Board (NSB) Commission on Precollege Education in Mathematics, Science, and Technology reported later in 1983:

> Alarming numbers of young Americans are ill-equipped to work in, contribute to, profit from, and enjoy our increasingly technological society. Far too many young Americans have emerged from the nation's elementary and secondary schools with an inadequate grounding in mathematics, science, and technology. . . . At a time when America's national security, economic well-being, and world leadership increasingly depend on mathematics, science, and technology, the nation faces serious declines in skills and understanding in these areas among all our youth.

The concerns are comprehensive, encompassing issues of general literacy, including science and technology, as well as the recruitment and education of our future scientists and technologists. While the nation still takes justifiable pride in the education of its top students, the question is whether we are maintaining a large enough pool of students able to lead our scientific and technological endeavors in the future. To maximize this nation's resources, as much as to promote educational equity, there must be a much greater recruitment into this pool of students who are female, from minority groups, and/or socio-economically disadvantaged.

What is the underlying pathology that has led to decreased student achievement and participation in mathematics and science, just at a time when both the needs of the nation and of its individual citizens require otherwise?

The evidence is that students enter school in the primary grades with an interest in numbers, in spatial relationships, and certainly in the world around them but are "turned off" from the study of mathematics and science in the early grades and generally discouraged from continued study in these subjects. Children with encouragement from home and out-of-school opportunities to pursue these subjects (as will be discussed later) tend to be those electing to study them further. Clearly, middle- and upper-class white males predominate in such a population. In the secondary school, election of advanced science courses is usually by the already motivated, college preparatory, preprofessional student. Future career choices and the mathematics electives that go with them are generally made around the eighth and ninth grades, when disenchantment with mathematics and science is prevalent and encouragement most needed. Minorities, females, and the socially disadvantaged are generally lacking appropriate counseling and encouragement and consequently are underrepresented in college preparatory science and mathematics courses, as well as among science and engineering majors and in careers.

Dropouts among college science majors include some of the most creative students and a high percentage of females and minorities. Graduates electing doctoral work and electing university teaching in science and engineering are not sufficient in number to meet the nation's projected needs for research and advanced teaching. The number electing elementary and secondary school teaching in mathematics and science most certainly are not nearly adequate to meet the current and projected needs of our school population. Most states now report acute shortages of physics and chemistry teachers, and science and mathematics teachers are leaving the profession at a much faster rate than ever—primarily for jobs in industry.

Most secondary schools' science courses are designed for the college preparatory, preprofessional student and make little, if any, attempt to relate science to society and the individual, let alone relate each of the sciences to each other. College courses remain discipline centered with few real efforts at interdisciplinary or technology related approaches successful or capable of replication from one faculty to another. University courses of study and departmental offerings became increasingly fragmented after World War II under faculty members who became more research oriented in response to spectacular increases in available funding. New technologies and advances in science led to a change of thrust in many of the sciences, with introductory science courses often left behind and unchanged. Science courses for the nonscientist continued to be remarkably unsuccessful. Of course, notable exceptions to these generalities can be cited, but it is the overall situation that concerns us.

Perhaps the most promising development in undergraduate science and teaching has been involvement of undergraduates in research. Liberal arts colleges led the way, but the large research universities are now increasingly providing such opportunities and extending them to high school students. Such programs have been notably successful in encouraging students to continue in science and to develop creative and innovative approaches.

GOAL CONFUSION AND EXTRANEOUS FORCES IN HIGHER EDUCATION

The American Assembly's final report on *The Integrity of Higher Education* (1979) states:

> . . . public confidence in [American higher education] has been eroded in recent years. Consensus on what constitutes legitimate higher education has been reduced and expectations of it—and claims for it—have not been fulfilled. . . .

Dissatisfaction with college education in general can be traced to changes following World War II. According to the 1983 publication of the American Association of Colleges Project on Redefining the Meaning and Purpose of Baccalaureate Degrees entitled *A Search for Quality and Coherence in Baccalaureate Education,* American colleges have now created over 500 different baccalaureate degrees with little in common and with widely different standards. Clearly a desire to maintain enrollments, as the college-age population declined, has motivated the introduction of such degree programs and has caused some changes in standards. Public loss of confidence in what a college degree stands for—what degree of literacy, skill, or understanding it can be relied upon to provide—has much justification.

We continue to be in the middle of a confusion rather than a congruence of the historic trends summarized earlier.

Such confusion in our objectives also leads to the phenomenon of the "hidden curriculum," as articulated by Dr. Benson Snyder at M.I.T. There is often an incongruence between the messages coming to students from the formally stated goals of teachers and the curriculum and the means that students must use to attain high grades and other academic recognition. Alienation, hopelessness, the dropping out by the most creative of students as well as the most hopeless (albeit for different reasons), and much of the unrest that schools and colleges lived through in the 1960s and 1970s can be traced to educators' failure to recognize the discrepancy between what they were preaching and what the "hidden curriculum" of their values and practices required of students. "Don't do as I do, do as I say" is perhaps the most honest cry of parents, teachers, and professors alike!

POSSIBLE CAUSES OF DISAFFECTION

Before considering recommendations for action to turn back and redirect this tide now running against mathematics and science in our schooling, it is important to try to understand its causes. Rather than the *symptoms* that every study, report, and journalist finds temptingly easy to list, it is the underlying pathology and its elusive diagnosis and therapy that must be the focus for those who seek to address the symptoms. What has been going on in our nation's classrooms and lecture halls to discourage students and their teachers from further participation in these fields? Studies funded by the National Science Foundation and carried out in the late 1970s and early 1980s by the National Science Teachers Association, the American Chemical Society, the American Association for the Advancement of Science, and other professional organizations provide comprehensive and in-depth data and analyses. A synthesis of all the reports and observations reveals the following characteristics of most elementary and secondary science instruction:

1. the supremacy of the textbook—90 percent of all science teachers in the U.S. use a textbook 90 percent of the time and attempt to cover all the book's content;
2. the implicit justification of course content as preparation for the next level—not as a response to student need, interests, or skill level;
3. limitation of the goals of science instruction to certain specific knowledges and practices—rather than recognition of the multidimensional scope of science;
4. continued compartmentalization of science in the order of presentation of the various disciplines—rather than consideration of the *total* interdisciplinary science curriculum as a dynamic relationship of materials, teacher, and environment;
5. the predominance of the lecture format, the teacher talking and maintaining control—an approach effective only for students who want to succeed in traditional ways; and
6. laboratory exercises that merely require following directions and verifying information given by the text or the teacher—most science courses do not include a single laboratory experiment where students can identify and define a problem and participate in any decisions about procedures, observations, and interpretation.

With success in school science deriving from emphasis upon content for its own sake, the teacher's lectures, and textbook presentations, the students who achieve in this context generally experience great disillusionments later (unless they continue along the same track in college) when they find that this kind of science (which is not science!) is not of use to them in later life.

John Goodlad, in reporting in 1983 on an eight-year, in-depth study of 1,016 classrooms across the country, found the same phenomenon in all classrooms in all subjects: teachers appear to teach within a very limited repertoire of pedagogical alternatives emphasizing teacher talk and the monitoring of seatwork. Customary pedagogy places the teacher very much in control. Feedback-with-guidance associated with helping students to understand and correct their mistakes is rarely found. The result is a numbing boredom and alienation of students—and a failure to grow in learning and in the ability and confidence to solve problems. "Rarely did we observe laughter, anger, or any overt display of feelings," Goodlad comments. "If I myself were in such classrooms hour after hour, I would end up putting my mind in some kind of 'hold' position, which is exactly what students do." Most of us undoubtedly have done the same.

New Educational Objectives Needed: Where Should We Be Going?

The current status of the nation's educational practices indicates that, at a time when we would like our *total* population to have some skills and understanding in areas of mathematics, science, and technology, we have been most successful in discouraging general interest and achievement in these subjects. At the same time, although we would like to ensure a continuing supply of innovative thinkers and workers for our scientific and engineering (and also teaching) endeavors, we have been leaving the development of such talent to chance cultural and educational advantage and to out-of-school (informal education) opportunities. In fairness to all who have been laboring so hard in these vineyards, the objectives we now identify as in the best interest of the nation and of its citizens are new; that the old ways cannot meet new objectives should not be surprising. To say that mathematics and science must move from the periphery of learning for all but a few to center stage for everyone represents change and requires consequent change. Indeed, once we can agree on the new educational goals and objectives, the routes which must be taken to reach them will be clear—and become possible.

EDUCATIONAL GOALS FOR MATHEMATICS, SCIENCE, AND TECHNOLOGY

The National Science Board commission report cited above recommends that the nation's educational systems, both formal and informal, should have the capacity:

1. to continue to develop and broaden the pool of students who are well prepared and highly motivated for advanced careers in mathematics, science, and engineering;
2. to widen the range and increase the quality of educational offerings in mathematics, science, and technology at all grade levels so that more students would be prepared for, and thus have greater options to choose among, technically oriented careers and professions; and
3. to increase the general literacy in mathematics, science, and technology of all citizens for life, work, and full participation in the society of the future.

All these goals require new objectives for mathematics and science education and the addition of technology education—a newcomer to the liberal arts tradition.

New goals for the nation require new commitments: that the understanding of mathematics and science is not only possible but also a benefit for all, *and* that the pool of future leaders and talent in these fields must include those for whom a challenging education has not previously been provided. There appears to be general agreement that a changing technological society requires youth who are "trainable" and well prepared for further education in industrial and other sectors of the economy. Focusing on specific job related skills rather than on a general education at the elementary and secondary level is deemed ill advised by most of those reporting on the nation's needs in its work force.

Fundamental changes in instruction are required in the mathematics and sciences, not only to reverse declining student participation and achievement and to deal with new national goals of technological and scientific literacy, but *also* to adapt to:

1. the explosion of scientific and technical knowledge and concomitant change in judgment about what students should learn in each discipline;
2. the escalating availability of most effective interactive educational technological aids, particularly computers; and

3. advances in the cognitive and behavioral sciences in understanding how people learn and how such learning can improve teacher training, curriculum, and software development.

Acceptance of mathematics and science as additional windows on learning and growing, deserving places within general literacy, requires fundamental change in teacher and administrator attitude. Mathematics must be seen, as suggested by De Morgan in the 1830s, as a way of thinking that opens doors to new knowledge in virtually every field of endeavor (art, music, business, social science, etc.) and that is essential for advanced understanding of all science and technology.

A report by the Conference Board of Mathematical Societies (1983) suggests that elementary mathematics instruction in this computer age should emphasize practical, real-life applications, informal mental arithmetic, estimation, and approximation rather than paper and pencil computation, even though comprehensive understanding of and facility with number facts and related processes are considered as important as ever. At the secondary level, finite (discrete) mathematics must now be included with the precalculus topics, and new approaches for both must be anticipated from the development of computer science and computer technology. The current curriculum must be streamlined, leaving way for important new topics, such as the use and understanding of computers. Undergraduate mathematics curricula must necessarily respond to changes in secondary school teaching and could also constructively affect precollege curricula by judicious change in requirements and course prerequisites. The development of courses for current undergraduates should include discrete and computer mathematics not covered in secondary school. Applications to other fields of study, including technology, should be emphasized as much in college as in school.

PREPARATION FOR TECHNOLOGY INNOVATION

With respect to new criteria for technology and science education, the NSB commission recommends, in part:

> Students must be prepared to understand technological innovation, the productivity of technology, the impacts of the products of technology on the quality of life, and the need for critical evaluation of societal matters involving the consequences of technology. Further, the nature of scientific inquiry and observation presents frequent opportunities for experiencing

> success. Such inquiry does not require unique answers. Students can rightly and successfully report what they have seen and found. This type of experience should be encouraged.

The commission report lists recommended criteria for improving and changing instruction in the sciences. Above all, observation, student inquiry, and "hands-on" approaches must be encouraged. Teacher or classroom "coverage" of any prescribed amount of material is to defer to development of interest and skill in scientific observation and to motivation of understanding the results of this observation. Particular talents for innovative and creative thinking must be developed and enhanced, along with the capacity for problem solving, critical thinking, and knowledge useful for living, as well as for advanced study.

The commission report recommends that technology should be included in the curriculum of kindergarten through grade 12 as a topic integrating science, mathematics, and other fields of study—not as a separate subject in the curriculum. With the leadership of the Alfred P. Sloan, Jr., Foundation, some liberal arts colleges are now exploring ways to integrate understanding of technology into their curricula. One can anticipate that such efforts will escalate at the college level, as indeed they should.

Coupled with objectives for the development of student skills and understanding areas of mathematics, science, and technology must be a clarification of the essence of these subjects—what is the nature of the mathematics, science, and technology that should be understood? Study after study indicates that, through school and college (always, of course, with notable and most precious exceptions) we have been communicating science as a factual, difficult, textbook-bound subject governed by "known facts" and something rigidly defined as "The scientific method"—the keys to this kingdom being discipline centered courses which are as effective in locking students out as in inviting them in.

SCIENCE EDUCATION: A PERSONAL VIEW

In thinking about the need to turn around such perceptions, I am reminded of a prayer I was given by a fellow school head many years ago: "Help us from speaking those things which are not true or, being true, are not the whole truth or, being wholly true, are merciless."

It appears, wherever one turns in exploring science and mathematics education, that the formal curriculum has been merciless in excluding our children from consideration of the unknown in both the process and the product of the study of the natural world. We have taken the results of several centuries of creative, risk-taking investigation and thinking, organized it into a hierarchical framework, and presented this organized body of knowledge as symbolic of the search itself. My favorite definition of science comes from Gerald Edelman: "Science is imagination in the search for verifiable truth." Imagination and the search are so often missing in the teaching of science.

So many thoughtful persons, whether coming from the point of view of psychology (like Jerome Bruner), from biology and medicine (like Lewis Thomas), from education and computer science (like Seymour Papert), or from physics and chemistry (like Gerald Holton), independently suggest that the unknowns in math and science should be the takeoff point of science teaching, titillating imagination and motivating learning. Bruner wants "the schools, like life, to bring into light the tough predicaments that pupils are already beginning to recognize and make them part of the coin of discussion. . . . Do not ask whether children are ready. Nobody is ever ready until given a chance."

Thomas speaks of the essence of science:

> The endeavor is not, as is sometimes thought, a way of building a solid, indestructible body of immutable truth, fact laid precisely upon fact in the manner of twigs in an anthill. . . . Science is not like this at all: it keeps changing, shifting, revising, discovering that it was wrong and then heaving itself explosively apart to redesign everything. . . . It is a living thing, a celebration of human fallibility; at its very best it is rather like an embryo.

Papert speaks comparably of mathematics:

> Mathematical work, as scientific work, does not proceed along the narrow logical path of truth to truth, but bravely and gropingly follows deviations through the surrounding marshland of propositions which are neither simply and wholly true nor simply and wholly false.

Gerald Holton and others suggest that science is inaccessible to the nonscientist. The scientist works on ever-increasing levels of abstraction until eventually:

> there is a fundamental logical independence of the concepts from the sense experience. The concepts are not some distillation of the experi-

> ences which anybody, using the *kind of logical reasoning one supposedly learns in school,* should sooner or later be able to trace. . . . On the contrary, the concepts themselves are freely formed, subject to the *a posteriori* usefulness of the whole structure when confronted with experience.

If one's learning went beyond logical reasoning at school, would science be more accessible? When synthesis of thought or observation does not proceed along lines that previously yielded solutions of like problems, the creative and talented mind steps back, takes all the pieces of the puzzle apart, and then finds ways to reassemble them in new ways that fit. Is this approach ever part of any but the *most* talented teacher's or professor's teaching methodology? Can it be? Should such approaches be incorporated into instructional design? Would this help science be more accessible?

Teachers frequently comment that students assigned to classes for "low achievers" will often give wonderfully practical and imaginative answers to an unconventional question. Students identified as gifted and talented will more frequently have a "single right answer" orientation. Children from classes identified as for the "gifted" make clear how they carry constant and pervasive anxiety with them—e.g., pressure from parents and teachers. They worry about school performance and grades and, consequently, identify learning with single, correct answers. Successful students become adept at dealing with the "hidden curriculum"—a requirement for their success. They learn that innovation is not rewarded—except in very rare situations.

SIGNIFICANT OMISSIONS

Until there is a broader understanding of how the best scientists, engineers, and mathematicians perceive their fields, and how important technology and creative and innovative thinking are to them, mathematics, science, and technology will still be communicated in ways guaranteed to "turn off" most humanistic and imaginative students and adults alike. That this point fails of appreciation, consider some representative comments excerpted from recent reports on the status of our schooling.

The Commission on Excellence report (April 1983), *A Nation at Risk,* has much to say about the meaning of "excellence" for both students and schools. While the report speaks of maximizing all students' talents, it does not make a special point of innovative and/or creative thinking or of technology. However, in listing the "tools at hand," the "*ingenuity* of our policymakers and scientists" is considered one of our assets.

In the College Board report (1983) on *Academic Preparation for College: What Students Need to Know and Be Able to Do,* there is an emphasis on what are called "basic academic competencies" (reading, writing, speaking and listening, mathematics, reasoning, and studying). Although the mastery of currently accepted wisdom is included in each of these categories, there is no mention of skills of observation or the ability to challenge, to deal with ambiguity, to consider alternative answers/procedures, or to imagine new ideas. In the detailed explication regarding mathematics and science, knowledge of facts, skills in observation, and analysis are well covered; technology is not, however, and the only mention of inquiry is under laboratory training, i.e., "the ability to distinguish between scientific evidence and personal opinion by inquiry and question."

The Task Force on Education for Economic Growth of the Education Commission of the States, in its June 1983 report, does note that "technological change and global competition make it imperative to equip students in public schools with *skills that go beyond the basics.*" In discussing improving academic experience for students neither technology nor innovation is included but the report does note:

> The goal should be both richer substance and greater motivational power: to involve students more enthusiastically in learning, and to encourage mastery of skills beyond the basics—problem-solving, analysis, interpretation, and persuasive writing, for example.

A comprehensive research study by the National Association of Secondary School Principals and the Commission on Educational Issues of the National Association of Independent Schools delivered a preliminary report, *A Study of High Schools,* in 1983. The most prevalent observation is students' docility, lack of engagement with ideas, and disinterest in school. After discussing the need for policy makers to understand the complexities of adolescence, the processes of learning, and the nature of teaching (as well as the variety of the human beings who are teachers!), the report goes on to say, "Secondary schools should be primarily places where young citizens learn to use their minds. One learns to reason—to imagine, to hypothesize, to analyze, to synthesize—by practice." Here is another definition of new educational objectives!

Recommendations for Action: What Can We Do?

Clearly our national need is to set and to implement educational goals, particularly for mathematics, science, and technology, that are more in tune with our times and our students—and with the nature of these fields of inquiry themselves.

CALLS FOR LEADERSHIP AND ONGOING ASSESSMENT

Considering the lack of mechanisms now in place to recommend, implement, and monitor the necessary changes, the NSB commission points to the need for new leadership to set and implement new goals at the national and state level, involving all sectors of American society. Among its forty-one recommendations was that a "National Education Council" be established, as well as state councils (such as those already initiated in several states) to provide focus, coordination, direction, and midcourse corrections, as well as assessment of student participation and performance, in order to achieve constructive change for education in mathematics, science, and technology. Another pertinent recommendation was that local school boards take appropriate steps to form partnerships with institutions and individuals who can aid in science and technology education.

EARLY EXPOSURE: EARLY ADVANTAGE

It is important to recognize, *particularly* in the mathematics and sciences, that early talent identification means early advantage. Early advantage compounds during the student's subsequent life and creates an increasing separation between the talented student's achievement and that of others.

As in the critical work of Robert Merton, American science can be demonstrated to be meritocratic, in that identified talent tends to be rewarded on the basis of performance rather than origin. The ultraelite continue to come largely from the middle and upper classes.

In her definitive study of U.S. Nobel laureates, Harriet Zuckerman identifies early advantage and early identification as common to all laureates interviewed. The proportion of all scientists coming from families of skilled and unskilled workers has, over the past fifty years, trended slightly upward, but no change is evident in the social origins of laureates. Thus, although inequalities in the socioeconomic origins of American scientists at large have been reduced during the past half-century, this has not been true for the ultraelite in science. According to Zuckerman, the origins of Nobel laureates remain highly concentrated in families that can provide their offspring a head start in system-recognized opportunities.

To quote Lilli Hornig, in a 1982 National Research Council annual review of issues:

> The traditional approach to science teaching is grounded in a belief that quantitative talent appears early in life, and that potential scientists are likely to be identified in adolescence or sooner. Their education is therefore designed on a largely sequential model that leaves little room for late bloomers or those whose social condition made early identification and fostering of talent unlikely. The model persists through higher education and scientific careers: those who move fastest are likely to be labeled "best."

Giftedness in the socioeconomically disadvantaged child may be discouraged rather than encouraged in getting on an upward track of achievement. The work of Donald McKinnon documents a commonly held impression that gifted children may not be valued by teachers in the classroom or parents at home because they are not necessarily held to be good prospects to succeed as adults; children themselves do not necessarily want to be gifted in the home/school value context of giftedness.

One also recalls here the overriding influence of the "Hawthorne effect": student self-image and the teacher's image of that student are of overwhelming influence in teaching and learning.

The seminal work of Seymour Papert and his students and colleagues at M.I.T. helps to update these speculations and observations about early identification and advantage. His book, *Mindstorms,* notes the deeply embedded assumption in our culture that the appreciation of mathematical beauty and the experience of mathematical pleasure are accessible only to a minority, perhaps a very small minority, i.e., uniquely creative, gifted, and talented children. French mathematician Henri Poincaré accepted this as a truism while expostulating that the distinguishing feature of the mathematical mind is not logic but aesthetics and that this aesthetic sense is innate. Papert suggests that, if Poincaré's model of mathematical thinking (i.e., predominantly aesthetic, not logical) is correct, then the affective and aesthetic dimensions of mathematics should be included in curricula. If this were done, could hidden talent thereby be unlocked and the assumption that the mathematical mind's aesthetic sense is entirely innate be challenged?

The NSB commission found "a striking relationship between achievement in mathematics, science, and technology and the early exposure of students to stimulating teaching, good learning habits in these fields, and enrichment by regular exposure to informal educational activities." It thus recommends that top priority should be placed on providing increased and more effective instruction in mathematics, science, and technology in kindergarten through grade 6 (K–6). From the foregoing discussion it seems clear that it is essential to introduce mathematics in the earliest grades (K–3) in ways that encourage and develop innate imagination, gamesmanship, and numerical and spatial sense. Thus our society might involve a broader cultural grouping than predominantly upper- and middle-class white males in an education leading to innovative work in science and/or technology. To enable students' minds to be opened and remain open to mathematics and sciences in high grades requires the type of creative and comprehensive early introduction recommended by Papert.

IMPROVED INSTRUCTION: CONTINUING ADVANTAGE

Discrepancies observed between recommended educational objectives and the learning that goes on in most classrooms, as summarized above, indicate the quantity and quality of improvement that must be made in instruction. To the multitude of challenges and obstacles faced by education in general, the sciences add the exploding complexity of the subject itself and the critical need for laboratory and/or field experience for its understanding. In analyzing why the extensive involvement of science teachers in National Science Foundation sponsored teacher institutes in the 1960s and 1970s did not lead to more long-lasting improvement in the classroom, Arnold Arons, Emeritus Professor of Physics at the University of Washington, notes the failure of most teacher institutes to guide teachers slowly and carefully through the intellectual experiences they were subsequently to convey in their classrooms: "Most teachers had developed little genuine understanding of scientific subject matter in their previous school and college courses and were very nearly at the same level of conceptual development as their pupils." The interdependence of school and college teaching is clear. He also notes that science teachers, particularly in elementary and junior high school, need much better logistic support (in time, equipment, and materials) if they are to successfully try new curricular and teaching concepts.

Nevertheless, the federally funded efforts in curriculum development and in teacher training between 1957 and 1977 yielded a sound base of experience, partnerships between teachers, scientists, mathematicians and professional societies on which to build for the future. High school curricula were developed that could be readily updated and that are good preparatory sequences for those preparing for advanced careers in the sciences. New instructional strategies were explored with model materials to support them. Most importantly, new views of science education, along the lines of the objectives discussed above, were promulgated, which include philosophical, historical, sociological, technological, and humanistic dimensions. Thus with renewed commitment, agreement on new educational objectives (including technology), and broad-based leadership, a reservoir of knowledge and experience is available to embark on a massive effort to retrain and to improve the continuing education of the nation's mathematics and science teachers.

The NSB commission suggests such a commitment at the national level, in partnership with states, to accomplish extensive retraining of the nation's elementary teachers and secondary mathematics and science teachers over a five-year period. Coupled with these recommendations are others relating to increasing graduation requirements and time spent on mathematics and science for high school students, as well as for baccalaureate degrees for future teachers. More mathematics and science and technology for everyone is the consensus today.

To ensure that the objectives of teacher training are geared toward the approaches in mathematics, science, and technology recommended above will require a fundamental change in attitude about these subjects, and about teaching, by administrators, parents, and community leaders. Citizens and educators must look at what is really happening in the classroom and beyond. It is hoped that their tremendous current interest and focus will prompt those concerned to take the studies by the mathematics, science, and engineering societies very seriously and press these recommendations widely.

Needed change in the role and function of the teacher may develop through computer science education. With both teacher *and* student relatively new to this field, it is legitimate for them to learn together. The role of the teacher, in these classes, is more that of an information transfer agent, the person who knows and has access to learning resources. In the best cases, the teacher understands the students and can guide, manage, and facilitate the transfer of knowledge and understanding. Teachers thus assume their proper role—the agent for learning—not the source of all knowledge.

Leadership of future technological innovation in the nation requires young people capable of both subject matter mastery and innovative thought, so ways must be found to help communities and school administrators understand that student behavior reflecting both capacities is in line with new educational objectives and is to be rewarded. Teacher training must incorporate such recognition, as must administrative procedures in schools and in teachers' continuing education.

Gifted and talented students can block out learning if there is too much drill and repetitive practice, even though others may need it. How can we protect the learning needs of all students; move all to a certain degree of general, as well as technological and scientific literacy; and, at the same time, deal with the evident and not so evident talent that needs the opportunity to develop inventive thinking? The only answer is, of course, improved training, continuing education, and improved resources for teachers.

NEW LEARNING ABOUT HOW PEOPLE LEARN

Among the new resources available for direct assistance to teachers and to curriculum developers to help improve the effectiveness of teaching and the efficiency of learning is the promise of current research in the cognitive and behavioral sciences. Perhaps this field will supply ways to address the special needs of the gifted student, the "breakaway mind," and the underachiever. Publications by the National Science Teachers Association (e.g., *What Research Says to the Science Teacher)* and recommendations of the various commissions and studies cited earlier certainly indicate a general and growing recognition among professionals of what this field has to offer them. For example, theoretical representations of knowledge structures needed to represent problems in physics, elementary arithmetic, and electronics have been developed in the form of schematic mental models, from which instructional methods are being designed to increase students' skills in representing problem information. Current analyses are showing how understanding of general concepts can facilitate learning and performance of correct procedures, as well as understanding of the procedures themselves.

Some of the most interesting work, which has immediate application to the classroom, is in the domain of physics—the subject so often perceived to be the "hardest" and most "beyond" the average pupil. Students apparently bring to the classroom significant misconceptions of general principles which persist despite their instruction, so that their subjective or qualitative understanding of the principles of physics (i.e., gravitational force and laws of motion) is inconsistent with and *thus interferes with* the formulas thrust on them in the classroom. Instructional methods that take into account students' prior conceptualizations, especially instructional materials that use the capabilities of computer simulation to represent systems that behave according to ideal principles, can help students make great strides in comprehension. This is an example of applying computer simulation in order to improve understanding of fundamental principles—the aspect of learning previously considered the exclusive domain of the gifted or scientifically and mathematically intuitive student. How much greater a percentage of the minds of our student population can be opened to such understanding and new potential in innovative work remains for the next generation of teachers —those using computer simulation together with other improved instructional techniques—to determine.

TECHNOLOGICAL AIDS: COMPUTERS

Undoubtedly the most significant resources now available to help teachers increase their effectiveness and expand and increase student learning are the technologies: computers, educational television, videotext data bases and computer based telecommunications, videodiscs and intelligent videodiscs, and robotics.

Computers are the most widely considered technology in the current educational scene and can be used in three distinct modes: learning *about* computers, the most widely used application in schools to date; learning *with* computers (i.e., drill-and-practice and tutorial), the most widely researched area; and learning *through* computers, the area with the most exciting potential for future computer impact on learning. Student and teacher use of computers as aids to learning and teaching is growing and developing at an exponential rate as the cost of hardware decreases and the variety and capacity of hardware increases. There is already strong evidence that computers, used in the "learning-through" mode, make significant contributions to the learning experiences of children in a variety of disciplines (experience with the LOGO language of Papert is an example). Even though there is much less evidence in other areas of application, computers used in the "learning-about" and "learning-with" modes have a great deal to offer educators and students as well.

As explicated earlier, one can anticipate that student interactive work with computers will be literally "mind expanding" as courseware is developed through partnerships between learning psychologists, artificial intelligence specialists, teachers, and subject matter specialists. The potential of students educated through such modes to contribute, in their turn, to innovative work in technology can only be prognosticated, but it should be extraordinary.

As with any change and with any new technology, there are certainly problems involved with incorporating computers most effectively in our educational system.

1. The overall quality of existing courseware is very low.
2. Since there is a well-articulated consensus that *all* teachers should be computer literate and that mathematics and science teachers should have special facility for using computers as aids in instruction, training all teachers to develop and maintain such skills will require a monumental investment in time, talent, and money.
3. The investment cost estimate to develop an adequate base of quality computer courseware in mathematics, science, and technology for all the nation's schools, K–12, is in the hundreds of millions of dollars, and this work should proceed in tandem with curriculum development.
4. Although several fine efforts have been developed on a small scale,

ongoing review of existing courseware and dissemination of results and recommendations require a capacity not now present on the national or regional level.

5. There are serious inequalities of computer access and computer instruction between those schools and school districts that are privileged or targeted and those that are not. The danger is that computer instruction and access will be another case of the "rich getting richer." In this case the "rich" will become those with a particular potential for innovations in this technology. Another consequence of inequality of access is that computers tend to be used more for remedial work in socioeconomically disadvantaged schools than for more creative and advanced use. Computers for drill and practice do not put the child in control or give the child the sense that the child can master the computer rather than vice versa—learning *through* computers does.

An important development in learning with and through computers is already, and will increasingly be, through informal learning environments. These have several advantages over schools, including access by everyone in the community and creation of a nonjudgmental climate without the time constraints of more formal environments. As technology becomes incorporated in school programs, "hands-on" experience with technology may have to depend on such out-of-school access as technology centers and participating science museums. Examples include the Capital Children's Museum in Washington, community based centers like Playing to Win in New York, and ComputerTown USA in Menlo Park, California. However, it is the private home that may be the most powerful influence of all.

Educators must develop ways to take advantage of home computers and to build cooperative relationships with parents in acquisition of hardware and courseware. Some school systems are already involving parents in computer education and enabling school computers to go home in an effort to redress the economic barrier to home computers for many families. School structures and classroom design will undoubtedly and beneficially be forced to change as this technology becomes more widely distributed.

With respect to other technologies, the impact of educational television is strongly favorable, especially when it is accompanied by support documentation for teachers and students. Examples on public television for the precollege and general adult population are the "Nova" series, "3-2-1 Contact," "Connections," and the extensive use of television by colleges, particularly for distance learning. The combination of telecommunications with computers is also one that can be expected to be particularly fruitful for distance learning, as well as learning in rural areas. The other technologies mentioned are so new to education that the only evidence of effectiveness is anecdotal—although positive.

These new technologies have unique potential in expanding the capacity of teachers, particularly in relation to education about the technologies themselves, as well as to excite interest and achievement in mathematics and science where the nonjudgmental, discovery-learning environment provided by computers, television, and related technologies has a special value. Partnerships of industry, higher education, and schools are essential to set guidelines and develop strategies ensuring the most effective introduction of these technologies and the most effective courseware. Leaders in technology, government, business, and higher education would be well advised to give these issues top priority, as the NSB commission recommends.

PARTNERSHIP AMONG SCHOOLS, HIGHER EDUCATION, AND INDUSTRY

Such partnerships have high potential to increase the effectiveness of schools and colleges by providing better market information and community resources. Considering the direct interest, indeed, proprietary interest, that higher education has in secondary schools—either in their product, i.e., students who will purchase university services, or in their market, i.e., teaching positions for university graduates—it is surprising how independently each has functioned in recent decades. Neither has ordinarily been in the position, on a systematized or mandated (let alone recommended) basis to give the other useful feedback concerning the efficacy of its product—the teachers trained or the students enrolled. With new economic constraints on universities and marked dissatisfaction with schools, there is increasing talk about and beneficial development of such partnerships. One hears of more and more initiative on the part of colleges and universities to share information on student participation and performance with the sending high school, particularly with respect to mathematical and writing proficiencies. Can schools find the same capacity to feed back information to colleges on the efficacy of their preparation of teachers?

Will students' capacity to be innovative and/or productive in technological fields become part of this feedback to schools? This possibility can occur only if the value of such student qualities is identified and given emphasis. If this message could then come from colleges to schools, a direct effect in developing teaching methodologies encouraging such thought and action could be anticipated.

Increasing interaction of colleges and neighboring schools in student mentor projects, summer teaching assistantships for teachers, and adjunct teacher programs has already encouraged, and will further increase, informal feedback, and therefore more systematic communication. Programs to encourage student work in laboratories, such as those initiated by the New York Academy of Sciences, the Work in Technology and Science Program at M.I.T., the North Carolina School of Science and Mathematics and Duke University Medical Center, the University of Michigan, and the University of Rochester, can be cited as among those that were initiated tentatively and then more fully developed as success bred success in the relations between high school students and college mentors and those between high school teachers and college laboratories and professors.

Partnerships between schools and industry appear to be burgeoning, as are those between schools and higher education. A review by educator Michael Timpane indicates that the business community thought and acted as though it "owned" the schools until twenty or twenty-five years ago. Business and professional men dominated school board membership and were, until the 1950s, the most powerful and consistent source of civic support for the schools. School administrators increasingly identified themselves as managers in the image of the American businessman. With radical changes in the political economy of urban schools in the mid- to late 1960s, the corporate representatives gradually left the scene, particularly in urban areas. The current image of schools as viewed by corporate officers tends to be one set in rather absolute terms such as "declining test scores, unruly students, unworkable innovations, and newly militant teachers." Corporate officials have had little personal contact to soften this stereotype.

Corporations have recently begun to invest substantial financial and political resources in the rejuvenation of city schools. Many programs have started: Adopt-a-School and Join-a-School programs and privately supported foundations to assist public schools. Donated equipment, loaned adjunct teachers, and summer employment for students and, increasingly, for teachers are among the forms of participation initiated by science and technology based industries. Such programs show a unique potential for providing laboratory experience and up-to-date equipment information for teachers and students.

With respect to innovation in teaching and learning, one could suggest a very special role for higher education and industry for students with high potential in this area. Volunteer scientists and engineers in the schools or in their own laboratories can encourage students with the innovative risk-taking type of thinking that is so hard to provide in large classes and understaffed schools. In out-of-school settings, other types of thought and action can be explored that might, in a school setting, threaten other students and personnel who do not have the confidence or perception to deal with them.

MUSEUMS AND TECHNOLOGY CENTERS

Museums and technology centers have been leaders in demonstrating how much more readily out-of-school settings adapt themselves to encouraging creative and innovative approaches to and learning in science. In recent decades, a new sort of educational institution has become popular around the world—the science and technology center. Although the name "museum" is often included in the title, they are quite different from the traditional museum. Rather, they are populist, interactive facilities designed to expose the inner workings of natural phenomena and man-made processes and are alive with a multitude of participatory exhibits and educational programs. Their origins in Germany, England, and the U.S. (beginning with The Franklin Institute) are closely identified with inventions and technology. Although, for the most part, they have emerged in the United States only within the last fifty years, they raise pertinent questions about places for technology education today.

A historical review of these institutions by V. J. Danilov, director of the Chicago Museum of Science and Industry, makes it clear that for the last three centuries there has been a general assumption that both technology education and stimulation of invention and innovation were best done in a physical setting where things could be observed. Another assumption was that technology education provided through an exhibition was good for everyone, but mathematics and science were for schools and the elite. Is it because of this assumption that technology *is* interesting to everyone that there is virtually no technology education in schools today? Inventions and innovation have not been considered to be part of the school's training responsibility, but rather for out-of-school opportunities.

In the late nineteenth century, G. Browne Good, a director of the U.S. National Museum (operated by the Smithsonian Institution) said:

> The museum of the future must stand side by side with the library and the laboratory, as part of the teaching equipment of the college and the university, and in great cities cooperate with the public library for the enlightenment of the people.

This is, indeed, a role that the NSB commission is recommending for today. With 150 million Americans annually visiting museums, the role such centers, whether large or small, could play in greatly expanding the horizons of science and technology education for students and adults is clear. With their capacity to emphasize innovation and technology in an informal setting, museums and technology centers could serve as unique resources for teacher education, particularly for those teaching at the elementary level.

YOUTH ORGANIZATIONS, INCENTIVES, PUBLIC AWARENESS

Americans have been great "joiners" since the founding of the Republic; yet there is a lack of general recognition of the vast array of opportunities afforded our youth through the over 250 adult sponsored youth organizations that enroll millions of youths in groups, troops, teams, and clubs. A veritable army of adult volunteers and well over 50,000 staff members are involved. Opportunities abound through our youth organizations for developing educational programs, scientific and technological experiences, awards, and incentives to encourage student participation. These informal educational opportunities allow participation of interested professionals in a host of ways.

The positive effect of awards, rewards, and honors on the development of interest and self-confidence in youth is well documented. The Westinghouse Talent Search, science fairs, and various national and international competitions (such as the Mathematics Olympiad and Math-Count) are well-known examples. Such programs serve as incentives to teachers as well as students. With all that has been said earlier of the limitations of schools and college administered written tests of cognitive ability, there are almost unlimited opportunities to develop incentives and rewards for creative, experimental, and innovative activity through the entire informal education system—youth organizations, church groups, museums, and local television stations. While more direct opportunities are clearly available through these channels for affecting attitudes, such programs help raise public awareness and disseminate information about the nature of science and technology in ways that are not restricted by the academic organization of formal educational institutions.

EXEMPLARY PROGRAMS, "MAGNET SCHOOLS"

The magnitude of the tasks ahead is overwhelming: teachers to recruit, train, and retrain; public attitudes to change and expand; new curricula to develop and old curricula to revamp; equipment to evaluate, purchase, and use; and all the students, young and old, to reach. The existence of many wise and wonderful teachers and students in excellent exemplary programs lends not only hope but the expectation of success to this task. Lasting change in education has come from discrete individual steps—the development of programs that work in given communities has a "ripple effect," encouraging others to follow or adapt them to other situations and people. The NSB commission suggests strongly that the development of such exemplary programs, particularly "magnet schools," where appropriate, be given a national priority. This strategy is based upon the recognition that change cannot be made all at once but should be initiated in special situations and then disseminated through outreach, example, and competition.

The "ethos" of a school is key. In some cases model programs can be developed within the school or the school can become a "model." In others, the environment in and around the school is such that change and positive attitudes can only be developed with the creation of a new school or a school-within-a-school where student and teacher commitment to higher goals becomes the admissions credential. The strategy of focusing the school program around a subject area such as the arts, science and mathematics, or engineering has been used successfully in several inner city schools. Again, it is the positive attitude about the subjects chosen for emphasis *and* the assumption that all children can succeed within it that make the difference. Those interested in finding fertile environments for special incentives or special programs to develop student interest in innovation in technology and the sciences might find it easiest as a first step to initiate such a program within the receptive environment of the over 1,100 "magnet" elementary and secondary schools now in operation across the nation.

Summary

This chapter has concentrated its discussion and recommendations on elementary and secondary schooling simply because this is where the quality of future students and workers is controlled and innovation first encouraged. Change and improvement at this level will both force and catalyze improvements in colleges and in the workplace—and vice versa.

Both innovation and technology can and must be included in our objectives for the learning of all students. Our nation has reached the point in its development and maturation where equal opportunity required for and by its citizens must include the early development of the creative, investigative mind as well as skills. This is a right for all and, according to the many resounding calls for action, a need of the nation. The liberal arts, the Jeffersonian, and the Jacksonian traditions for education can no longer be left just to develop side by side; they must be integrated—perhaps to create a recombinant form. To focus on the growth of young minds, both for innovative thinking and for technological understanding, will require also the integration of student centered approaches, particularly those utilizing educational technologies—an update of progressivism, if you will.

The new educational objectives called for include a redefinition of mathematics to meet the needs of all, as well as be of interest to all. Also included is a reinterpretation, both for the public and teachers, of the essence of science and technology that can involve all in searching enthusiastically for understanding and mastery. To include representatives from our total population in our future pool of scientists and engineers, new ways must be found which develop creative and aesthetic awareness and which introduce stimulating approaches to mathematics and science beginning in kindergarten and primary school and, with instruction becoming more comprehensive and rigorous, continuing throughout the later grades and secondary school. Only by early identification and advantageous opportunity can latent talent develop sufficiently to become both interested and productive in the research or industrial laboratory. Only by continuing efforts to involve all students and all community resources in secondary and college mathematics, science, and technology education can all our citizens be prepared for the future and can our leaders in innovation be developed and supported.

To direct our educational approaches toward these goals, a "sea change" is required in the expectations of schools, parents, and professionals regarding teacher training, curriculum development, and community-school relationships and the nature of science and technology themselves. With public awareness of the need for increased and broader emphasis on these subjects throughout school and college and with improved training, resources, and objectives available for teachers, the satisfactions and rewards of the profession should be so vastly improved that their ranks should swell with both quality and quantity. In terms of the long-run security of this nation resulting from the satisfaction and productivity of its citizens, its professional leadership, its political judgment, and its continued capacity for innovation in technology, there can be few other public policy goals of such ultimate consequence.

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The American Assembly

COLUMBIA UNIVERSITY

About The American Assembly

The American Assembly was established by Dwight D. Eisenhower at Columbia University in 1950. It holds nonpartisan meetings and publishes authoritative books to illuminate issues of United States policy.

An affiliate of Columbia, with offices in the Sherman Fairchild Center, the Assembly is a national educational institution incorporated in the State of New York.

The Assembly seeks to provide information, stimulate discussion, and evoke independent conclusions in matters of vital public interest.

AMERICAN ASSEMBLY SESSIONS

At least two national programs are initiated each year. Authorities are retained to write background papers presenting essential data and defining the main issues in each subject.

A group of men and women representing a broad range of experience, competence, and American leadership meet for several days to discuss the Assembly topic and consider alternatives for national policy.

All Assemblies follow the same procedure. The background papers are sent to participants in advance of the Assembly. The Assembly meets in small groups for four or five lengthy periods. All groups use the same agenda. At the close of these informal sessions, participants adopt in plenary session a final report of findings and recommendations.

Regional, state, and local Assemblies are held following the national session at Arden House. Assemblies have also been held in England, Switzerland, Malaysia, Canada, the Caribbean, South America, Central America, the Philippines, and Japan. Over one hundred forty institutions have cosponsored one or more Assemblies.

ARDEN HOUSE

Home of The American Assembly and scene of the national sessions is Arden House which was given to Columbia University in 1950 by W. Averell Harriman. E. Roland Harriman joined his brother in contributing toward adaptation of the property for conference purposes. The buildings and surrounding land, known as the Harriman Campus of Columbia University, are 50 miles north of New York City.

Arden House is a distinguished conference center. It is self-supporting and operates throughout the year for use by organizations with educational objectives.

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