed that it is possible to construct rules of participation in the classroom that are a functional blend of Anglo school curriculum and Native American discourse styles and that make the classroom run more effectively. Moreover, it appears that these patterns can be learned; an Anglo teacher was observed to change his rules for classroom participation over the course of the school year in the direction of the style of instruction used by the Odawa teachers.

Classroom settings can be transformed for the better by taking students' language and culture into account. The best documented example is the decade-long research and development effort at the Kamehameha Early Education Program (KEEP) in Hawaii (Tharp, 1982). The teacher allows the children to discuss text ideas and therefore learn to read, using rules for speaking and turn-taking similar to those familiar to their culture, particularly overlapping speech and the cooperative production of narrative. In a series of related studies Moll and Diaz (1980, 1982, 1984) analyzed student and teacher language used in reading lessons in two bilingual classrooms. Moll and Diaz concluded that students' reading skills in their native language were seriously underestimated and were not being effectively taken advantage of in the second language setting because the teacher was mistakenly aiming the lessons at the students' oral skills and not their reading skills. They reorganized reading lessons so as to permit students to rely on and display reading skills acquired in their native language, at the same time acquiring advanced reading skills in their second language.

Most of the research on language and culture is focused on instruction in literacy. Relationships of culture and language to instruction in science and mathematics are barely understood. Cazden (1979) has speculated about the benefits and liabilities associated with the use of students' first or second language in science and mathematics. Science instruction that involves laboratory investigation may be a particularly good environment for learning in a second language because of the presence of concrete referents of objects and operations. However, as far as the role of culture is concerned, present knowledge does not even allow one to speculate.

To further the goal of developing more effective mathematics and science instruction for all students, the committee urges research and development to explore the relationships among the cultures of various student subpopulations, the culture of the classroom, and the cultures of mathematics, science, and technology; and research to understand the role of language and culture in the teaching of science and mathematics.

RESEARCH ON THE POLITICAL AND SOCIAL CONTEXT OF MATHEMATICS AND SCIENCE EDUCATION

The goals of mathematics, science, and technology education as stated by planning commissions and scientists consistently emphasize reasoning, thinking, and problem-solving skills (see, for example, National Council of Teachers of Mathematics, 1980; National Science Foundation, 1983; Task Force on Education for Economic Growth, 1983; American Chemical Society, 1984). Some of the research we cite shows that such an education is possible but that it is not typically achieved in contemporary American education. Apparently, an insufficient portion of the education experienced by most students is aimed toward developing reasoning skills. This deficiency may be even more severe among minority and female students in that they are less frequently enrolled in higher-level mathematics and science courses.

The question is why the recommendations and policies of special commissions, boards of education, and superintendents about higher-order thinking skills appear to have so little effect on day-to-day classroom activities. What are the barriers that keep political and educational institutions from fully grappling with the achievement of stated goals in mathematics and science education? Are they to be found in the deployment of resources, the apportionment of responsibility among the several governance structures, local district policies and operating procedures, the decisions of individual teachers on what to teach?

The resources used for instruction in mathematics, science, and technology are provided by the combined contributions of federal, state, and local governments. Historically, the bulk of these resources and the rules by which they were to be allocated were determined locally. In recent decades, however, both the federal government and, even more importantly, state governments have begun to play an increasingly significant role--both in terms of financial resources and as sources for new initiatives and undertakings. Thus, between 1971 and 1980, the state contribution to revenue receipts of public schools rose from 38.3 to 47.4 percent, while the local share decreased from 52.8 to 43.3 percent; the federal share stayed relatively level (National Center for Education Statistics, 1983).

It is often assumed that an increased role in funding brings with it increased authority for policy. However, little is known for certain about the significance of shifts in funding sources for instruction in mathematics and science. For education in general, four different views have been offered in the literature. The first regards federal and state initiatives as having little more than symbolic impact: the key decisions relating to the organization and morale of individual schools remain in the hands of local principals and superintendents who are selected by local school boards. The National Defense Education Act of 1958, for example, was the first major federal effort to raise the quality of public education. Yet it had had little direct impact on local school decision making, although it may have created a climate of opinion in which science and mathematics were thought to be important (Peterson, 1983; Sufrin, 1983).

In the second view, federal and state initiatives present opportunities for upgrading and enhancing instruction for populations or subjects of special concern. Minimum standards can be set; states can attract higher-quality teachers through differentiated salary schedules; new, higher-quality curricula can be disseminated more easily in a more centralized system. At this time, quite clearly, much of the impetus for school reform is coming from governors, state legislatures, and state departments of education (Dougherty, 1983; Education Commission of the States, 1983). Local attentiveness to initiatives varies widely, however, and is dependent on local conditions (Elmore, 1983; Berman and McLaughlin, 1974-1975; Wimpelberg and Ginsberg, 1985) as well as on the vigor with which states implement policies and standards.

A third view (see, for example, Atkin, 1980) regards the greater involvement of federal and state governments with skepticism, if not outright suspicion. At best, compliance with federal and state requirements is seen as being accomplished through scrupulous attention to ritual, such as meeting special requirements for certifying mathematics teachers without further attention to what the mathematics teacher does once in the classroom (Meyer and Rowan, 1978). Worse, more regulations, guidelines, and controls are said to frustrate the creative teacher and impose operating procedures that may be entirely inappropriate in many local circumstances (Boyer, 1983; Sizer, 1984). In this view, many of the federal regulations of the 1960s governing the categorical programs for disadvantaged, handicapped, and other special groups of students were ineffectual, counterproductive, or had unfortunate secondary consequences.

Still another view, perhaps a variant of the second, expects that current state and federal efforts for improving the quality of education will mainly be directed toward enhancing learning opportunities for the more able students, and that these efforts will be made at the expense of socially and educationally disadvantaged students. The fear is expressed that the progress toward equality in educational opportunity made over the past three decades will be reversed. Surveys on the use of microcomputers in schools lend some substance to this concern (Center for Social Organization of Schools, 1983-1984; Lepper et al., 1984).

The committee recommends a greater investment in research on the effects of the policy-making system on learning experiences in the classroom, particularly those related to the teaching and learning of higher-order skills, including (1) the effects of federal, state, and local district policies and procedures; (2) the understandings that teachers and administrators have of goals proclaimed at the national and state levels; and (3) the decision-making processes of classroom teachers regarding the amount of time spent on and emphasis given to various aspects of the curriculum.

Schools have often been described as both excessively resistant to change and excessively faddish in adopting change. Although some of the differences in description are undoubtedly due to differences in the prejudices toward specific changes and change in general on the part of observers, it is possible that both descriptions are partly correct. Change superimposed from above might be adopted in outward form but then be turned into a marginal alteration compatible with established values, operating procedures, and investment of resources (Purkey and Smith, 1983; Zaltman et al., 1973). More general research on change in organizations suggests tnat both the mix of organizations and the character of individual organizations change over time, but that those changes are not ordinarily attributable to the intention of organizational leaders (March and Simon, 1958; Cyert and March, 1963; Cohen and March, 1974). Rather, they reflect adaptations through differential birth and growth of different organizational forms (Greiner, 1972; Kimberley, 1980), incremental trial-by-trial learning from experience (Herriott et al., 1985), diffusion of ideas (Rogers, 1962; Rogers and Shoemaker, 1971), and serendipitous discovery of the organizational value of changes initiated for the local benefit of subgroups or individuals within the organization (March, 1981).

Education organizations, specifically, tend to undergo changes because of the pressures exerted by interest groups and emerging societal issues rather than in accord with plans and initiatives of governing boards or administrators (Dreeben, 1976; Cusick, 1983). School systems often respond to such pressures through changes in organizational form such as decentralizing the administration of large urban districts or the creation of new forms such as regional vocational centers. Sometimes changes that are initiated for the benefit of particular subgroups--Title I (now Chapter I) providing for compensatory education for disadvantaged children, special programs for handicapped children, the creation of specialized science and mathematics schools and of magnet schools--result in improved staffing patterns for other students as well and greater attention to curriculum. Schools also change through the diffusion of ideas, methods, and curricula, albeit through a slow process of adaptation (Berman and McLaughlin, 1974-1975; Kiesler and Turner, 1977). Evidence from recent studies of school processes and practices (Goodlad, 1984; Lightfoot, 1983) indicates that an important differentiating characteristic between schools is their receptivity to change, or their being a "renewing school" (Sarason, 1985).

Although systems for planned change in education have been designed (Havelock, 1969) and occasionally tried out (Raizen, 1979), how change processes operate in different types of schools and school systems to facilitate or hinder educational improvement is not well understood

(Mann, 1976). The accelerating introduction of computers into schools and their various uses in different settings (Center for Social Organization of Schools, 1983-1984) sharpen the need for better understanding of the change processes involved when innovations are adopted (Education Turnkey Systems, 1985).

The committee recommends more focused research on the extent to which the conditions for specific changes exist in educational institutions, where the loci for change are and how they vary in different schools, and how curricular and instructional changes are related to specific conditions. Because of the potential of computers and information technology, the committee recommends special attention to the processes of change involved in their introduction and use in schools.

RESEARCH ON THE HOME AS A SETTING FOR EDUCATION

A sizable body of research shows that the home setting influences educational outcomes, although little of the work specifically addresses outcomes in mathematics, science, and technology. Most of the research concerns four characteristics of home settings: the composition of the household, the socioeconomic status of the family, parental attitudes and behavior toward education, and resources in the home.

Research on household size and mathematics achievement shows a rather consistent correlation between the number of persons in the household and achievement: larger household size is associated with lower achievement. For example, this finding appears in a study of fifth- and sixth-graders drawn from 700 schools in two geographic regions (Hanushek, 1972). An analysis based on sixth-graders in a large, eastern city also confirms a correlation between family size and mathematics achievement (Michelson, 1970). Whether this result or one relating high scores in mathematics to schools in which most students live with both parents (Mayeske et al., 1972) stems from a causal link between household composition and performance is not established.

The attribute used most commonly in research on home and learning is socioeconomic status (SES), usually measured by parental education, income, and occupation. SES, based on these three indicators, bears a strong relationship to outcomes in mathematics and science. A study of school districts in Colorado found that the greater the number of persons in the district who had completed high school, the higher the mathematics achievement test scores for high school students (Bidwell and Kasarda, 1975). Likewise, the Hanushek (1972) analysis cited earlier shows a positive correlation for individual students between father's education and performance on mathematics tests.

The correlations, however, may be misleading. Rakow (1984) included parental education in a model of science achievement that used four other predictors: student ability, student motivation, quantity of science instruction, and quality of instruction (as measured by size of the budget for teaching science). Student ability emerged as the most significant predictor; parental education was not nearly as important in the model. Moreover, home environment was even less predictive for the sample of nonwhite students than for the white students. In a study of determinants of student achievement for seniors who participated in the High School and Beyond Study in 1982, family SES seemed to be less important than parental encouragement and support, and the effect of SES on achievement by black students was even smaller than for other groups (Rock et al., 1985). Gemmill et al. (1982) studied attitudes toward and performance in mathematics for Mexican-American students and a matched group of Anglo students and found that parental behavior made a difference for both groups. A review of research on gender and mathematics (Fox, 1977) shows that support and encouragement from parents is crucial to participation in mathematics, but that parents give less encouragement to their daughters than to their sons. Parental involvement also appears to have a positive effect on incidental learning from television (Walling, 1976) and other informal learning situations outside school (Rock et al., 1985).

Parental encouragement is a major explanatory factor cited in research on the high performance of Japanese students in science and mathematics. Troost (in press) found that Japanese parents have a high participation rate in schools and that parents and schools are consistent in placing high demands on students. Japanese students spend three to four times as many hours on homework as do U.S. students (Fetters et al., 1983; Walberg et al., no date), commonly attend after-school schools (jukus), and spend more time discussing school work with their parents than do U.S. students (Fetters et al., 1983; Stevenson, 1983).

Several analyses suggest that the presence of educational resources in the home facilitates learning (e.g., Walberg et al., 1981; Rakow, 1984). But the resources matter only if they are used. The National Assessment of Educational Progress survey on science (Hueftle et al., 1983) found that females were less likely to participate in science-related activities at home than were males. Females watched fewer science programs on television, read fewer books on science, and were less likely to work on science projects or hobbies.

The research literature on the home in relationship to mathematics, science, and technology education is limited in several respects. First, it is underdeveloped theoretically. There is no overarching perspective that indicates the kinds of variables that should make a difference and the reasons they deserve attention. Consequently, the variables selected for analysis and the measures of these variables vary considerably among research studies. Second, most of the studies on achievement use tests of basic skills, not tests on reasoning. It is not obvious that the home influences that appear to affect the acquisition of basic skills have similar effects on other types of skills. Third, many of the studies fail to look simultaneously at both home and other influences. They tend to be more descriptive and conventional than causally sophisticated. Fourth, the research seldom examines how effects differ for various segments of students.

To remedy these limitations, the committee recommends research on factors associated with the home that bear on mathematics, science, and technology education, including (1) identification of critical variables and development of a theoretical framework that relates them to different types of learning outcomes; (2) disaggregating effects for different segments of the student population, e.g., by age, ability, ethnic group, and type of school district; and (3) studies that distinguish factors associated with the home from those in the wider community (e.g., influences of peers, neighborhoods, mass media) but examine their interactions and joint effects on learning.

RESEARCH ON OUT-OF-CLASSROOM SETTINGS

In science, technology and, to a lesser extent, mathematics, educational experiences are increasingly available to individuals outside the traditional school settings

(Bryant and Anderson, 1983). Museums, science centers, newspapers, and hobby groups and other clubs all have potential for influencing large numbers of people. Some of this instruction is intentional: it happens on television, through such programs as 3-2-1 Contact, Newton's Apple, Mr. Wizard, New Tech Times, Nova, Discover, Science & Technology Week, Voyage of the Mimi, and Search for Solutions; in the community, through public facilities such as science museums, planetaria, marine aquaria, and libraries; in print, through publications such as Ranger Rick, Odyssey, and Highlights; and through such associations as JETS (Junior Engineering Technical Society) and model rocket groups (Sneider et al., 1984). There is also some tentative evidence (Krugman and Hartley, 1970; Hawkins, 1973; Gaffney, 1980; Comstock and Tully, 1981) to suppose that some unintentional instruction occurs, again, on television, through such programs as Quincy, The Whiz Kids, and Otherworld; on film, through motion pictures such as Ice Man, Quest for Fire, The Swamp Thing, E.T., War Games, and Splash; and also in print through such comic books as Superman, Spiderman, and The Incredible Hulk.

Some information has been accumulated on the goals, methods, effectiveness, and relation to school curricula of educational programs provided by the more popular of these media, like television and museum programs. With respect to goals, such programs as the Nova series (Ambrosino and Burns, 1977) and 3-2-1 Contact (Thomson, 1980) must constantly take into account the goals of television itself as well as their own educational goals. Regarding methods, there are pedagogical strengths and weaknesses endemic to every informal educational method, including the use of museum exhibits (Danilov, 1982), television animation (Dusewicz, 1981), and computer simulation (Library of Congress, 1971; Stevens and Roberts, 1983; White 1984). Research on the effectiveness of news programs (Berry, 1983) suggests that redundant pictures and words enhance learning from television, while redundant printed information does not (Reese, 1984). Other research has addressed the efficacy of the timing of pictorials in mathematics learning (Brody and Legenze, 1980), of high-impact production features like action and music (Calvert and Watkins, 1979) and color (Chute, 1980), and of the participation of parents (Gaffney, 1981). An interesting question concerns the associations, possible and actual, between out-of-school education and in-school experiences (Passow, 1985). Some museums, for example, sponsor precollege science education programs for school classes (Goldman, 1970; Screven, 1984; Pittman-Gelles, 1985), and there are other ongoing efforts to integrate educational programming using mass media into the school curriculum (University of Iowa, 1978).

Concerning the intentional educational programs, there is some evidence for the pedagogical success of such individual efforts as the children's television programs Sesame Street and the Electric Company (Lesser, 1975; Harvey et al., 1976; Pearl, 1982) and various museum exhibits. However, general understanding of intentional learning efforts is not sufficient to account for their effects--why some succeed and others fail--or predict their impact. Much more needs to be known before the potential of the nonschool media for providing quality learning time in informal settings can be adequately exploited.

Therefore, the committee recommends research on the effects of various nonschool instructors on children's knowledge and perceptions of mathematics, science, and technology, including both the effects of intentionally educational programs provided outside school and unintentional learning or mislearning acquired through science fiction and other entertainment programming through the mass media, especially television, film, and print. We also recommend research to determine how the effects of instruction that children receive in the school are influenced by the informal instruction they receive in the larger world. Developing an understanding of this relationship might eventually lead to making school instruction more effective by taking account of children's learning from intended and unintended out-of-school instruction.

5

Research on New Learning Systems

In the committee's view, a significant increase in the amount of effective learning time devoted to mathematics, science, and technology will probably involve extensive use of computers and telecommunications. In this chapter, we discuss three targets for development that hold promise for improving both the quality and the amount of time devoted to education in mathematics, science, and technology. There is, however, an important related question about the application of modern technology to education: if improperly used, it may aggravate rather than relieve disparities among groups regarding their knowledge about mathematics, science, and technology. Surveys of computer use (Center for Social Organization of Schools, 1983-1984) indicate that more computers are being placed in the hands of middle- and upper-class children than poor children; where computers are found in the schools of poor children, they tend to be used for rote drill and practice instead of the cognitive enrichment that they provide for middle- and upper-class students. In addition, female students have less involvement with computers in schools, irrespective of class or ethnicity, and this problem grows worse in secondary school (Miura and Hess, 1983).

RESEARCH ON INTERACTIVE COMPUTER SOFTWARE

Computer microworlds provide new capabilities for teaching science and technology because they make apparent things that students usually cannot see (diSessa, 1984). For example, with the Dynaturtle program (diSessa, 1982; White, 1984), which models a universe obeying Newton's laws, children try to control objects moving in a frictionless world and thus learn to reexamine their intuitive notions about relationships between moving bodies; in Steamer (Stevens and Roberts, 1983), the student can see inside the pipes and boilers of a steam plant that in the real world covers two huge rooms; in a circuit simulation (White and Frederiksen, 1985), the student can see how voltage changes depending on different configurations of a circuit, because voltage is color coded. More generally, it is possible to speed things up, slow things down, provide microscopes and telescopes, represent abstract properties, and reconfigure space in ways that science laboratory experiments or demonstrations ordinarily do less well.

Microworlds also create environments in which doing mathematics and science makes sense to students, that is, in which learning is intrinsically motivating (Lepper and Greene, 1978; Lepper and Malone, in press). For example, in Geography Search, groups of students sail off to the New World to look for treasure. But as they sail, they must compute their latitude and longitude and keep track of their food and supplies so they don't run out before returning home. In Ice Cream Price Wars (Collins, 1985), groups of students run competitive ice cream stands, and they must calculate how to make the most money and defend their pricing strategies to other students in their group.

At the same time, microworlds can be used to facilitate active learning by using effective tutoring strategies. As noted above, reasoning is hard to learn without active work and without using an instructional system--a teacher, peers, an interactive workbook, a computer system--that provides suggestions and advice. Several promising lines of research in developing tutoring strategies and principles have been mentioned above, for example, Anderson's set of principles (Anderson et al., 1985) in the domain of geometry and the work of Reif and others in devising strategies that guide learners in understanding problems in physics. There are several computer-based prototypes in this area (Burton and Brown, 1978; Anderson, 1981; Sleeman and Brown, 1982; Anderson et al., 1983). Such tutoring systems are not traditional computer-assisted instruction that guides a learner through a lesson, but rather systems that follow a learner's reasoning processes and give advice when the learner is working unproductively. Thus, they seem to improve the use of time by intervening when the learner has reached an impasse and is engaging in a long, frustrating, and unproductive sequence of work. However, much remains to be learned about when and how to intervene so as to make the tutoring maximally effective.

Further understanding of how computer-based microworlds and tutoring systems should be designed to enhance mathematics and science learning requires the development of pilots to serve as experimental settings for the testing of alternatives.

The committee therefore recommends a systematic program for the development of pilot educational systems using computers to create microworlds and tutoring strategies that engage learners in science- and mathematics-linked tasks and thereby advance both the acquisition of knowledge and the learning of reasoning and problem-solving skills.

RESEARCH ON MICROSYSTEMS

Research reviewed earlier in this report and in the report of a subgroup on noncognitive factors in education (Cole, 1985) makes it evident that coordinated attention should be given to a category of activities that, for lack of a better term, might be called microsystems research. Microsystems research is distinguished from the microworlds approach discussed in the preceding section in that it explicitly concerns itself simultaneously with the curriculum content and the social organization of instruction. Three kinds of microsystems are of special interest: within-classroom activity centers, community-based after-school centers, and mixed institutional structures.

Successful methods of classroom instruction frequently involve breaking classes into smaller activity groups that combine theoretical understanding with hands-on familiarity. Unfortunately, these conditions have been maintained only in hothouse environments (Moll and Diaz, 1982; Hawkins and Sheingold, 1983; Goodlad, 1984; Peterson et al., 1984). One reason may be that the simultaneous effects of such contributory factors as materials production, school organization, teacher training, and small group dynamics--especially the question of group heterogeneity discussed earlier--are not well understood. Even programs with demonstrated success, such as the activity-based elementary school curricula of the 1960 , currently languish in obscure places and end up being used only because individual teachers make heroic efforts or an especially well-educated parent group creates a demand.

We recommend research on how to create "hardy" varieties of effective activity-based instructional systems for mathematics and science education so that they will be taken up and institutionalized in a wide variety of school systems.

There is agreement that more time on task is needed for American students, but the public's willingness to expand the school day or the school year is limited. Assigning homework is an unsatisfactory amplifying technique because those students who need it most tend to get the least effective support outside school. It may be time for a significant experiment in organizing educational after-school activities for children, using such settings as community centers, churches, libraries, and the school facilities themselves. A variety of prototypes that suggest the range of possible activities and institutional arrangements already exist (Moll and Diaz, 1982; Woodson, 1982). What does not exist is an overall understanding of the potential and limitations of such activities. Research should be designed to exploit the potential and discover the limitations of various forms of after-school activity centers through the development and evaluation of several pilot models.

One promising model is offered by San Diego's Community Resource and Research Center (Diaz, 1984). Children from two minority group communities go to local centers to practice basic skills in the process of becoming "communications experts" or "computer experts." Each center resembles within-classroom activity centers, raised to the level of a community educational setting; each center involves children in an interlocking set of interesting activities with microcomputers (including computer-based message systems) as part of the mix. The centers require that parents take initiative to enroll their children, and the children must sign a contract promising to become expert enough to teach others in their community--starting at home.

Systems that cross institutional boundaries such as school-community programs and school-museum programs (Fantini and Sinclair, 1985) also hold promise for mathematics and science education. The American Association for the Advancement of Science (AAAS, 1984) summarized a large number of exemplary educational programs serving women and minorities; it is clear from the report that much informal knowledge has been gained from practical experience on how to create educational programs that are successful with these populations. Many of the programs exhibit a key structural property: they create a system of education that is integrated both vertically (from early education through later years) and horizontally (they coordinate and draw support from a range of departments/institutions/bureaucracies). For example, the Community Educational Resource and Research Center of the University of California, San Diego, brings adults, college students, and high school students into a single activity setting after school, creating vertical integration. Horizontal integration is achieved by involving multiple parties responsible for some part of children's education: the university, the school system, the community.

The problem with such systems, even when they are demonstrated successes, is that they are difficult to fit into existing bureaucratic arrangements. As the AAAS report notes, demonstrations of success based upon short-term funding of experiments does not insure uptake within the originally sponsoring institutions. Innovative educational successes have had long-term social failure built into them (AAAS, 1984; Stage et al., 1985). This history suggests a requirement for sophisticated systems analysis on how to create mixed institutional systems for mathematics and science education that are sustained rather than diminished by bureaucratic and social structures.

DEVELOPING A SYSTEMS APPROACH TO IMPROVING MATHEMATICS AND SCIENCE EDUCATION

Education is a major industry with a minor research and development activity. Expenditures for education amounted to $226.5 billion ($136.5 billion for elementary and secondary schools) in 1983 (U.S. Department of Commerce, 1984), while investment in educational research and development was less than one-tenth of one percent of that amount (National Science Foundation, 1985). This contrasts to national defense and health, in which research and development represent 15 percent and about 2 percent of total expenditures, respectively. Industry investment of its own funds in research and development averages 2.6 percent of net sales, with highs of 7-10 percent in industries concerned with the manufacture of drugs, computers, and communication equipment (National

Science Foundation, 1982). Even the lowest-investing industries, foods and textiles, spend four to five times as much on research and development as does education. Moreover, this large, complicated, and subtle enterprise has almost no systematic approach for applying new knowledge and technology to the design of better learning situations (Raizen, 1979).

There is irony in the circumstance that the transfer and use of knowledge from the mathematical and scientific disciplines, through the evolution of agricultural, medical, and engineering schools and of industrial and governmental development centers and laboratories, has led to the economic and technological advancement of the United States and improved health for its citizens, yet the transfer of information about the teaching and learning of mathematics, science, and technology has been severely limited. More is known than is used.

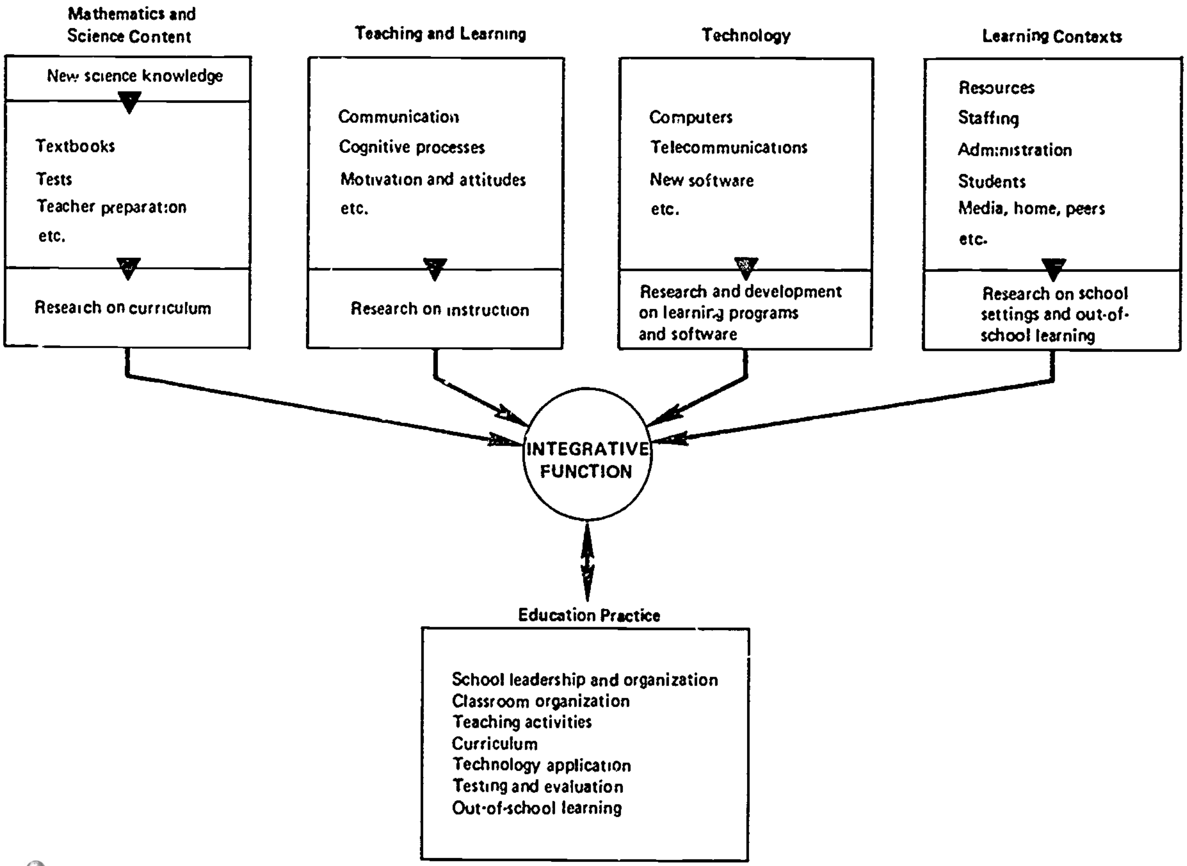
As the committee's review indicates, the past decades have seen a cumulation of knowledge from several pertinent disciplines and the development of new technologies, but application to science and mathematics education, as to all education, has been episodic, unsystematic, and limited in scope. A new approach is needed, one that combines the changes taking place in mathematics and the sciences with new knowledge about human learning capabilities and different learning settings, at the same time taking advantage of the potential of computers and related information technology. At present, there is no mechanism to serve the function of integrating the new knowledge and technology deriving from different sources and applying them to the development of improved systems for the teaching and learning of mathematics, science, and technology.

In other enterprises, this integrative function has been called systems design and engineering. The term probably originated in the telecommunications community, was continued and expanded in the aerospace industry, and has since been widely used wherever it has been recognized that proper design involves more than just assembling various components that have been developed in isolation. Designing components to function optimally for overall improvement of a system requires that the properties of the system and the functioning of each component must be considered as an entirety before individual components are reconfigured.

Modern educational activities, too, should be considered a system in which improvement of components in isolation may not lead to improvement of the overall system. The various components that make up the system of educational activities are common to all subjects and levels and are schematically represented in Figure 2. Of the major components illustrated, the area of technology is changing most rapidly, under the impact of current developments in computers, displays, interactive input-output devices, and communications and storage networks. New techniques for improving cognitive development, motivation, communication, and instructional processes have also evolved rapidly, as researchers into the fundamental aspects of these human faculties and behaviors gain knowledge that can be employed in developing teaching and learning methodologies. With respect to the cont . - areas of precollege education, probably none is developing more quickly than mathematics and the sciences. University researchers, responding to the needs of the marketplace and the government, to the advent of new technology that makes possible qualitatively different research, and to the most basic drive for inquiry--the need to understand--are developing new facts and techniques that must be transmitted to new generations of students if they are to be as productive as possible in engineering, medicine, economics, agriculture, and the many other fields pertinent to human advancement. The rapid advances in technology, cognitive science, and science and mathematics knowledge present new opportunities for improving the system, but only if mechanisms can be developed that would facilitate the integrated application of these advances to education.

There is an important and instructive lesson for education in the history of systems engineering for the communications and aerospace industries. Although systems engineering has become a discipline in itself, it is significant that even now university programs devoted to communications and aerospace do very little research in systems integration engineering for these technologies. Papers that appear in the literature in this field are largely the result of the efforts of scientists and engineers in industrial companies and independent research laboratories devoted to communications or aerospace, that is, organizations closer to the end product and its users. For education, too, more is needed than the existing university-based research activities.

It is not enough that mathematics and science content or the theories underlying the development of displays,



E 2 Model for improving mathematics, science, and technology education through grating knowledge and innovation.

computers, communications equipment, and associated software are the subject of university research. Nor is it sufficient that new knowledge is being uncovered about the cognitive processes and social structures underlying teaching and learning methodology and that curriculum development and the application of computer information systems to education are taking place. There remains a strong need to bring together researchers from all these and associated fields--mathematics, the physical and biological sciences, psychology, sociology, anthropology, and information sciences, among others--who have an interest in and dedication to integrating these various components into educational systems. It is important for such individuals to work with creative school administrators, curriculum developers, and teachers to design more effective learning structures. Examples from other fields also suggest that the success of such an endeavor requires an environment in which innovative approaches can make use of the latest output from the content, methodology, and technology areas and can be tested in realistic settings--that is, in classrooms, schools, and school systems.

The idea of developing mechanisms equivalent to systems design and engineering in education is attractive, although the limited successes of such an approach with systems involving political, social, and behavioral (as well as technical) elements are warnings against excessive expectations of success. It is arguable that evolving combinations of market, political, and bureaucratic structures provide the best means for achieving effective education, better than is achievable through deliberate planning of a systemic sort. The committee is sensitive to the limitations in the social arena of systems design and engineering adapted from industries based on highly developed technologies, yet there remains the need to design each single component in concert with the other components of the educational system.

There may be several ways of accomplishing this integrative function. One that has proved effective in other fields is a free-standing entity different from any that currently exists in that it would use a systems approach to educational improvements rather than retrofit individual pieces, such as a new curriculum or an innovative form of classroom organization, into structures that may or may not be able to accommodate them successfully. Whatever the mechanism, the following characteristics are seen as essential to the integrative function:

(1) Because the anticipated work needs to draw on developments in several fast-moving fields, the setting must be able to attract researchers from the scholarly disciplines within the natural, behavioral, and social sciences as well as engineering and technological experts and creative educational researchers, developers, and practitioners.

(2) Interdisciplinary teams should be used to design, develop, and test comprehensive teaching and learning models in science and mathematics, taking advantage of the most advanced research and technologies.

(3) Experiments and findings arising from local school operations need to be assessed and extended--for example, practices from schools that consistently produce Westinghouse National Talent Search winners and results of state initiatives such as those going forward in Arizona, California, New Jersey, North Carolina, Tennessee, and Texas.

(4) Connections with schools must be established so that new educational models can be evaluated in the reality of the classroom and effective implementation strategies for widespread use of successful innovations can be developed.

(5) An efficient communications network is necessary through which administrators, teachers, university faculty, book publishers, and public bodies can keep in touch and collaborate with important findings and developments, possibly through an electronic/photonic network tied into the communications common carriers.

The design of an institution or mechanism with the capacities to integrate new knowledge and developments from disparate fields and apply them to educational improvement in a systemic manner is a complex undertaking. Characteristics of the new entity must be defined; means must be found for establishing it so as to embody the desired characteristics; relationships with existing institutions that are crucial to its mission or appear already to perform certain parts of it must be worked out. For example, some questions that need to be addressed in the formulation include:

- How should the integrative institution or mechanism be organized so as to be buffered from the pressures exerted on and by existing hierarchial structures in education, yet enable it to work effectively with both schools and institutions of higher education?

- What kinds of staffing patterns would encourage constant regeneration of innovative approaches--e.g., balance between permanent staff and short-term visiting researchers and practitioners in the mathematics/science/education fields, or opportunities for young researchers to work with senior scholars?
- What size and structure of budget would be needed, and what would be appropriate funding sources--federal, private foundations, states and large school districts, consortia of industries that provide new equipment in the computer/communications fields, or, more likely, a mixture of several of such sources?
- What kinds of linkages need to be created to schools to ensure that effective classroom practice becomes part of the store of knowledge going into improvement efforts, that newly developed learning and teaching models undergo realistic testing, and that effective models are widely adopted and appropriately implemented?
- What kinds of linkages need to be created with the many institutional entities that produce relevant knowledge, develop alternative educational components, and work with schools and teachers? Examples of such entities include mathematics, science, and engineering departments, behavioral and social science departments, and schools and departments of education in institutions of higher education; research centers and regional laboratories supported by the Department of Education; state education authorities and various state subunits providing services to schools; and the textbook and computer hardware and software industries.
- What institutions or organizations exist in other social service fields that might provide instructive guidance for developing a systems approach to improving mathematics and science education? Would it be useful, for example, to assess the successes and failures of the Manpower Demonstration Research Corporation (see the MDRC Annual Report, 1984), which is concerned with developing and testing a variety of employment programs, or the Clinical Center of the National Institutes of Health, which brings scientists and clinicians together for studies of specific diseases?

In sum, the committee finds that current efforts to improve mathematics, science, and technology education take a piecemeal approach rather than integrating available knowledge and technology. Therefore, we recommend a serious effort to design appropriate models for education analagous to systems design and engineering institutions in other fields that would use a systems approach in applying pertinent research and development to overall educational improvement. As a necessary first step, we recommend that the Department of Education, in concert with the National Science Foundation, convene a task force or similar group to think through the best means for carrying out the integrative and systems design function that is missing in current efforts to improve education, including consideration of such issues as organization, staffing, budgets, and linkages to other institutions.

6

Summary of a Research Agenda

American research funding traditions appropriately emphasize multiple sponsors and multiple agendas. We believe those traditions will continue to serve the nation well. Within that framework of variety, we commend a research agenda focused on the amount of time devoted to active teaching and learning of reasoning skills--called "quality learning time" in our report. Learning to reason is central to learning mathematics, science, and technology. We contrast reasoning with recalling facts in essentially the same form as they were learned. Reasoning involves making inferences from organized facts or using them to solve problems. It includes the ability to apply scientific concepts usefully. Understanding how to increase the amount of quality time devoted to learning to reason is a primary objective of this research agenda.

Quality learning time affects the development of reasoning ability through basic psychological processes occurring within the context of lessons. The learning of concepts or skills from lessons is mediated by instructors, peers, curricula, and equipment in a learning situation. Learning situations, in turn, are embedded in larger contexts of schools, school systems, families, social norms, communication systems, and political institutions. Understanding the ways in which students learn, or fail to learn, mathematics, science, and technology involves an appreciation of how these factors and their nested interactions affect quality time devoted to learning to reason.

Within such a perspective, the agenda recommended here includes four separable, but closely related, categories of research:

- Research on the <u>development of reasoning</u>;
- Research that facilitates increasing the amount of quality learning time through <u>better instruction</u>;
- Research that facilitates increasing the amount of quality learning time through <u>better settings for learning</u>; and
- Research that facilitates increasing the amount of quality learning time through the development of <u>new learning systems</u>.

Separating the agenda into these categories has the advantage of identifying relatively coherent clusters of possible research, tapping relatively clear disciplinary strengths and traditions. It has the potential disadvantage of underestimating the linkages among the clusters, and of research that explores those linkages. Education involves a complex combination of experiences and institutions interacting over relatively long periods of time. A thorough understanding of how children learn or fail to learn to reason will require fundamental research that involves the highest order of both disciplinary and interdisciplinary research skills.

It is also clear that each of these research categories includes projects that range from research that is unambiguously basic to research that is equally unambiguously developmental. Historically, the understanding and improvement of education through research has confounded simple distinctions. Basic research feeds applications, and experience with applications has generated material for the most fundamental research.

RESEARCH ON REASONING

A major research challenge is to understand better the dynamic process through which reasoning skills are acquired, the relation between domain-specific knowledge and general skills of thinking and reasoning, and the possibilities for precise learning interventions in the development of such skills. Specifically, the committee recommends:

- Research on how competence in reasoning skills is acquired, including:
  - -- the mechanisms of reasoning skills, particularly as evidenced in the differences between novice and experienced learners;

  - -- the dynamic processes through which reasoning skills are acquired in the context of specific domains of knowledge; and
  - -- the scientific reasoning skills of children.
- Research on reasoning in particular disciplines, aimed at understanding how abilities to make inferences, to reason, and to generate new information can be fostered by ensuring contact with prior knowledge that can be restructured and further developed as learning takes place.
- Focused research on self-regulatory or metacognitive capabilities--what they are, how they develop, and how learners can be helped to acquire them.
- Systematic tracking of outcomes resulting from efforts to teach generalized thinking and reasoning skills.

RESEARCH ON INSTRUCTION

The development of practical procedures for the acquisition of reasoning skills in mathematics, science, and technology requires an understanding of instruction. This includes attention to the capabilities and motivations of teachers, to alternative modes of instruction and materials, and to the effective assessment of the outcomes of instruction. Specifically, the committee recommends:

- A research program to develop improved understanding of:
  - -- the response to various monetary incentives designed to attract able individuals to mathematics and science teaching and keep them in these fields;
  - -- how to improve the subject-matter education of both pre- and inservice teachers, including optimal volume and pace of subject-matter coverage in different sciences and experiences that develop and enhance abstract reasoning capacity; and
  - -- the effects of alternative requirements for entering and being certified in the profession, particularly with respect to developing an adequate pool of teachers competent to teach mathematics and science.

- The development of a national data base on teacher preparation and qualifications sufficiently detailed and appropriately stratified to reflect conditions in different types of school districts and for varying student populations.
- Research on how societal pressures, school organization, and educational policies affect teacher effort.
- Research directed toward effective instructional strategies based on explorations of:
  - -- the design of pedagogical theories that students can test, evaluate, and modify;
  - -- the techniques of ingenious teachers who are able to devise such temporary models or pedagogical theories; and
  - -- the design of intelligent computer-assisted instruction that incorporates interrogation and exploration.
- Research targeted at:
  - -- providing characterizations of the cognitive skills and knowledge needed for understanding of and successful performance in technological systems;
  - -- based on such characterizations, development of usable school curricula in computer literacy; and
  - -- investigating the effects of computers on the knowledge structure of mathematics and various sciences and the implied changes for the school curriculum.
- Research on the importance of curricular orientation and context to learning, including:
  - -- how important tasks can be embedded in contexts that reduce the time needed for learning;
  - -- under what circumstances and in what ways activity systems using physical objects and "real" events (whether hands-on experience, models based on systematic laws, or story lines that mirror common experiences) can be used to enhance learning; and
  - -- what makes theory-oriented instruction work, especially with individuals from some minority groups and women generally said to require a more pragmatic, utilitarian approach.

- A concerted research effort on how educational curricula and materials are created, their content, and how they are used, specifically, on:
  - -- whether and how the treatment of substantive content in current textbooks and software supports the learning of reasoning, thinking, and problem-solving skills as well as lower-order recall and memorization tasks;
  - -- the exploration of new content areas within various fields and at various grade levels that might be productive additions to promoting higher-order skills;
  - -- the abilities, skills, and perspectives of those who write textbooks and software (for example, to what extent do they understand the importance of curricular context?) and the means for attracting better prepared individuals to those fields;
  - -- the development of consensus on appropriate subgoals, content, and sequencing by grade level to facilitate greater emphasis on higher-order skills;
  - -- the effects of state approval processes on content issues; and
  - -- further studies on the relation between what is tested and what is included in textbooks and software and between the intended and the implemented curriculum.
- Research on:
  - -- the development of practical tests that reliably assess reasoning ability, perhaps using interactive testing made possible by microcomputers;
  - -- improving the testing of mathematics and science achievement to reflect important instructional goals and objectives; and
  - -- techniques for educating teachers to become better writers of test questions, particularly of questions that test for the higher-order intellectual skills and levels of learning.

RESEARCH ON SETTINGS

Formal instruction takes place in classrooms, but classrooms are not isolated from the rest of society.

Classrooms are subject to school policies, explicit and implicit educational goals, and the mundane realities of making a school run. Schools, in turn, are shaped by the social and political context in which they operate. Moreover, schools are not the only settings for learning. Children and teachers come to class shaped by their homes and by informal learning and relations outside school. Thus, a research program directed to augmenting quality time devoted to learning to reason must include attention to the social settings of instruction. Specifically, the committee recommends:

- Research on how to make student activity groups successful in multi-ethnic classrooms for a range of mathematics and science tasks, including:
  - -- improved understanding of the ideological and pragmatic reasons teachers group their students by ability and prefer teacher-led groups to cooperative student-led groups;
  - -- investigating systemic factors relating to societal and institutional pressures on schools and teachers to arrange their classrooms and instruction so as to produce easily measurable performance results; and
  - -- developing kinds of teacher training that facilitate widespread adoption of activity-centered curricula when this approach is appropriate.
- o Research and development:
  - -- to explore the relationships among the cultures of various student subpopulations, the culture of the classroom, and the cultures of mathematics, science, and technology and
  - -- to understand the role of language and culture in the teaching of science and mathematics.
- Research on the effects of the policy-making system on learning experiences in the classroom, particularly those related to the teaching and learning of higher-order skills, including:
  - -- the effects of federal, state, and local district policies and procedures;
  - -- the understandings that teachers and administrators have of goals proclaimed at the national and state levels; and

  - -- the decision-making processes of classroom teachers regarding the amount of time spent on and emphasis given to various aspects of the curriculum.
- More focused research on the extent to which the conditions for specific changes exist in educational institutions, including:
  - -- loci for change and how they vary in different schools;
  - -- how curricular and instructional changes are related to specific conditions; and
  - -- special attention to the processes of change involved in the introduction and use of computers and information technology in schools.
- Research on factors associated with the home that bear on mathematics, science, and technology education, including:
  - -- identification of critical variables and development of a theoretical framework that relates them to different types of learning outcomes;
  - -- disaggregating effects for different segments of the student population, e.g., by age, ability, ethnic group, and type of school district; and
  - -- studies that distinguish factors associated with the home from those in the wider community (e.g., influences of peers, neighborhoods, mass media) but examine their interactions and joint effects on learning.
- Research on the effects of various nonschool instructors on children's knowledge and perceptions of mathematics, science, and technology, including:
  - -- the effects of intentionally educational programs provided outside school and
  - -- unintentional learning or mislearning acquired through science fiction and other entertainment programming through the mass media, especially television, film, and print;
- Research to determine how the effects of instruction that children receive in the school are influenced by the informal instruction they receive in the larger world.

RESEARCH ON NEW LEARNING SYSTEMS

The committee believes that modern computers and telecommunications provide an opportunity for a significant increase in the amount of effective learning time devoted to mathematics, science, and technology education if properly used. Since there is evidence that improper use aggravates, rather than relieves, disparities among groups in the society in their knowledge about mathematics, science, and technology, a substantial research effort both to develop information technology as an instrument of learning and to ensure that it contributes to reducing reasoning disabilities throughout the population is essential. Specifically, the committee recommends:

- A systematic program for the development of pilot educational systems using computers to create microworlds and tutoring strategies that engage learners in science- and mathematics-linked tasks and thereby advance both the acquisition of knowledge and the learning of reasoning and problem-solving skills.
- Research on how to create "hardy" varieties of activity-based instructional systems for mathematics and science education so that they will be taken up and institutionalized in a wide variety of school systems.
- Research designed to exploit the potential and discover the limitations of various forms of after-school activity centers through the development and evaluation of several pilot models.
- Sophisticated systems analysis on how to create mixed institutional systems for mathematics and science education that are sustained rather than diminished by bureaucratic and social structures.
- Design of appropriate models for education analogous to systems design and engineering institutions in other fields that would use an integrative systems approach in applying research and development to educational improvement. Characteristics seen as essential to the integrative function include:
    - -- strong interdisciplinary teams to design, develop, and test comprehensive teaching and learning models in science and mathematics;

- extension of successful experiments and findings arising from local school operations;
- evaluation of new educational models in the reality of the classroom and development of effective implementation strategies; and
- an efficient communications network linking administrators, teachers, university faculty, book publishers, and public bodies to important findings and developments.

As a necessary first step, we recommend that the Department of Education, in concert with the National Science Foundation, convene a task force or similar group to think through the best means for carrying out the integrative and systems design function that is missing in current efforts to improve education, including consideration of such issues as organization, staffing, budgets, and linkages to other institutions.

The research agenda outlined in this report builds on what is already known to suggest basic, applied, and developmental research that will advance the capabilities of American society to increase scientific knowledge among Americans and reduce disparities in knowledge among groups within the country. The task we propose is not a small one. It demands substantial commitment, not only on the part of the society through its political representatives, but also on the part of the research community. This committee believes that such a commitment is possible. We also believe it is essential.

We think that investment in educational research and development is vital to mathematics, science, and technology education; we think that more is known about education than is currently being utilized effectively, either in research planning or in educational programs; we think that the research community can respond to a coherent, relatively focused research agenda that will make a difference; and we think that the educational community can improve education by more effective integration of research and professional experience.

References

Alexander, K.L., and McDill, E.L.
1976 Selection and allocation within schools: some causes and consequences of curriculum placement. *American Sociological Review* 41:963-980.

Ambrosino, Michael, and Burns, Blair, eds.
1977 *The Science Program Group for Public Television in the United States*. Report No. AAAS-Misc-Pub-73-3. Washington, D.C.: American Association for the Advancement of Science.

American Association for the Advancement of Science
1984 *Equity and Excellence: Compatible Goals. An Assessment of Programs That Facilitate Increased Access and Achievement of Females and Minorities in K-12 Mathematics and Science Education*. AAAS publication 84-14. Office of Opportunities and Science. Washington, D.C.: American Association for the Advancement of Science.

American Chemical Society
1984 *Tomorrow*. The Report of the Task Force for the Study of Chemistry Education in the United States. Washington, D.C.: American Chemical Society.

Anderson, John R.
1981 Tuning of Search of the Problem Space for Geometry Proofs. Technical Report. Pittsburgh: Carnegie-Mellon University, Department of Psychology.

Anderson, John R., Farrell, R., and Sauers, R.
1983 Learning to Program in LISP. Technical Report. Pittsburgh: Carnegie-Mellon University, Department of Psychology.

Anderson, John R., Boyle, C. Franklin, and Reiser, Brian J.
1985 Intelligent tutoring systems. Science 228:456-462.

Armento, B.
1977 Teacher behaviors related to student achievement on a social science concept test. Journal of Teacher Education 28:46-52.

Arons, Arnold B.
1981 Whither do we hurry hence? In Melba Phillips, ed., AAPT Pathways. Stony Brook, N.Y.: American Association of Physics Teachers.
1983 Achieving wider scientific literacy. Daedalus 112(Spring):91-122.

Atkin, J. Myron
1980 The government in the classroom. Daedalus 109(Summer):85-97.

Barr, R., and Dreeben, R.
1983 How Schools Work. Chicago: University of Chicago Press.

Berman, Paul, and McLaughlin, Milbrey W.
1974-1975 Federal Programs Supporting Educational Change. Eight volumes prepared for U.S. Department of Health, Education, and Welfare. Santa Monica, Calif.: Rand Corporation.

Berry, Colin
1983 Learning from television news: a critique of the research. Journal of Broadcasting 27(4):359-370.

Bidwell, C.E., and Kasarda, J.D.
1975 School district organization and student achievement. American Sociological Review 40:55-70.

Boyer, Ernest L.
1983 High School: A Report on Secondary Education in America. New York: Harper and Row.

Brody, Philip J., and Legenze, Alice
1980 Can pictorial attributes serve mathemagenic functions? Educational Communication and Technology: A Journal of Theory, Research, and Development 28(1):25-29.

Brookover, W., Beady, C., Flood, P., Schweitzer, J., and Wisenbaker, J.
1979 School Social Systems and Student Achievement: Schools Can Make a Difference. New York: Praeger.

Brophy, Jere, and Evertson, C.
1976 *Learning From Teaching: A Developmental Perspective*. Boston: Allyn and Bacon.

Brophy, Jere and Good, Thomas
1985 Teacher behavior and student achievement. In M. Wittrock, ed., *Handbook of Research on Teaching*. New York: Macmillan.

Brown, A.L.
1978 Knowing when, where, and how to remember: a problem of metacognition. In R. Glaser, ed., *Advances in Instructional Psychology*. Vol. 1. Hillsdale, N.J.: Erlbaum.

Bryant, J., and Anderson, D.
1983 *Children's Understanding of Television*. New York: Academic Press.

Burton, R.R., and Brown, J.S.
1978 *An Investigation of Computer Coaching for Informal Learning Activities*. BBN Report No. 3914; ICAI Report No. 12. Cambridge, Mass.: Bolt Beranek and Newman, Inc.

Calvert, Sandra, and Watkins, Bruce
1979 *Recall of Television Content as a Function of Content Type and Level of Production Feature Use*. Chicago: Spencer Foundation.

Carey, S.
1985 Are children fundamentally different kinds of thinkers and learners than adults? In Susan F. Chipman, Judith W. Segal, and Robert Glaser, eds., *Thinking and Learning Skills: Research and Open Questions*. Vol. 2B. Hillsdale, N.J.: Erlbaum.

Cazden, Courtney B.
1983 Environments for language learning. *Language Arts* 60:121-122.

Center for Social Organization of Schools
1983-1984 *School Uses of Microcomputers: Reports From a National Survey*. Issues Nos. 1-6. Baltimore, Md.: Johns Hopkins University.

Champagne, A.B., and Klopfer, L.E.
1977 A sixty-year perspective on three issues in science education: I. Whose ideas are dominant? II. Representation of women. III. Reflective thinking and problem solving. *Science Education* 61:431-452.

Champagne, A.B., Klopfer, L.E., and Anderson, J.
1980 Factors influencing learning of classical mechanics. *American Journal of Physics* 48:1074-1079.

Chase, W.G., and Simon, H.A.

1973 The mind's eye in chess. Pp. 215-281 in W.G. Chase, ed., *Visual Information Processing*. New York: Academic Press.

Chi, M.T.H., Feltovich, P.J., and Glaser, R.

1981 Categorization and representation of physics problems by experts and novices. *Cognitive Science* 5(2):121-152.

Chipman, Susan F., Segal, Judith W., and Glaser, Robert, eds.

1985 *Thinking and Learning Skills: Research and Open Questions*. Vol. 2B. Hillsdale, N.J.: Erlbaum.

The Chronicle of Higher Education

1985a AFT's president proposes national exam for teachers akin to tests for professions. February 6:19(21).

1985b New Jersey's schoolteacher plan alarms schools of education. March 13:30(2).

Chute, Alan G.

1980 Effect of color and monochrome versions of a film on incidental and task relevant learning. *Education Communication and Technology: A Journal of Theory, Research, and Development* 28(1):10-18.

Cicourel, A.V., and Kitsuse, J.I.

1963 *The Educational Decision Makers*. Indianapolis: Bobbs Merill.

Clark, C., Gage, N., Marx, R., Peterson, P., Stayrook, N., and Winne, P.

1979 A factorial experiment on teacher structuring, soliciting, and reacting. *Journal of Educational Psychology* 71:534-552.

Clement, J.

1982 Students' preconceptions in introductory mechanics. *American Journal of Physics* 50:66-71.

Cohen, Michael D.

1984 Exemplary computer use in education. *Sirgue Bulletin, Computer Uses in Education* 18(1):16-19.

Cohen, Michael D., and March, James G.

1974 *Leadership and Ambiguity*. New York: McGraw-Hill.

Cole, Michael

1985 Noncognitive Factors in Education. Paper prepared for the Committee on Research in Mathematics, Science, and Technology Education, National Research Council.

Coleman, James S.
1985 Internal comparisons of cognitive achievement. Phi Delta Kappan February:403-406.

Collins, Allan M.
1985 Teaching, reading, and writing with personal computers. In Judith Orasanu, ed., A Decade of Reading Research: Implications for Practice. Hillsdale, N.J.: Erlbaum.

Collins, Allan M., and Stevens, A.L.
1982 Goals and strategies of inquiry teachers. In R. Glaser, ed., Advances in Instructional Psychology. Vol. 2. Hillsdale, N.J.: Erlbaum.

Comstock, George, and Tully, H.
1981 Innovation in the movies, 1939-1976. Journal of Communication 31(2).

Crosswhite, F. Joe, Dossey, John A., Swafford, Jane O., McKnight, Curtis C., and Cooney, Thomas J.
1985 Second International Mathematics Study Summary Report for the United States. Champaign, Ill.: Stripes Publishing Company.

Cusick, Philip
1983 Secondary Public Schools in America. Paper commissioned by the National Commission on Excellence in Education, Washington, D.C.

Cyert, Richard M., and March, James G.
1963 A Behavioral Theory of the Firm. Englewood Cliffs, N.J.: Prentice-Hall.

Danilov, Victor J.
1982 Chicago's fountain of discovery: education programs at the Museum of Science and Industry. Children Today 11(1):14-19.

Davis, R., Buchanan, B., and Shortliffe, E.
1977 Production rules as a representation for a knowledge-based consultation program. Artificial Intelligence 8:15-45.

DeLoache, J.S., and Brown, A.L.
1979 Looking for Big Bird: studies of memory in very young children. The Quarterly Newsletter of the Laboratory of Comparative Human Cognition 1(4):53-57.

Denham, Carolyn, and Lieberman, Ann, eds.
1980 Time to Learn. Available from the U.S. Government Printing Office. Washington, D.C.: National Institute of Education.

Diaz, S.
1984 Bilingual-Bicultural Computer Experts: Traditional Literacy Through Computer Literacy.

Paper presented at American Anthropological Association Conference, Denver, Colo.

diSessa, Andrea A.

1982 Unlearning Aristotelian physics: a study of knowledge-based learning. *Cognitive Science* 6:37-75.

1984 The Third Revolution in Computers and Education. Paper prepared for the Committee on Research in Mathematics, Science, and Technology Education, National Research Council.

Donaldson, Margaret

1978 *Children's Minds*. New York: Norton.

Dougherty, Van

1983 State Programs of School Improvements, 1983: A 50-State Survey. Working Paper No. 1. Prepared for the Education Commission of the States, Denver, Colo.

Dreeben, Robert

1976 The organizational structure of schools and school systems. Pp. 857-873 in J.J. Loubser et al., eds., *Explorations in General Theory in Social Science*. Vol. 2. New York: Free Press.

Driscoll, Mark

1982 *Research Within Reach: Secondary School Mathematics*. Washington, D.C.: National Institute of Education.

Druva, Cynthia A., and Anderson, Ronald D.

1983 Science teacher characteristics by teacher behavior and by student outcome: a meta-analysis of research. *Journal of Research in Science Teaching* 20(5):467-479.

Duda, R.O., Hart, P.E., Barrett, P., Gashnig, J.G., Konolige, K., Reboh, R., and Slocum, J.

1978 Development of the PROSPECTOR Consultation System for Mineral Exploration. Technical Reports 5821 and 6415. SRI International, Palo Alto, Calif.

Dunkin, M., and Biddle, B.

1974 *The Study of Teaching*. New York: Holt, Rinehart & Winston.

Dusewicz, Russell A.

1981 Technology in the education of young children. *Journal of Children in Contemporary Society* 14(1):3-14.

Education Commission of the States

1983 *A 50-State Survey of Initiatives in Science, Mathematics and Computer Education*. No.

SM-83-1. Denver, Colo.: Education Commission of the States.

Educational Research Service
1979 Merit Pay for Teachers. Arlington, Va.: Educational Research Service.

Education Turnkey Systems, Inc.
1985 Uses of Computers in Education. Washington, D.C.: National Commission for Employment Policy.

Egan, D.E., and Schwartz, B.J.
1979 Chunking in recall of symbolic drawings. Memory and Cognition 7:149-158.

Elmore, Richard F.
1983 Complexity and control: what legislators and administrators can do about implementing public policy. In L. Shulman and G. Sykes, eds., Handbook of Teaching and Policy. New York: Longman.

Entwisle, D.R., and Hayduk, L.A.
1982 Early Schooling. Baltimore, Md.: Johns Hopkins University Press.

Erickson, F., and Mohatt, G.
1982 Cultural organization of participant structures in two classrooms of Indian students. Pp. 132-174 in G.D. Spindler, ed., Doing the Ethnography of Schooling. New York: Holt, Rinehart & Winston.

Ernst, G.W., and Newell, A.
1969 GPS: A Case Study in General Problem Solving. New York: Academic Press.

Estes, W.K., Shiffrin, R.M., Simon, H.A., and Smith, E.E.
1982 The science of cognition. In National Research Council, Outlook for Science and Technology: The Next Five Years. San Francisco: W.H. Freeman.

Evertson, C., Anderson, C., Anderson, L., and Brophy, Jere
1980 Relationships between classroom behaviors and student outcomes in junior high mathematics and English classes. American Educational Research Journal 17:43-60.

Fantini, M.D., and Sinclair, R.L.
1985 Linking school and nonschool education: public policy considerations. In M.D. Fantini and R.L. Sinclair, eds., Education in School and Nonschool Settings: Eighty-fourth Yearbook of the National Society for the Study of Education, Part 1. Chicago: University of Chicago Press.

Fetters, William B., Quingo, Jeffrey A., Suter, Larry E., and Takar, Ricky T.
1983 Schooling Experiences in Japan and the United States: A Cross-National Comparison of H.S. Seniors. Paper presented at the annual meeting of the American Educational Research Association, Montreal, Canada.

Fey, J.T.
1982 Mathematics education. In H.E. Mitzel, ed., Encyclopedia of Educational Research. Fifth ed. Vol. 3, pp. 1166-1182. New York: Free Press.

Fisher, Charles W., Berliner, David C., Filby, Nikola N., Marliave, Richard, Cahen, Leonard S., and Dishaw, Marilyn M.
1980 Teaching behaviors, academic learning time, and student achievement: an overview. In Carolyn Denham and Ann Lieberman, eds., Time to Learn. Available from the U.S. Government Printing Office. Washington, D.C.: National Institute of Education.

Fox, L.H.
1977 The effects of sex role socialization on mathematics participation and achievement. In J. Shoemaker, ed., Women and Mathematics: Research Perspectives for Change. NIE Papers in Education and Work No. 8, Education and Work Group, National Institute of Education. Washington, D.C.: U.S. Department of Health, Education, and Welfare.

Frederiksen, N.
1984 The real test bias: influences of testing on teaching and learning. American Psychologist 39(3):193-202.

Freeman, Donald J., Kuhs, Therese M., Porter, Andrew C., Floden, Robert E., Schmidt, William H., and Schwille, John R.
1983 Do textbooks and tests define a national curriculum in elementary school mathematics? Elementary School Journal 83(5):501-513.

Gaffney, Maureen, ed.
1980 Examining television. Young Viewers Magazine 3(3-4).
1981 What kids learn from the screen. Young Viewers Magazine 4(1).

Gage, N.L.
1978 The Scientific Basis of the Art of Teaching. New York: Teachers College Press.

Gelman, R., and Gallistel, C.R.
1978 The Child's Understanding of Number. Cambridge, Mass.: Harvard University Press.

Gemmill, L.M., Bustoz, J., and Montiel, M.
1982 Factors Influencing Mathematics Participation of Highly Able Mexican-American Adolescents. Available from the National Science Foundation.

Gersten, Russell
1984 Follow-Through revisited: reflections on the site variability issue. Education Evaluation and Policy Analysis 6(4):411-423.

Glaser, R.
1981 The future of testing. American Psychologist 36(9):923-936.
1984 Education and thinking: the role of knowledge. American Psychologist 39(2):93-104.

Glass, Gene V., Cahen, Leonard S., Smith, Mary L., and Filby, Nikola N.
1982 School Class Size. Beverly Hills, Calif.: Sage Publications.

Goertz, Margaret E., Ekstrom, Ruth B., and Coley, Richard J.
1984 The Impact of State Policy on Entrance Into the Teaching Profession. Princeton, N.J.: Educational Testing Service.

Goldman, Katherine J., ed.
1970 Opportunities for Extending Museum Contributions to Pre-College Science Education. Washington, D.C.: National Science Foundation.

Good, T.L., and Marshall, S.
1984 Do students learn more in heterogeneous or homogeneous groups? Pp. 15-38 in P.L. Peterson, L.C. Wilkinson, and M. Hallinan, eds., The Social Context of Instruction. London: Academic Press.

Good, T., and Grouws, D.
1977 Teaching effects: a process-product study in fourth grade mathematics classrooms. Journal of Teacher Education 28:49-54.

Goodlad, John I.
1984 A Place Called School. New York: McGraw-Hill.

Grant, Gerald
1981 What Makes a Good School? Five Case Studies. Syracuse, N.Y.: Syracuse University.

Greeno, James L.
1980 Psychology of learning, 1960-1980: one participant's observations. American Psychologist 35(8):713-728.

Greiner, L.E.
1972 Evolution and revolution as organizations grow. Harvard Business Review 50:37-46.

Hallinan, Maureen T., and Sorensen, Aage B.
1984 Instructional Grouping and Mathematics Education. Paper prepared for the Committee on Research in Mathematics, Science, and Technology Education, National Research Council.

Hanushek, Eric A.
1972 Education and Race: An Analysis of the Educational Production Process. Lexington, Mass.: Lexington Books.

Harms, Norris C., and Yager, Robert E., eds.
1981 What Research Says to the Science Teacher. Washington, D.C.: National Science Teachers Association.

Harvey, Francis A., et al.
1976 Evaluation of Eight "Infinity Factory" Programs; Part 1: Analysis of the Eight-Show Series. Newton, Mass.: Education Development Center, Inc.

Havelock, Ronald G.
1969 Planning for Innovation. Ann Arbor, Mich.: Institute for Social Research, Center for Research on Utilization of Scientific Knowledge, University of Michigan.

Hawkins, J., and Sheingold, K.
1983 Programming in the classroom: ideals and reality. Pp. 17-18 in M. Cole, N. Miyake, and D. Newman, eds., Procedures of the Conference on Joint Problem Solving and Microcomputers. Washington, D.C.: Office of Naval Research.

Hawkins, Robert P.
1973 Learning of peripheral content in films: a developmental study. Child Development 44(1):214-217.

Hilton, Thomas L., Rock, Donald A., Ekstrom, Ruth, Goertz, Margaret E., and Pollack, Judith
1984 Study of Excellence in High School Education: Cross-Sectional Study, 1972-1980. Draft Technical Report: Relational Analysis Section. Educational Testing Service, Princeton, N.J.

Herriott, Scott R., Levinthal, Daniel, and March, James G.
1985 Learning from experience in organizations. American Economic Review 75:298-302.

Holdzkom, David, and Lutz, Pamela B.
1984 *Research Within Reach: Science Education.* Washington, D.C.: National Institute of Education.

Holmes, B.J.
1980 *Black Students' Performance in the National Assessments of Science and Mathematics.* NAEP No. SY-SM-50. Denver, Colo.: Education Commission of the States.

Hueftle, Stacey J., Rakow, Steven J., and Welch, Wayne W.
1983 *Images of Science: A Summary of Results from the 1981-82 National Assessment in Science.* Minneapolis, Minn.: Minnesota Research and Evaluation Center.

Hunt, E., Frost, N., and Lunnenborg, C.
1973 Individual differences in cognition: a new approach to intelligence. In G.H. Bower, ed., *The Psychology of Learning and Motivation.* Vol. 7. New York: Academic Press.

Hunter, Madeline
1984 Knowing, teaching, and supervising. In P.L. Hosford, ed., *Using What We Know About Teaching.* Alexandria, Va.: Association for Supervision and Curriculum Development.

Husén, Torsten
1967 *International Study of Achievement in Mathematics: A Comparison of Twelve Countries.* Vols. I and II. New York: John Wiley.

Iker, S.
1983 A lifetime of listening. *Mosaic* 8:13.

Istomina, Z.M.
1975 The development of voluntary memory in preschool-age children. *Soviet Psychology* 13(4):5-64.

Jeffries, R., Turner, A.T., Polson, P.G., and Atwood, M.E.
1981 Processes involved in designing software. In J.F. Anderson, ed., *Cognitive Skills and Their Acquisition.* Hillsdale, N.J.: Erlbaum.

Johntz, William F.
no date The Unique Role of Project SEED in U.S. Education. Project SEED, Inc., Dallas, Tex.

Jones, Lyle V.
1984 White-black differences: the narrowing gap. *American Psychologist* 39:1207-1213.

Kagan, S., Zahn, G.L., Widaman, K.F., Schwarzwald, J., and Tyrrell, G.

in press Classroom structural bias: impact of cooperative and competitive classroom structures on cooperative and competitive individuals and groups. In R. Slavin, S. Sharon, S. Kagan, R. Hertz-Lazarowitz, C. Webb, and R. Schmuck, eds., Learning to Cooperate, Cooperating to Learn. New York: Plenum.

Kiesler, Sara B., and Turner, Charles F., eds.

1977 Fundamental Research and the Process of Education. Committee on Fundamental Research Relevant to Education, National Research Council. Washington, D.C.: National Academy of Sciences.

Kimberly, John R., Miles, Robert H., et al.

1980 The Organizaional Life Cycle: Issues in the Creation, Transformation, and Decline of Organizations. San Francisco: Jossey-Bass.

Krugman, Herbert E., and Hartley, Eugene L.

1970 Passive learning from television. Public Opinion Quarterly 34(2):184-190.

Larkin, Jill H., and Reif, F.

1976 Physically important integrals with calculus. American Journal of Physics 44(6):515-518.

Larkin, Jill H., Carbonell, J., Gugliotta, A., and Reif, F.

1983 FERMI: A Flexible Expert Reasoner With Multi-domain Inferencing. Technical Report. Pittsburgh: Carnegie-Mellon University, Departments of Psychology and Computer Science.

Lepper, M.R., and Greene, D.

1978 Overjustification research and beyond: toward a means-end analysis of intrinsic motivation. Pp. 109-148 in M.R. Lepper and D. Greene, eds., The Hidden Costs of Reward. Hillsdale, N.J.: Erlbaum.

Lepper, M.R., and Malone, T.W.

in press Intrinsic motivation and instructional effectiveness in computer-based education. In R.E. Snow and M.C. Farr, eds., Aptitude, Learning and Instruction: III. Cognitive and Affective Process Analyses. Hillsdale, N.J.: Erlbaum.

Lepper, M.R., Daley, H., Chen, M., Hess, R., Kuspa, L., and Walker, D.

1984 Computers and Education: The Social Equity Issues. Manuscript, Stanford University.

Lesgold, A.M.

1983 Acquiring Expertise. Technical Report No. PDS-5. Pittsburgh, Pa.: University of Pittsburgh, Learning Research and Development Center.

Lesser, Gerald

1975 Children and Television: Lessons from Sesame Street. New York: Random House.

Levin, Henry M.

1980 Educational production theory and teacher inputs. In C.E. Bidwell and D.M. Windham, eds., The Analysis of Educational Productivity: Issues in Macroanalysis. Vol. 2. Cambridge, Mass.: Ballinger.

Library of Congress

1971 New Technology in Education: Selected References. Washington, D.C.: Congressional Research Service.

Lightfoot, Sara Lawrence

1983 The Good High School. New York: Basic Books.

Lipsitz, Joan

no date Successful Schools for Young Adolescents: A Summary. The Center for Early Adolescence, Carrboro, N.C.

Little, Judith Warren

1981 School Success and Staff Development: The Role of Staff Development in Urban Desegregated Schools. Boulder, Colo.: Center for Action Research.

Lortie, Dan C.

1975 Schoolteacher: A Sociological Study. Chicago: University of Chicago Press.

Mann, Dale

1976 For the record. Teacher College Record 77(3).

Manpower Demonstration Research Corporation

1981 Annual Report. New York: Manpower Demonstration Research Corporation.

March, James G.

1981 Footnotes to organizational change. Administrative Science Quarterly 26:563-577.

March, James G., and Simon, Herbert A.

1958 Organizations. New York: John Wiley.

Mayeske, G.W., Cohen, W.M., Wisler, C.E., Okada, T., Beaton, A.E., Jr., Proshek, J.M., Weinfeld, F.D., and Tabler, K.A.

1972 A Study of Our Nation's Schools. DHEW OE-72-142. Washington, D.C.: U.S. Department of Health, Education, and Welfare, Office of Education.

McCloskey, M.

in press Naive theories of motion. In D. Gunther and A.L. Stevens, eds., Mental Models. Hillsdale, N.J.: Erlbaum.

McCloskey, M., and Kohl, D.

1982 Naive physics: the curvilinear impetus principle and its role in interactions with moving objects. Journal of Experimental Psychology: Learning, Memory, and Cognition 9(1):146-156.

McCloskey, M., Caramazza, A., and Green, B.

1980 Curvilinear motion in the absence of external forces: naive beliefs about the motion of objects. Science 210:1139-1141.

Medley, D.

1979 The effectiveness of teachers. In P. Peterson and H. Walberg, eds., Research on Teaching: Concepts, Findings, and Implications. Berkeley, Calif.: McCutchan.

Meyer, John, and Rowan, Brian

1978 The structure of educational organizations. Pp. 78-109 in M. Meyer et al., eds., Environment and Organizations. San Francisco: Jossey-Bass.

Michelson, S.

1970 The association of teacher resources with children's characteristics. In Do Teachers Make a Difference? A Report on Recent Research on Pupil Achievement. Washington, D.C.: U.S. Department of Health, Education, and Welfare, Office of Education, Bureau of Educational Personnel Development.

Miura, I.T., and Hess, R.D.

1983 Sex Differences in Computer Access, Interest in Usage. Paper presented to the annual meeting of the American Psychological Association, Anaheim, Calif.

Moll, L.C., and Diaz, E.

1980 The organization of bilingual lessons: implications for schooling. The Quarterly Newsletter of the Laboratory of Comparative Human Condition 2(3).53-58.

1982 Bilingual Communications in Classroom Contexts. Final Report No. NIE-G-0155. Washington, D.C.: National Institute of Education.

1984 Bilingual Communication and Reading: The Importance of Spanish in Learning to Read in English. Manuscript submitted for publication. Available from the Laboratory of Comparative Human Cognition, La Jolla, Calif.

Murnane, Richard J.

1985 An economist's look at federal and state education policies. In John M. Quigley and Daniel L. Rubinfeld, eds., American Domestic Priorities: An Economic Appraisal. Berkeley: University of California Press.

National Assessment of Educational Progress

1983a Reading, Science, and Mathematics Trends: A Closer Look. Denver, Colo.: Education Commission of the States.

1983b The Third National Mathematics Assessment: Results, Trends, and Issues. Denver, Colo.: Education Commission of the States.

1985 NAEP Field-Test Teacher Questionnaire. Princeton, N.J.: Educational Testing Service.

National Center for Education Statistics

1981 A Capsule Description of High School Students: A Report on High School and Beyond, A National Longitudinal Study for the 1980s. Prepared by Samuel S. Peng, William B. Fetters, and Andrew J. Kolstad. Available from the U.S. Government Printing Office, Supt. of Doc. no. NCES 0-729-575/2100. Washington, D.C.: U.S. Department of Education.

1983 Digest of Education Statistics 1983-84. Available from the U.S. Government Printing Office. Washington, D.C.: U.S. Department of Education

1984 High School Seniors: A Comparative Study of Classes of 1972 and 1980. Prepared by William B. Fetters, Jeffrey A. Owings, and George H. Brown. Available from the U.S. Government Printing Office, Supt. of Doc. no. 065-000-00204-3. Washington, D.C.: U.S. Department of Education.

National Commission on Excellence in Education

1983 A Nation at Risk: The Imperative for Educational Reform. Available from the U.S. Government Printing Office, Supt. of Doc. no. 065-000-00177-2. Washington, D.C.: U.S. Department of Education.

National Commission for Excellence in Teacher Education

1984 What the Reports Said About Teacher Education: A Summary. Prepared for the May 2, 1984, meeting of the Commission. American Association of Colleges for Teacher Education, Washington, D.C.

National Council of Teachers of Mathematics

1980 An Agenda for Action: Recommendations for School Mathematics in the 1980's. Reston, Va.: National Council of Teachers of Mathematics.

National Science Foundation

1982 Research and Development in Industry. NSF No. 84-325. Washington, D.C.: National Science Foundtion.

1983 Educating Americans for the 21st Century. National Science Board Commission on Precollege Education in Mathematics, Science and Technology. Washington, D.C.: National Science Foundation.

1985 Federal R&D Funding by Budget Function, Fiscal Years 1984-86. NSF No. 85-319. Washington, D.C.: National Science Foundation.

Palincsar, A.S., and Brown, A.L.

1984 Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. Cognition and Instruction 1(2):117-175.

Passow, A.H.

1985 Combined efforts: models for nonschool settings for learning. In M.D. Fantini and R.L. Sinclair, eds., Education in School and Nonschool Settings: Eighty-fourth Yearbook of the National Society for the Study of Education, Part 1. Chicago: University of Chicago Press.

Pearl, David, ed.

1982 Television and Behavior: Ten Years in Scientific Progress and Implications for the 1980s. Washington, D.C.: National Institute of Mental Health.

Penick, John E., ed.

1983 Focus on Excellence. Vol. 2, No. 1. Elementary Science. Washington, D.C.: National Science Teachers Association.

Persell, C.
1977 *Education and Inequality: The Roots and Results of Stratification in America's Schools*. New York: Free Press.

Peterson, Paul E.
1983 *Making the Grade: Report of the Twentieth Century Fund Task Force on Federal Elementary and Secondary Education Policy*. Background paper. New York: Twentieth Century Fund.

Peterson, P.L., Wilkinson, L.C., Spinelli, F., and Swing, S.R.
1984 Merging the process-product and the sociolinguistic paradigms: research on small group processes. In P.L. Peterson, L.C. Wilkinson, and M. Hallinan, eds., *The Social Context of Instruction*. London: Academic Press.

Phillips, S.
1972 Participant structures and communicative competence: Warm Springs children in community and classroom. In C.B. Cazden, V. John, and D. Hymes, eds., *Functions of Language in the Classroom*. New York: Teacher's College Press.

Piaget, J., and Inhelder, B.
1975 *The Origin of the Idea of Chance in Children*. C. Leake, Jr., P. Burrell, and H.D. Fishbein, trans. (from French). New York: Norton.

Pittman-Gelles, B.
1985 Museums and schools: a meaningful partnership. In M.D. Fantini and R.L. Sinclair, eds., *Education in School and Nonschool Settings: Eighty-fourth Yearbook of the National Society for the Study of Education, Part 1*. Chicago: University of Chicago Press.

Polya, G.
1957 *How to Solve It*. Garden City, N.Y.: Doubleday.

Purkey, Stewart C., and Smith, Marshall S.
1983 Effective schools: a review. *Elementary School Journal* 83(4):427-452.

Raizen, Senta A.
1979 Dissemination programs at the National Institute of Education. *Knowledge: Creation, Diffusion, Utilization* 1(2):259-292.

Raizen, Senta A., and Jones, Lyle V., eds.
1985 *Indicators of Precollege Education in Science and Mathematics*. Committee on Indicators of Precollege Science and Mathematics Education, National Research Council. Washington, D.C.: National Academy Press.

Rakow, S.J.

1984 Predictors of Science Inquiry Knowledge. Paper presented at 57th annual meeting of the National Association for Research in Science Teaching, New Orleans, April 30.

Reese, Stephen D.

1984 Visual-verbal redundancy effects on television news learning. Journal of Broadcasting 28(1):79-87.

Resnick, Lauren B.

1983 Mathematics and science learning: a new conception. Science 220(4):477-478.

Riley, M.S., Greeno, J.G., and Heller, J.I.

1983 Development of children's problem-solving ability in arithmetic. In H.P. Ginsburg, ed., The Development of Mathematical Thinking. New York: Academic Press.

Rock, Donald A., Ekstrom, Ruth B., Goertz, Margaret E., and Pollack, Judith M.

1985 Determinants of Achievement Gain in High School. Briefing paper for U.S. Department of Education and National Center for Education Statistics. Educational Testing Service, Princeton, N.J.

Rogers, Everett M.

1962 Diffusion of Innovations. New York: Free Press.

Rogers, Everett M., and Shoemaker, F.

1971 Communications of Innovations. New York: Free Press.

Rosenbaum, J.E.

1976 Making Inequality: The Hidden Curriculum of High School Tracking. New York: John Wiley.

Rosenshine, Barak V.

1968 To explain: a review of research. Educational Leadership 26:275-280.

1979 Content, time, and direct instruction. In Penelope L. Peterson and Herbert J. Walberg, eds., Research on Teaching: Concepts, Findings, and Implications. Berkeley, Calif.: McCutchan.

Rumelhart, D.E., and Norman, D.A.

1981 Analogical processes in learning. In J.R. Anderson, ed., Cognitive Skills and their Acquisition. Hillsdale, N.J.: Erlbaum.

Rutter, M., Maughan, B., Mortimore, P., Ouston, J., with Smith, A.

1979 Fifteen Thousand Hours: Secondary Schools and Their Effects on Children. London: Open Books. Cambridge, Mass.: Harvard University Press.

Sarason, Seymour B.
1985 The school as a social situation. Annual Review of Psychology 36:115-140.

Scannel, D.P., and Guenther, J.E.
1981 The development of an extended program. Journal of Teacher Education 32(1):7-12.

Schlechty, Phillip C., and Vance, Victor S.
1983 Recruitment, selection, and retention: the shape of the teaching force. The Elementary School Journal 83(4):469-487.

Schoenfeld, A.H.
1979 Explicit heuristic training as a variable in problem-solving performance. Journal for Research in Mathematics Education 10:174-187.
1980 Teaching problem solving skills. American Mathematical Monthly 87(10):794-805.

Screven, Chandler G.
1984 Educational evaluation and research in museums and public exhibits: a bibliography. Curator, Journal of the Museum of Natural History 27(2).

Segal, J.W., Chipman S.F., and Glaser, R., eds.
in press Thinking and Learning Skills: Relating Instruction to Research. Vol. 1. Hillsdale, N.J.: Erlbaum.

Sharan, S., Kussell, P., Hertz-Lazarowitz, R., Bejarano, Y., Ravid, S., and Sharan, Y.
1984 Cooperative Learning in the Classroom: Research in Desegregated Schools. Hillsdale, N.J.: Erlbaum.

Shumway, Richard J., ed.
1980 Research in Mathematics Education. Reston, Va.: National Council of Teachers of Mathematics.

Shymansky, James A., Kyle, William C., Jr., and Alport, Jennifer M.
1983 The effects of new science curricula on student performance. Journal of Research in Science Teaching 20(5):387-404.

Sirotnik, Kenneth A.
1981 What You See Is What You Get: A Summary of Observations in Over 1000 Elementary and Secondary Classrooms. A Study of Schooling Technical Report No. 29. University of California, Graduate School of Education, Laboratory in School and Community Education, Los Angeles.

Sizer, Theodore
1984 *Horace's Compromise: The Dilemma of the American High School*. New York: Houghton Mifflin.

Slavin, R.
1978 Student teams and achievement division. *Journal of Research and Development in Education* 12:39-49.

Sleeman, D., and Brown, J.S., eds.
1982 *Intelligent Tutoring Systems*. New York: Academic Press.

Smith, L., and Sanders, K.
1981 The effects on student achievement and student perception of varying structure in social studies content. *Journal of Educational Research* 74:333-336.

Sneider, Cary, Kurlich, Kevin, Pulas, Steven, and Friedman, Alan
1984 Learning to control variables with model rockets: a neopiagetian study of learning in field settings. *Science Education* 68(4):463-468.

Stage, E., Kreinberg, N., Eccles (Parsons), J., and Becker, J.
1985 Increasing the participation and achievement of girls and women in mathematics, science and engineering. In S.S. Klein, ed., *Handbook for Achieving Sex Equality Through Education*. Baltimore, Md.: Johns Hopkins University Press.

Stake, Robert E., and Easley, Jack A., Jr.
1978 *Case Studies in Science Education*. NSF SE-78-74. Available from the U.S. Government Printing Office. Washington, D.C.: National Science Foundation.

Stallings, Jane
1975 Implementation and child effects of teaching practices in Follow-Through classrooms. *Monographs of the Society for Research in Child Development* 40(7-8).

Sternberg, R.J.
1977 Component processes in analogical reasoning. *Psychological Review* 89:353-378.

1984 Toward a triarchic theory of human intelligence. *The Behavioral and Brain Sciences* 7:269-315.

Stevens, A., and Roberts, B.
1983 Quantitative and qualitative simulation in computer-based training. *Journal of Computer-Based Instruction* 10:16-19.

Stevenson, Harold W.
1983 Making the Grade: School Achievement in Japan, Taiwan, and the United States. Report presented to the Board of Trustees of the Center for Advanced Study in the Behavioral Sciences, Palo Alto, Calif.

Stoldolsky, Susan
1984 Frameworks for studying instructional processes in peer work-groups. In P.L. Peterson, L.C. Wilkinson, and M. Hallinan, eds., *The Social Context of Instruction*. Orlando, Fla.: Academic Press.

Sufrin, Sidney
1963 *Administering the National Defense Education Act*. Syracuse, N.Y.: Syracuse University Press.

Summers, Anita A., and Wolfe, Barbara L.
1977 Do schools make a difference? *American Economic Review* 67(4):639-652.

Sykes, Gary
1983 Public policy and the problem of teacher quality: the need for screens and magnets. Pp. 97-125 in Lee S. Schulman and Gary Sykes, eds., *Handbook of Teaching and Policy*. New York: Longman.

Task Force on Education for Economic Growth
1983 *Action for Excellence: A Comprehensive Plan to Improve Our Nation's Schools*. Denver, Colo.: Education Commission of the States.

Tharp, R.G.
1982 The effective instruction of comprehension: results and description of the Kamehameha Early Education Program. *Reading Research Quarterly* 17(4):501-527.

Thomson, Peggy
1980 A TV series starring science. *American Education* 16(2):6-13.

Travers, Kenneth J.
1984 Second International Mathematics Study: Summary Report for the United States. U.S. National Coordinating Center, University of Illinois, Urbana-Champaign.

Troost, Kay Michael
in press Society and Science Education in Contemporary Japan. In Margrete Klein and James Rutherford, eds., *A Challenge for American Precollege Education: Scientific Literacy in Japan, China, the Germanies and the Soviet Union*. Washington,

D.C.: American Association for the Advancement of Science.

Twentieth Century Fund Task Force
1983 Report of the Twentieth Century Fund Task Force on Federal Elementary and Secondary Education Policy. New York: Twentieth Century Fund.

U.S. Department of Commerce, Bureau of the Census
1984 Statistical Abstract of the United States 1985. 105th edition. Available from the U.S. Government Printing Office. Washington, D.C.: U.S. Department of Commerce.

U.S. Department of Education
1984 The Nation Responds. Washington, D.C.: U.S. Department of Education.

University of Iowa
1978 Mass Media Impact on Learning. Washington, D.C.: Association for Educational Communications and Technology.

Voss, J.F., Greene, T.R., Post, T.A., and Penner, B.C.
1983 Problem solving skill in the social sciences. In G. Bower, ed., The Psychology of Learning and Motivation: Advances in Research Theory. New York: Academic Press.

Walberg, Herbert J., and Rasher, Sue Pinzar
1985 Synthesis of research on teaching. In Merlin C. Wittrock, ed., The Handbook of Research on Teaching. Third ed. New York: Macmillan.

Walberg, Herbert J., Haertel, G.D., Pascarella, E., Junker, L.K., and Boulanger, F.D.
1981 Probing a model of educational productivity in science with national assessment samples of early adolescents. American Educational Research Journal 18(2):233-249.

Walberg, Herbert J., Harnisch, Delwyn L., and Tsai, Shiow-Ling
no date Mathematics Productivity in Japan and Illinois. Unpublished paper, University of Illinois at Chicago and Urbana.

Walker, Decker F.
1981 Learning science from textbooks: toward a balanced assessment of textbooks in science education. In James T. Robinson, ed., Research in Science Education: New Questions, New Directions. Columbus, Ohio: Clearinghouse for Science, Mathematics, and Environmental Education.

Walling, James I.

1976 Communication education in the home, in the schools, and in higher education. In the home: the effect of parental interaction on learning from television. Communication Education. 25(1):16-25.

Weaver, W.T.

1979 The need for new talent in teaching. Phi Delta Kappan 61:29-46.

Weiss, D.J.

1983 New Horizons in Testing. New York: Academic Press.

Weiss, Iris S.

1978 Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education. Prepared for the National Science Foundation. Available from the U.S. Government Printing Office, Supt. of Doc. no. 083-000-00364-0. Washington, D.C.: National Science Foundation.

White, B.Y.

1984 Designing computer games to help physics students understand Newton's laws of motion. Cognition and Instruction 1:69-108.

White, Barbara Y., and Frederiksen, John R.

1985 QUEST: Qualitative Understanding of Electrical System Trouble-Shooting. Sigart 93 (July).

Wimpelberg, Robert, and Ginsberg, Rick

1985 Are school districts responding to A Nation at Risk? Education and Urban Society 17(2):186-203.

Wise, Arthur E., Darling-Hammond, Linda, McLaughlin, Milbrey W., and Bernstein, Harriet T.

1984 Teacher Evaluation: A Study of Effective Practices. Santa Monica, Calif.: Rand Corporation.

Wolf, Richard M.

1977 Achievement in America. New York: Teachers College Press.

Woodson, R.L.

1982 Helping the poor help themselves. Policy Review: The New Quarterly Journal of the Heritage Foundation. Reprinted from the National Center for Neighborhood Enterprise, Washington, D.C. Summer.

Yager, Robert E.

1983 The importance of terminology in teaching K-12 sciences. Journal of Research in Science Teaching 20(6):577-588.

Zaltman, G., Duncan, R., and Holbek, J.

1973 Innovations and Organizations. New York: John Wiley.

APPENDIX A

Background Papers

In the course of its work, the committee commissioned a number of papers on various aspects of research in mathematics, science, and technology education. The papers proved helpful in the preparation of this report; they are available from the individual authors.

The Participation of Women and Minorities in Mathematical, Scientific, and Technical Fields
- Susan F. Chipman, Office of Naval Research, U.S. Department of Defense
- Veronica G. Thomas, Institute for Urban Affairs and Research, Howard University

The Third Revolution in Computers and Education
- Andrea A. diSessa, Laboratory for Computer Science, Massachusetts Institute of Technology

Conditions for Higher-Order Thinking in Teaching and Learning: An Anthropologist's Perspective on Mathematics, Science, and Technology Education
- Frederick Erickson, Institute for Research on Teaching, Michigan State University

Instructional Grouping and Mathematics Education
- Maureen T. Hallinan, Department of Sociology, University of Notre Dame
- Aage B. Sorensen, Department of Sociology, Harvard University

APPENDIX B

Biographical Sketches of Committee Members and Staff

JAMES G. MARCH is the Fred H. Merrill professor of management at Stanford University; he also holds appointments in political science, sociology, and education. From 1953 to 1964 he was professor at Carnegie Institute of Technology and from 1964 to 1970 was dean of social sciences at the University of California, Irvine. He has been a leading scholar in the field of organization behavior and management for 30 years. March, a member of the National Academy of Sciences, has served on the National Science Board, on the National Council of Educational Research, and on advisory bodies for the National Science Foundation, the Social Science Research Council, and the National Research Council. He holds Ph.D. and M.A. degrees in political science from Yale University and four honorary doctorates.

ARNOLD B. ARONS is professor of physics at the University of Washington, where he has been on the faculty since 1968. Previously he was on the faculty of Amherst College and Stevens Institute of Technology. His research has included explosion phenomena, physical oceanography, science education, and hydrodynamics. He has been a leader in the development of innovative curricula and instructional methods in science. He is a trustee of the Oceanographic Institute at Woods Hole, has served as consultant to the Naval Ordnance Laboratory, and has received several honorary awards for his contributions in physics and physics education. He has a Ph.D. degree in physical chemistry from Harvard University and M.E. and M.S. degrees from Stevens Institute of Technology.

WILLIAM O. BAKER, retired chairman of the board of Bell Telephone Laboratories, Inc., serves as chairman of Rockefeller University and the Andrew Mellon Foundation. For 25 years, he carried overall responsibility for research programs at Bell Labs. His personal work has been on solid state and polymers; his Ph.D. degree in physical chemistry is from Princeton University. Baker has served on numerous national commissions and advisory bodies concerned with science, technology, and education, including the President's Science Advisory Committee, the National Science Board, the National Science Board, and the National Commission on Excellence in Education. Currently, he chairs the Diplomatic Telecommunications Service Policy Board and the General Accounting Office Advisory Council; he serves on the Board of Higher Education of New Jersey and the Carneige Forum on Education and the Economy. He is a member of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. His contributions to American science and technology have been acknowledged by 25 honorary degrees and the Bush, Priestley, Gibbs, Madison, Perkin, and the President's National Security and National Technology awards, among others.

JEROME S. BRUNER is George Herbert Mead university professor of experimental psychology at the New School for Social Research. From 1945 to 1973 he was professor of psychology at Harvard University; from 1960 to 1972 he was director of Harvard's Center for Cognitive Studies. His research in psychology has included the areas of perception, attention, learning, memory, early language acquisition, and problem solving by children. He is the recipient of many honorary degrees and professional awards, including the Distinguished Scientist Award of the American Psychological Association. Bruner has a Ph.D. in psychology from Harvard University.

MICHAEL COLE is professor of psychology at the University of California, San Diego, where he is also director of the Laboratory for Comparative Human Cognition. Previously, he was a Ford Foundation fellow, an exchange scholar with Moscow University and a professor at several other universities. His research has included the cultural context of learning, the psychology of literacy, and child development. He has a Ph.D. degree in psychology from Indiana University.

ALLAN M. COLLINS is principal scientist at Bolt Beranek and Newman, Inc., with research interests in semantic information processing and education. He has been active in analyzing learning processes and developing computer-based tutoring systems for teaching reasoning. He recently directed a project for the Office of Naval Research to study the different kinds of conceptual models people have of complex systems. He has a Ph.D. degree in psychology and an M.A. degree in communication sciences from the University of Michigan.

MARGARET B. DAVIS is Regents professor of ecology at the University of Minnesota, where she was head of the Department of Ecology and Behavior from 1976 to 1981. She was on the faculty of the University of Michigan and a research biologist with the Great Lakes Research Division from 1961 to 1973, and was professor of biology at Yale University from 1973 to 1976. Her primary areas of research are Quaternary paleoecology and forest ecology. She is a past president of the American Quaternary Association and a member of the National Academy of Sciences. She has a Ph.D. degree in biology from Harvard University.

FREDERICK ERICKSON is professor of education and medicine and a member of the Institute for Research in Teaching at Michigan State University, where he has been a faculty member since 1978. His research has focused on social and cultural factors in learning, ethnographic studies in education, and sociolinguistic study of cross-cultural communication. Erickson has been a consultant to many education and cross-cultural organizations. He is past president of the Council for Anthropology and Education of the American Anthropological Association and is the editor of that society's journal Anthropology and Education Quarterly. He has a Ph.D. degree in education and anthropology and M.A. and B.A. degrees in music from Northwestern University.

ROBERT GLASER is university professor of psychology and education and codirector and founder of the Learning Research and Development Center at the University of Pittsburgh. His recent research has focused on the cognitive psychology of learning, instructional psychology, expert/novice problem solving in science, and the effects of structures of knowledge on learning and reasoning skills. He is current president of the

National Academy of Education, past president of the American Educational Research Association, and recipient of honorary degrees and awards including the Edward L. Thornedike medal of the American Psychological Association. He has a Ph.D. degree in psychological measurement and learning theory and an M.A. degree in experimental psychology from Indiana University and a B.S. degree in chemistry from City College of New York.

ANDREW GLEASON is Hollis professor of mathematics and natural philosophy at Harvard University, where he has been on the faculty since 1950. His areas of research are topological groups and Banach algebras. He is a member of the National Academy of Sciences, has received the Cleveland Prize, and is a past president of the American Mathematical Society. He has an A.M. degree in mathematics from Harvard University and a B.S. degree in mathematics from Yale University.

MICHAEL A. GUILLEN teaches mathematics and physics in the Core Curriculum Program at the Harvard University Science Center. His primary research specialities are kinetic theory, general and special relativity, and differential equations. His current research activities are chiefly in theoretical astrophysics. He has been active in communicating science to the public through newspaper and magazine articles, television programs, and as contributing editor of Science News and science consultant to Metro-Goldwyn-Mayer/United Artists. His most recent book is Bridges to Infinity: The Human Side of Mathematics. He has M.S. and Ph.D. degrees in physics, mathematics, and astronomy from Cornell University.

JILL H. LARKIN is associate professor of psychology and director of the Center for Design of Educational Computing at Carnegie-Mellon University, where she has been on the faculty since 1978. Her research has focused on cognition and problem solving, knowledge acquisition in science, and the application of cognitive science to education computing. She has developed computer simulations to teach problem solving in the physical sciences. Larkin has a Ph.D. degree in science and mathematics education and an M.A. degree in physics from the University of California, Berkeley, and a B.A. in mathematics from Harvard University.

ROBERT G. LOEWY is professor of mechanical and aerospace science at Rensselaer Polytechnic Institute. His areas of research are structural dynamics and aeroelasticity, unsteady aerodynamics, magnetohydrodynamics, servomechanisms, and systems stability. He is a member of the National Academy of Engineering. Loewy has been a member of advisory groups to branches of the Department of Defense, a consultant to government agencies and private industry, and a member of the President's Science Advisory Board. He has a Ph.D. degree in engineering mechanics from the University of Pennsylvania, an M.S. degree from the Massachusetts Institute of Technology, and a B.A.E. degree from Rensselaer Polytechnic Institute.

CORA B. MARRETT is professor of sociology and Afro-American studies at the University of Wisconsin, Madison, where she has been a member of the faculty since 1974. She taught earlier at the University of North Carolina at Chapel Hill and at Western Michigan University. Her research, conducted through the Wisconsin Center for Education Research, focuses on minority and female students in precollege mathematics and science. She serves as a member of the steering committee of Science World, a project sponsored by the Wisconsin Department of Public Instruction, and as a board member for the Argonne National Laboratory. She has Ph.D. and M.A. degrees from the University of Wisconsin in sociology.

SAMUEL MESSICK is vice president and distinguished research scientist at the Educational Testing Service, Inc., and adjunct professor of psychology at the City University of New York Graduate Center. His research has been concerned with psychometrics, test validity, problems in human assessment, and cognition and personality. He has frequently been an adviser to federal agencies and an invited fellow and teacher at universities. He has Ph.D. and M.A. degrees in psychology from Princeton University.

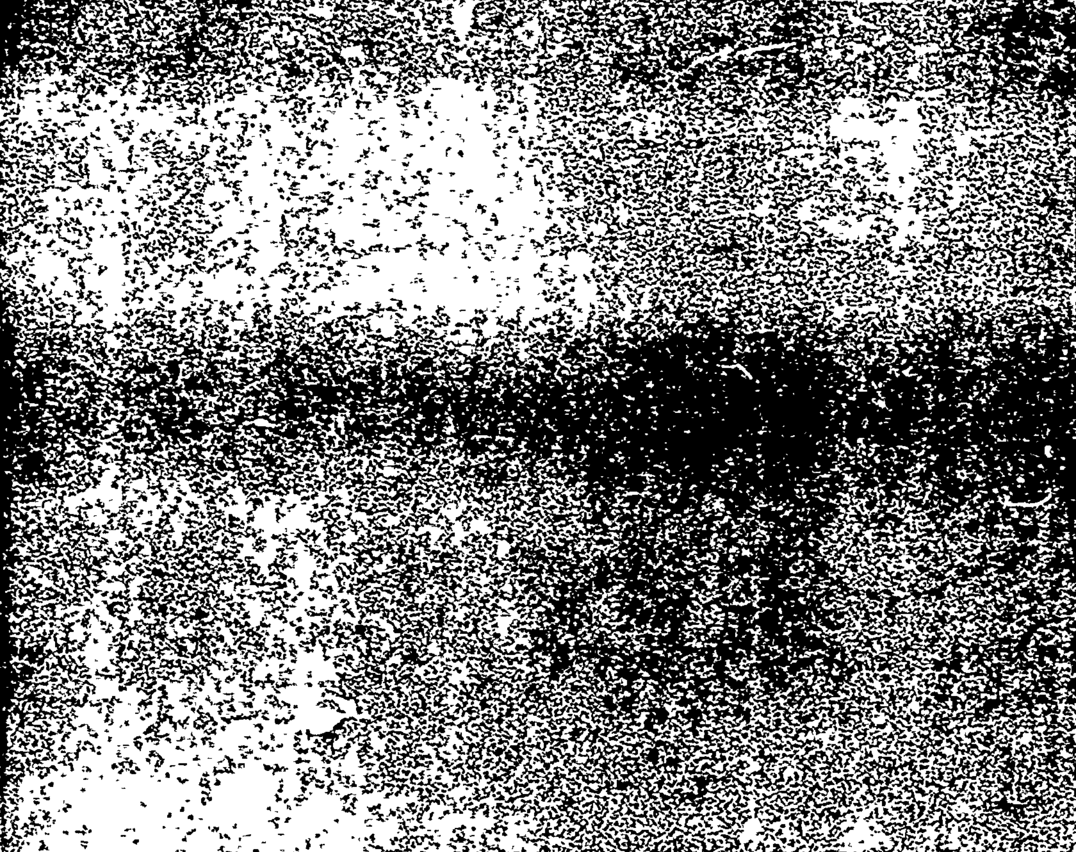
PAUL E. PETERSON is program director of governmental studies at the Brookings Institution. From 1967 to 1983 he was professor of political science and education and also chairman of the committee on public policy studies at the University of Chicago. His research involves urban politics and policies, especially as they relate to race and education. Peterson has Ph.D. and M.A. degrees in political science from the University of Chicago.

MARE TAAGEPERA is a lecturer in chemistry at the University of California, Irvine, where she has been on the faculty since 1975. She has been active in research in organic chemistry and has received several awards for outstanding teaching and leadership in science education. Taagepera is cofounder of a summer science institute for the retraining of elementary and secondary school classroom teachers. She has a Ph.D. degree in physical organic chemistry from the University of Pennsylvania.

DAVID E. WILEY is dean and professor in the School of Education at Northwestern University, a position he has held since 1979. From 1965 to 1979, he was a faculty member in the Departments of Education and Behavioral Sciences at the University of Chicago. During that period, he was also resident adviser to the Venezuelan Ministry of Education and a fellow at the Center for Advanced Study in the Behavioral Sciences. Wiley's research interests include educational policy, teaching-learning processes, evaluation, psychometrics, statistics, and survey research. He holds a Ph.D. degree in educational psychology from the University of Wisconsin, an M.S. degree in statistics from the same institution, and an A.B. degree in mathematics from San Diego State University.

SENTA A. RAIZEN is study director for the Committee on Research in Mathematics, Science, and Technology Education and also study director for the Committee on Indicators of Precollege Science and Mathematics Education. Previously, she served as study director for committees concerned with the evaluation of educational programs and the assessment of scientific research. From 1974 to 1978, she was associate director of the National Institute of Education, in charge of programs to disseminate and apply research results to education; before that she was a senior researcher at the Rand Corporation and, for 10 years, a program official in science education at the National Science Foundation. She is a fellow of the American Association for the Advancement of Science. She received a B.S. degree in chemistry from Guilford College and an M.A. degree in physical chemistry from Bryn Mawr College.

ROLF K. BLANK has served as research associate to the committee for six months. Previously, he was education study director at the COSMOS Corporation and at James Lowry and Associates, where he conducted a national study of magnet schools. He received a B.A. degree in history from Luther College, an M.A. degree in educational policy studies from the University of Wisconsin, and a Ph.D. degree in sociology from Florida State University.



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