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Science and Technology Education in the United States

> For every complex problem there is usually an answer that is forthright, simple, direct—and wrong.
>
> (Piel, 1981: 109 paraphrasing H. L. Mencken)

Life today is deeply influenced by science and technology. Many citizens are ill-prepared to exercise citizenship rights when facing complex social issues involving science and technology. Educating students about these complex issues and their underlying scientific and technological principles is vital to the future of our society. Helping them both understand and think through the implications of the social nature and culture of science and technology is essential to a well-rounded education as we enter the twenty-first century.

Science, technology, and society (STS) education is the name that has been given to this important endeavor within the nation's K–12 schools, colleges, and universities. STS education emphasizes complex thinking and decision making leading to a product (tangible or intellectual) and/or responsible social action. This book is the first extensive survey and analysis of this burgeoning movement across K–12 education levels and subject areas in the United States. It considers the context of STS education reform; the nature of science, technology, and society; current goals that have been formulated to guide STS education efforts; the contributions of social, cognitive, and developmental psychology to STS education reform; and a framework for curriculum and instruction in STS education.

The Context of STS Education Reform

National task forces and blue-ribbon committees of university professors, business leaders, and prominent professionals from various fields of endeavor have issued numerous reports in recent years concerning the state of education in the United States. Chilling recital of educational statistics and laundry lists of problems and recommendations have fueled debate regarding the American educational system at elementary, middle, high school, undergraduate and graduate levels. The National Commission for Excellence in Education (1982: 5) concluded that "If an unfriendly power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war." The Task Force on Education for Economic Growth (1983: 2,9) warned of a "real emergency" that left to take its course would result in a declining standard of living for all Americans and an end to America's role as a major player in world markets. Their list of recommendations were absolutely "crucial to our national survival."

The American corporate world has reinforced these task force perceptions in a number of reports and position papers in recent years, focusing especially on science, technology, and vocational education (e.g., Aerospace Education Foundation, 1989; Allstate Forum on Public Affairs, 1989; Triangle Coalition for Science and Technology Education, 1988, 1989, 1990). David Kearns, former CEO of the Xerox Corporation, went public with a major plan to overhaul K–12 education in the United States, committing his company to substantial and sustained involvement in school-business partnerships (Kearns and Doyle, 1988). The Triangle Coalition for Science and Technology Education, National Association of Partners in Education, National Association for Industry-Education Cooperation, and a host of other organizations represent this growing involvement of the corporate community in the educational business of American public and private schools. Federal agencies such as the U.S. Department of Energy, the National Oceanic and Atmospheric Agency (NOAA), and the Environmental Protection Agency, have recently launched initiatives designed to impact K–12 education (e.g., U.S. Department of Energy, 1990).

The first national education summit between the White House and the National Governors' Association was held in 1989 and a series of national education goals were adopted with extensive press coverage, praise, and criticism in 1990 (National Governors' Association, 1986, 1990). There is increased talk of a national curriculum, or at least national testing with state-by-state comparisons of outcome-based assessment (Finn, 1988; U.S. Department of Education, 1990). Kentucky, New York, California, and Connecticut are just a few of the states engaged in significant overhaul of their K–12 systems of education, including some form of outcome-based and assessed education. Whether such assessment will result in better quality education and global economic competitiveness has been questioned by more than one expert (e.g., Ross, Aubrey, Berte, and Cohen, 1990; Madaus, 1988; Organization for Economic Co-operation and Development, 1989).

A National Crisis in Science and Technology Education

Much of the national attention has focused on science, mathematics, and technology/vocational education. This is due to the belief that these areas are critical to national economic health and international economic competitiveness. Goal four of six national education goals from the National Governors' Association (1990) declares: "By the year 2000, U.S. students will be first in the world in mathematics and science achievement." Specific objectives identified by the governors of all fifty states to reach this goal include strengthening mathematics and science education, particularly at the elementary level; increasing by 50 percent the number of qualified science and mathematics teachers K–12; and significantly increasing the number of undergraduate and graduate degree students in mathematics, science, and engineering—particularly minorities.

The National Science Board's Commission on Precollege Education in Mathematics, Science, and Technology (1983: v) judged that "the quality of our manufactured products, the viability of our trade, our leadership in research and development, and our standards of living are strongly challenged. Our children could be stragglers in a world of technology. We must not let this happen: America must not become an industrial dinosaur." Several other reports supported this basic viewpoint (American Association for the Advancement of Science, 1982; Educational Equality Project, 1983; Exxon Education Foundation, 1984; Task Force on Federal Elementary and Secondary Education Policy, 1983; U.S. Congress, Office of Technology Assessment, 1988; American Chemical Society, 1989a). The professional body of science educators, The National Science Teachers Association, voiced their concerns about the looming crisis in their yearbook (Brown and Butts, 1983).

One of the most telling criticisms that can be leveled against nearly all these recent reports calling for reform within the American educational system is the lack of representation of persons active *within* the current K–12 educational system on these panels. As Doll (1986) notes, the 1983 Commission on Excellence in Education had eighteen members, only four of whom were from elementary and secondary education. The Education Commission of the States panel had fourteen governors, thirteen business leaders, and only six educators, while the twelve-member task force of the Twentieth Century Fund did not include a single educator! As Doll (1986: 5) dryly remarks: "These facts illuminate a circumstance that has long been acknowledged: when a crisis occurs in elementary or secondary education, most of the persons assigned to find ways of meeting it are not educators." We might add that even when educators are selected, they usually are *not* practicing K–12 classroom teachers.

Some other conclusions from these reports were that teachers in mathematics and science education at K–12 levels are apt to be underprepared in the specific content areas they are teaching. There is a critical shortage of qualified mathematics and science teachers at K–12 levels (cf. Darling-Hammond and Hudson, 1990). American students going on to college are electing science, engineering, and mathematics fields less frequently. Pursuit of a doctorate in these fields by American citizens is on the decline. Foreign students are filling undergraduate and graduate classrooms. Foreigners occupy increasing numbers of faculty positions in these fields. Finally, students at all levels within our educational system take the minimum number of science and mathematics courses required for graduation from that particular level of the system. There is a pervasive feeling that in the midst of an increasing technologically and scientifically oriented culture, Americans are losing their understanding of the very technological and scientific principles and processes exemplified in the artifacts of our everyday lives.

A recent study of precollege science achievement of American youths versus their counterparts in sixteen other nations reinforces these conclusions (International Association for the Evaluation of Educational Achievement [IEA], 1988). The seventeen nations whose results have been partially reported from the twenty-four nations of this study were: Australia, Canada (English speaking), Great Britain, Finland, Hong Kong, Hungary, Italy, Japan, South Korea, the Netherlands, Norway, the Philippines, Poland, Singapore, Sweden, Thailand, and the United States.

Three separate age levels were assessed in the IEA study: (1) ten-year-olds, (2) fourteen-year-olds, and (3) those in their final year of secondary school. American ten-year-olds ranked just below half the other nations in science achievement. The United States ranked last in science achievement for fourteen-year-olds. At the twelfth grade level, United States students taking a second course in biology ranked last in achievement (thirteen nations in this subsample). Second-year chemistry students ranked eleventh out of thirteen nations while second-year physics students ranked ninth out of thirteen nations.

A careful reading of the IEA report makes it clear that deriving information and conclusions from the standings alone does not reckon adequately with the complexity of the situation. The first question that comes to mind is, what content areas were tested in this study? The IEA (1988: 18) reports:

> 57 content areas that were judged by the IEA Committee to represent the major content areas likely to be taught in science at school. This can be conceived of as a common curriculum across the world. This common curriculum, was, however, not dreamt up in an ivory tower by a group of science educators not knowing what goes on in science classes in schools. In the period 1967 to 1969 an international test of science had been constructed. It was based on the analysis of the science actually

> taught in schools at the 10 year old, 14 year old, and terminal grade levels. In 1980-81, further content areas were suggested as likely to have entered the school curricula. When these additional content areas were checked against the school science curricula in the different countries, it was discovered that they had only entered with sufficient emphasis into the science curricula in a very few countries. They did not exist in the curriculum of enough countries to warrant their inclusion in the testing program.

It is readily apparent that a test designed along these lines is bound to be inappropriate for those countries which have added additional topics to science curricula (and presumably either dropped or deemphasized some other areas that were *still* in the test item batteries). A second point to note is that the United States dates of testing were nearly a full two years *later* that other countries (IEA, 1988: 77). American data from 1986 were compared with 1983/84 data from other countries in the study. This likely increased the mismatch between content tested in the IEA assessment and American science content taught in the nation's schools.

Thirdly, at the Population Three Level (terminal year of high school), "the USA did not administer all tests. . . no core test was administered and in the specialist tests a number of items were dropped and the order of items was changed" (IEA, 1988: 80). A fourth item of note is that only 1,729 American students were in the Population Three level, placing them at the very lowest rank per total number of students in their terminal year of high school and placing them third or fourth from last in actual numbers of students tested in the various subject areas (derived from tables in IEA, 1988: 83). Lastly, we should take note of the five million pupils in America (11 percent of the total American student K–12 population) who attend private schools and were not part of this assessment, except in a few states. This becomes important when results from the study's subset of the United States school population are compared with those nations that have lower proportions of students in nonpublic schools.

The conclusions are clear. The results may accurately reflect overall student achievement in some nations of the study but are inappropriate for other nations. These results do not give an accurate picture of American students' science achievement and should not be the basis for science education policy planning at state or local levels (Murnane and Raizen, 1988). It should be noted that the "report card" for American mathematics students from the International Association for the Evaluation of Educational Achievement (1987) is about the same as the science report and open to many of the same criticisms.

Another recent study of science students by the Educational Testing Service (Lapointe, Mead, and Phillips, 1989) compared five countries (Ireland, Korea, Spain, the United Kingdom, and the United States) and four Canadian provinces using selected test items from the 1986 National Assessments of Educational Progress in science and mathematics. A random sample of 2,000 students from 100 different schools in each country/province participated (the American sample was about 1,000 students in 200 schools). The science portion of the assessment was divided into five parts: (1) know everyday science facts; (2) understand and apply simple scientific principles; (3) use scientific procedures and analyze scientific data; (4) understand and apply intermediate scientific knowledge and principles; and (5) integrate scientific information and experimental evidence.

Almost all American thirteen-year-olds know everyday science facts according to the results. Only 42 percent of them can use scientific procedures and analyze scientific data. This fact is not surprising when we consider that the United States ranked last in the mathematics portion of the test. Overall, the investigators believe the results of this international assessment of education progress "confirm the findings of other international and national research projects on mathematics and science achievements" (Lapointe, Mead, and Phillips, 1989: 79).

Before prematurely seizing on these results, it is necessary to once again pause and reflect on this procedure. As the authors point out, the testing procedures were not the same for all participants (Lapointe, Mead, and Phillips, 1989: 84f): "In all locations *except* the United States, students completed one assessment booklet in the morning and the other assessment booklet in the afternoon. In a random half of the sampled schools, mathematics was assessed first, followed by science, and in the other half the order was reversed. . . . In the United States, two *equivalent* samples of students were assessed, one for mathematics and the other for science" (emphasis added).

Secondly, we still face the question of the match between the NAEP test items and the content of curricula in the various nations/provinces. We can see the importance of this fact in noting the comments of the discussant from British Columbia regarding results from English-speaking students in his province (Lapointe, Mead, and Phillips, 1989: 63):

> The achievement in science was exceptional with a ranking of first among all participating populations. Students scored consistently high on all content areas, excelling on questions requiring both knowledge and integration of scientific facts and principles, and especially on questions related to Chemistry. These findings are not surprising given the emphasis placed on problem solving and process learning in the elementary science curriculum. Recent assessments have found that teachers tend to integrate elementary science with other subjects, a fact that may help explain students' high standings on problem-solving questions.

The degree to which the test items reflect the curricular emphases of the various nations/provinces studied is not reported nor apparently considered. For all nations and Canadian provinces in the study an anonymous science education expert was asked to comment on the results for their particular nation. Interestingly, the United States discussant's views were those of the authors of the study and not an outside specialist.

Similar national findings pointing out American students' deficiencies in knowledge in various subject areas have been reported from the National Assessment of Educational Progress (NAEP), including analysis of twenty years' worth of NAEP results (e.g., Mullis and Jenkins, 1988; Anderson et al., 1990; Jones, 1989; U.S. Department of Education, 1990). Many of the criticisms directed toward international assessments of achievement hold true for these national assessments. The mismatch between standardized test items and local science and mathematics curricula is well known by practising teachers and administrators and will not be dwelt upon here (cf. Dowling, 1987). New forms of assessment that will become the standardized tests of the future will narrow the mismatch gap (The Nation's Report Card, 1987; Hein, 1990).

Much of the reported decline in test scores and low ranking of the United States student population in international comparisons can be explained by various factors that often are known and even discussed in the fine print of commission reports but that frequently get lost in the accompanying publicity over the summary of the findings. In the same way, a decline in SAT scores in math or science categories over a period of time may not signal any cause for alarm since changing demographic patterns, changes in curriculum, and changing test items are likely factors that account for much of the variation (negative or positive). There is no easy way to find out answers regarding the effects of these factors. Rather than look at these complicated issues, committees, the media, and citizens at large seize on the more easily addressed answer that "Our schools are failing us." Such perceived failure drives a political agenda and mechanisms for curriculum development, teacher enhancement, and research funding through another cycle to address the presumed crisis. We might do better to divert substantial funds into researching the *meanings* of the findings within contextual factors rather than falling prey to the cult of the easy answer. Morris Shamos (1988a, 1988b), a physicist and Past-President of the National Science Teachers Association, has argued that political factors create science education crises and that once political objectives are achieved, crises mysteriously vanish.

Another critical factor when considering standardized testing results is the nature of the test construction procedure. The only test items that make it into the final battery of items are those that discriminate between students A, B, and C. Those items which all students tend to get right or wrong are removed from the test. Test constructors seek those items that will result in a test that will differentiate a student from his peers. Once we adopt this ability to *differentiate* as the main criteria for test suitability, we have lost sight of what we often are trying to measure, i.e., does the student know the facts or possess the necessary skills to conduct task X in the real world? Without even giving the test, we can predict the overall dispersion pattern, since discrimination power is the principle upon which the test is predicated.

The issue of test validity has come with renewed vigor to the forefront of the educational testing community. Two experts, Samuel Messick of the Educational Testing Service and Lee Cronbach of Stanford University, argue that content and criterion-related validity by themselves are insufficient (Cronbach, 1988; Messick, 1989). Values play a role in test construction from start to finish, and social consequences of test construction and use must be taken into account in the design and validation process.

It is important to note that there are no national or statewide assessments of American students' knowledge of technology as there are for science, mathematics, social studies, reading, and writing. Unfortunately, since that which is tested indirectly yet powerfully influences that which is taught, education in and about technology within the nation's schools appears to be marked for the same marginal status as the other "nonessential" elective subjects. This oversight is particularly troubling to those familiar with the achievements of the large international movement which combines attention to both science and technology in primary and secondary schools as represented by the International Organization for Science and Technology Education (Layton, 1985, 1988b; Raat, Coenen-van der Burgh, DeKlerk Wolters, and DeVries, 1988; Lewis and Kelly, 1987). Additionally, there is the small but growing technology education movement within the United States that grew out of the American vocational education movement (International Technology Education Association, 1988, in press). Only New York State mandates a year of technology education as a graduation requirement, even though curricula that attempt to make up for this deficiency continue to be produced for various levels (New York State Education Department, 1987; Biological Sciences Curriculum Study, 1991; Zuga, 1989, in press; Kowal, in press; Gauger, 1990).

The Crisis in Science, Mathematics, and Technology Reconsidered

The nature of the crisis that exists in science, mathematics, and technology education in America, or whether there is a crisis at all, is open to question. There are no easy standards by which one can make a judgment—despite much publicity to the contrary. Project 2061 of the American Association for the Advancement of Science specifies the level of scientific and technological literacy that every American student needs to function in the twenty-first century (Project 2061 Staff, 1989). The five panel reports (Bugliarello, 1989; Johnson, 1989; Blackwell and Henkin, 1989; Appley and Maher, 1989; Clark, 1989) and the final summary document result from the efforts of over 300 individuals working within the panels or serving as reviewers. Of these 300 persons, this author counted only thirteen classroom teachers (split rather evenly between science, mathematics, and social studies) and twenty-three K–12 supervisors (mainly science supervisors). The reports, then, were produced primarily by persons who make their living by extensive, day-to-day involvement in the culture of science and technology. We should be wary of placing too much confidence in these recommendations of appropriate scientific and technological literacy for *all* Americans. Exactly how much knowledge and skill in scientific and technical fields an individual needs to work as an accountant, a construction worker, a clerk, a secretary, or a teacher has never been addressed in an appropriate manner by research. To this author's knowledge, there are no national studies of the amount of tacit scientific and technical knowledge utilized by everyday people in the affairs of American life.

There is a growing body of research showing that what we do teach in schools related to mathematical concepts and processes, for example, does *not* conform very well to the type of mathematics used by persons delivering goods or supermarket shoppers (Lave, 1988; Rogoff and Lave, 1984; cf. Steen, 1990). The fact that large numbers of individuals are not going back to school to pick up scientific and technological information (except as it directly relates to an on-the-job situation) may signal that the amount of scientific and technical knowledge students are leaving school with may well be sufficient for their daily needs.

Frequently it is alleged that greater knowledge of science and technology is needed on the part of all students in order for America to regain economic competitiveness. Xerox Corporation, despite being heavily targeted by Japanese rivals which enjoyed massive government support, regained their world-class status by reorganizing and reforming their entire technological system of production, delivery, and service—utilizing the skills of "products" of the American educational system (Kearns and Doyle, 1988). Several other American companies have accomplished similar feats and many American corporations rank among the world's largest, most admired, and most profitable enterprises. Examples like this should give us pause before quickly ascribing a lack of economic competitiveness to K–12 education. The Organization for Economic Co-operation and Development (1989), after a series of consultations, rightly points out the inexact and indirect relationship between elementary and secondary education and economic competitiveness. So many other factors are involved in the issue of international market competitiveness that quick ascriptions of blame should be ignored (cf. Saaty and Boone, 1990).

America has always imported scientific and technical talent from other nations. The heralded shortage of scientists, technicians, and engineers in the latter half of the twentieth century is based upon many assumptions about demographic trends, immigration quotas, and market demands (U.S. Congress, Office of Technology Assessment, 1988; Atkinson, 1990; Pool, 1990). Congress has recently passed legislation raising and realigning immigration quotas, favoring importation of technical and scientific talent from abroad. Much of the important work done in World War II, for example, was done by refugee scientists and engineers culled from all over Europe, as names like Szilard, Fermi, Oppenheimer, and Teller attest. Derek DeSolla Price (1986) has argued that ''Big Science'' requires the importation of scientific talent from overseas in order to maintain its growth. The fact that America is not currently producing enough native-born scientists and engineers may not be cause for alarm.

The crises in science, mathematics, and technology education in the United States then are *not* those things which are usually mentioned in most reports and in the media. One clear problem we are facing as a nation is attracting sufficient numbers of minority students and females into these three areas of endeavor (National Science Foundation, 1990; Oakes, 1990; Beane, 1985; National Coalition for Women and Girls in Education, 1990). Factors that mitigate against underrepresented groups pursuing study of these fields in secondary schools and in colleges are fairly well known at this point in time (Task Force on Women, Minorities, and the Handicapped in Science and Technology, 1989; Searing and Apple, 1988; Kavrell and Petersen, 1984). Effective intervention programs for minorities and females have been identified and common features of successful programs are well known (Clewell, Thorpe, and Anderson, 1987; Cheek, 1989a, 1989b). National organizations such as the American Indian Science and Engineering Society, the Association for Women in Science, the National Action Council for Minorities in Engineering, the National Technical Association, and the Office of Opportunities in Science of the American Association for the Advancement of Science are just a few of the many groups devoted to rectifying these inequities. Long-term funding for effective programs at the federal or state level are hard to come by due to funding cycles. The end result is that new projects are developed to re-invent the same successful strategies pioneered by others, rather than using state and national fiscal resources wisely in expanding successful programs with proven track records. STS education has also been put forward as a way to make science and technology more accessible and attractive to historically underrepresented minorities in scientific and technical fields (Carter, in press; Cheek, 1989b).

A second aspect of current dilemmas in science, mathematics, and technology education is almost never broached in national policy circles. This concerns the appalling state of undergraduate education in these fields. A recent study (Tobias, 1990) located a small number of individuals who did well in high school mathematics and science but avoided college undergraduate science courses. Recruited as participant-observers, these individuals were enrolled as auditors in a number of introductory physics and chemistry courses at major American universities. Their diaries, coupled with results of other studies, portray an undergraduate science curricula that weeds out all but the most deeply committed science types. Lest one think that this is merely a fringe view, it should be noted that Sigma Xi, the scientific research honor society, has recently published documents that back up this picture of the undergraduate experience and makes recommendations for substantial changes (Sigma Xi, 1987, 1989; cf. American Association for the Advancement of Science, 1990; The Alliance for Undergraduate Education, 1990). The New Liberal Arts Program of the Alfred P. Sloan Foundation has been assisting colleges and universities to introduce quantitative reasoning and concepts of modern technology in relevant ways within liberal education. Efforts like these need to be encouraged if we are to attract the "second-tier" of students who turn away from these undergraduate fields not because of a lack of ability or interest, but due to poor teaching practices and outmoded methods and courses.

Alternative Views of the State of American Education

Some educational researchers defend the teaching profession while indicating all is not well with American schools. Philosophers Prakash and Waks (1985) find the substance of reform reports derive from different ways in which communities of persons conceive of "excellence" in education. These four separate conceptions are the technical, the rational, the personal, and the social views of excellence. Each of these philosophical positions leads to radically different educational practices and assessment procedures. Some, but not all, of the differences in perspective about the state of American education derive from deep philosophical differences.

Sarason (1982) has argued that reforms are doomed since they fail to address the regularities of schooling within the contexts of the proposed initiatives. Conscientious teachers compromise due to demands placed upon them from outside the instructional setting, forcing them to do less than they are capable of doing for their students (Sizer, 1984). "Horace's compromise" is a familiar tale to any veteran teacher of the nation's classrooms. American schools in the post-World War II period are overextended and distressed institutions. Society keeps increasing the demands it places upon schools by enlarging their roles in meeting students' intellectual, social, moral, emotional, and physical needs (Ravitch, 1983).

Ernest Boyer (1983), President of the Carnegie Foundation for the Advancement of Teaching, summarizes the American high school as seen through 2,000 hours of classroom observation, coupled with interviews by a team of educators and recent educational statistics. While the situation in American schools has recently improved, he finds little reason to cheer. The picture drawn by Cusick (1983), who spent three years as participant observer in three schools (urban, factory, and suburban) in a Northeast industrial city, is a very grim picture of the harsh realities with which many teachers and students have to contend on a daily basis.

A 1984 study of more than 1,000 classrooms and 17,163 students reinforces these views (Goodlad, 1984). Goodlad finds state, district, and local goal statements and curriculum guides to be a "conceptual swamp." Overall, he reports "The data from our sample of classes are clear and convincing—teaching in the four basic subjects required for college admission is characterized, on the average, by a narrow range of repetitive instructional activities favoring passive student behavior" (Goodlad, 1984: 215). He goes on to recommend sweeping reforms, including decentralization from the state level on down, regional curriculum centers to advise schools, graduation at age sixteen, new procedures for selecting principals and the training and promotion of teachers, and non-graded school units.

Some general conclusions from these reports are:

1. Classrooms and curricula are boring; teachers are overstressed; curricula is a mess; administrative rules and hierarchies disenfranchise teachers and students; and order is more valued than learning (Goodlad, 1984; Cusick, 1983; Sizer, 1984; Boyer, 1983).
2. Learning is minimal due to an unspoken, negotiated arrangement between teachers and students of small demands in exchange for obedience (Sizer, 1984; Goodlad, 1984; Boyer, 1983; Cusick, 1983).
3. Schools still are in the "factory" mentality, attempting to mass-produce identical students with little attention to individuality (Sizer, 1984; Cusick, 1983; Goodlad, 1984; Boyer, 1983).
4. School curricular choices amount to an à la carte menu, whether educationally important or not (Cusick, 1983; Sizer, 1984; Boyer, 1983).
5. Most schools track students, an invalid practice on social and educational grounds (Boyer, 1983; Goodlad, 1984; Sizer, 1984; Adler, 1982, 1983; Cusick, 1983; but see Lightfoot, 1983).
6. Smaller school units need to be created, sensitive to the local community and its values, where each student can be approached as an individual—distinct from the crowd (Boyer, 1983; Goodlad, 1984; Sizer, 1984).
7. National reform reports fail to reckon seriously with these realities and concentrate on rhetoric without realism in their views of both problems and solutions.

Not all of these field-based studies by educators are negative in tone. Lightfoot (1983) describes good schools—six schools she believes hold positive lessons for all of us to consider as we think about restructuring schools. Her emphasis is on the performance of outstanding teachers and the skills of good teaching with only incidental mention of students in these classrooms. Helpful models for the future are already in place in our nation's schools. Paul Brandwein (1981) makes a similar argument based upon his personal knowledge of hundreds of schools over a distinguished career. He emphasizes the ecology of schooling and reminds us that schooling and education are not synonyms. This is important when we think about the role of informal organizations and institutions, such as science and technology museums, in promoting scientific and technological literacy (Association of Science-Technology Centers, 1987; Bedworth, 1985; Heltne and Marquardt, 1988).

Grant's 1988 interpretive work concerning four experienced high school teachers (teaching history, government, literature, and physics, respectively) is another example of this genre of educational reporting that is hopeful and helpful. She finds good teaching to consist of "challenging cognitive work." She notes that it is from action research study such as this that "we better understand the richness of classroom interactions and intellectual activities that inform them" (Grant, 1988: 215).

Science educators have been quite active in assessing the state of science education in schools in ways other than standardized tests or international comparisons (Linn, 1987). One of the most prolific scholars addressing science education has been Paul DeHart Hurd, Professor Emeritus of Science Education at Stanford University (Hurd, 1969, 1981, 1983, 1984, 1986a, 1986b, 1987a, 1987b, 1989). A summary of the state of science education in American high schools from 1969 to 1979 which Hurd prepared for a national committee (Hurd, 1983) reported the following:

1. The years of science American students take in high school varies considerably depending upon the state one resides in and the type of school program one is pursuing. Forty-one percent of students in the college-prep track will have taken three or more years of science versus only 13 percent in the general track and 9 percent in the vocational track.
2. Nearly all students take biology, only 37 percent study chemistry, and 19 percent take physics.
3. Mean reported grades in science have increased every year from 1969 to 1979. The best academic students seem to be getting even better.
4. Half of the decline in school achievement across academic areas since 1970 is likely due to social and cultural factors.

5. Children who live in suburbs with parents who have some college exposure showed little decline during the decade.
6. There is abundant evidence that America approaches science and mathematics education in a vastly different (and inferior) fashion than other industrialized and industrializing nations.

An extensive synthesis of three major National Science Foundation studies on science education and reports from the National Assessment of Educational Progress (NAEP) was conducted by five research teams and reported in a National Science Teachers Association document, edited by Harms and Yager (1981). Data were reviewed, analyzed, and interpreted using four major goal clusters: (1) personal life-time student needs for scientific and technological information; (2) science-related societal issues; (3) academic preparation for future study in science, mathematics, and technology fields; and (4) career education and awareness of science- and technology-related jobs. Some major conclusions of the report were (Harms, 1981: 114–117):

1. At all levels, science education in general is given relatively low priority when compared with language arts, mathematics, and social studies, and its status is declining. This low priority results in a general lack of support for science in most school systems.
2. Textbooks play a dominant role in science instruction.
3. Only the goals related to development of basic knowledge for academic preparation receive significant emphasis. Goals related to personal use of science in everyday life, to scientific literacy for societal decision making, and to career planning and decision making are largely ignored.
4. Teachers make most of the important decisions about course content, text selection and instructional methods, and in so doing, they determine the goals pursued by science education.

Paul Hurd (1981), presenting the findings of the group looking at data from biology education, emphasizes the significant discrepancy between biology curriculum in schools and changing, technologically oriented American society. Emphasis in biology classes was on rote memorization of information. There was little attempt to relate biology education to everyday life or current biologically related social issues. The use of inquiry methods in teaching was notably absent in American biology classrooms, despite the fact that biology lends itself particularly well to the use of such methods (cf. Rosen, 1989; Committee on High School Biology Education, 1990).

Finally, the entire Project Synthesis group believed that (Harms, 1981: 199):

> other thoughtful persons will come to conclusions similar to ours; that the goals of preparing the majority of students to use science in their everyday lives, to participate intelligently in group decisions regarding critical science-related societal issues and to make informed decisions about potential careers in science and technology are equally as important as the goal of preparing a minority of students for more advanced coursework in science.

A graphic picture of the current state of science education in American secondary schools comes from an integrated examination of four research perspectives by Eylon and Linn (1988: 251f.) who write:

> The curriculum is fragmented, and only rare attempts are made to relate one experience to another. Science courses often ignore students' everyday experiences. Science experiments, if they are done at all, tend to be exciting displays rather than experiences which illuminate concepts and relate them to other ideas. Whole disciplines are ignored when many students fail to "get to" physics because of required courses in other sciences. The table of contents of most precollege texts reads like the course catalog for a four-year college. These books provide fleeting coverage of numerous topics rather than integrated coverage of central topics. The new vocabulary in a one-week science unit often exceeds that for a one-week unit in a foreign language.

Observation of exemplary versus nonexemplary science classroom instruction and ethnographic research perspectives hold promise of informing efforts to alter what happens in K–12 science classrooms (Tobin, 1987; Tobin and Gallagher, 1987; Wallat and Piazza, 1989). Similar diversity in instructional quality has been observed in science classrooms outside America, suggesting that some of the problems are due to structural factors (Tobin and Fraser, 1988; Tobin, Capie, and Bettencourt, 1988; Kuiper, 1990).

Previous Science Reform Movements

It would be improper to lay total blame for this current state of affairs on the innovative science curriculum projects of the sixties and seventies, even though, as Jackson (1983: 157) notes, "Everyone by now seems to agree that a major fault of the NSF-sponsored science curricula was that they were too 'preprofessional'...characterized by a singleness of purpose...to ready students for college-level science and beyond." He reports that the National Science Foundation funded fifty-three projects from 1954 to 1975 to the tune of $117 million. Welch (1979), using a slightly different method of tabulation, reports a total of $130 million for course content improvement projects and another $565 million for teacher training activities during these two decades. While these numbers appear large, it is important to realize that funding varied greatly within these two decades and that the relative size of these figures is small compared with the $100 billion spent *each* year operating the elementary and secondary schools of our nation (Jackson, 1983).

Such projects ran into a number of barriers, not the least of which was the haphazard way in which textbooks are produced and curricula adopted by the nearly 16,000 public school districts in America (Tyson-Bernstein, 1988a, 1988b). Many districts purchase texts without allotting any funds or only minimal funds to in-service activities designed to familiarize teachers with adopted texts and recommended instructional strategies. Given the innovative, inquiry-centered nature of the science texts emerging from these curriculum projects, it is little wonder that many teachers, when applying their usual methods with these texts, found a less than adequate response on the part of pupils (James and Hord, 1988). Whether laboratory-based learning experiences in an inquiry mode actually contribute to effective student learning is still open to question (Hofstein and Lunetta, 1982; Blosser, 1988; Hegarty-Hazel, 1990) although a meta-analysis of research concerning hands-on elementary science programs reports such an effect (Bredderman, 1983).

Another key factor was the ambiguity surrounding federal policy in regards to curriculum development (Jackson, 1983). Money is usually doled out by Congress for education efforts in mathematics and science only when there is a perceived crisis. There is little evidence of a sustained interest in the quality of mathematics and science education in American schools by our congressmen. While it is erroneous to maintain that the successful Russian launch of Sputnik I prompted Congressional action (since the Physical Sciences Study Committee received funding in November of 1956) there is little doubt that Sputnik I opened up the conduit to greater federal funding for science education (Jackson, 1983).

Welch (1979) suggests several other reasons for the failure of the new science curricula to effect significant change in science education. He believes from his personal involvement in the Project Physics course that the recommendations for revision of texts by classroom teachers piloting material were ignored by the developers. Narrow federal funding timetables of three or four years for curriculum development projects continue to exacerbate this problem as developers have to rush through the pilot and field tests to reach the target completion dates for final curricular products. This frequently means that a final version is published and field test input from teachers is analyzed *ex post facto*. Curriculum developers also suffer from the frequent belief that a problem with curriculum in a field test must lie with the respective teacher rather than with the material per se. Welch regards this as the primary reason published science products in the sixties were so difficult for the majority of students. Primary emphasis on one particular viewpoint within cognitive psychology, i.e., the position of Jerome Bruner and the Woods Hole Conference that any child at any age can be appropriately taught anything, resulted in a less than adequate instructional approach. Finally, Welch concludes with a laundry list of problems over the past two and a half decades that combined to effectively derail any hopes of significant improvement (Welch, 1979: 292):

> From the beginning, there were the known challenges of unprepared and insecure science teachers, the inherent difficulty of change, the lack of federal policy for innovations, the natural conservatism of schools, and the threat of a national curriculum. But in the second decade were added the unforeseen problems of declining enrollments at the secondary level, inflation, student unrest, a fading public image of science, environmental concerns, competing demands such as integration, the back-to-basics movement, social concerns, and school reform movements.

There is a sense that one of the reasons for the failure of these curriculum projects was that too much was expected from them. Welch (1979: 301) notes that "Curriculum does not seem to have much impact on student learning no matter what curriculum variations are used. . . we at Project Physics eventually concluded that 5% [variance in student achievement of old versus new curriculum] was an acceptable return on our investment since we could seldom find greater curricular impact on the students." Current science curriculum reform movements such as the Triad Projects funded by the National Science Foundation in collaboration with science publishers, the Scope, Sequence and Coordination of Secondary Science Projects of the National Science Teachers Association, and Phase II of Project 2061 of the American Association for the Advancement of Science need to address more than curriculum to be successful.

Both Jackson (1983) and Welch (1979) believe that some positive benefits came from these innovative programs. Overall, the technical accuracy and the conceptualization of the science curriculum improved, even within textbooks outside the curriculum projects (due to marketing pressures). Practicing scientists and engineers, as well as academics, began to take a greater interest in the quality of science education programs within K–12 schools. We witness these benefits today with the various local, state, regional, and national partnerships between business and industry, professional science organizations, and the K–12 schools of America. A precedent was set for future federal involvement in America's 16,000 school districts to improve science education. This continues today with federal funding of district level science projects and the Dwight David Eisenhower Title II federal funds apportioned through state departments of education. A considerable body of research was undertaken which continues to guide and inform science education practice and procedures to this day. Finally, there were schools for which the curriculum projects were appropriate and a group of students who benefited from the emphases these programs provided (cf. Brandwein, 1981).

The manner in which science curriculum should be designed and the ways in which we must rethink and retool our efforts in science education in secondary schools will be addressed more substantially at a later point in this book. Reid (1988: 124) has squarely framed the relevant problems to be solved by changing curriculum in American high schools:

1. How to extend the curriculum to include new subjects such as science (in fact, how to accommodate a redrawing of the map of knowledge brought about by the technical and scientific advances of the nineteenth century);
2. How to make the curriculum available to wider sections of the population and, as part of that problem, how to relate it to the curriculum of the elementary school; and
3. How to enable the curriculum to serve the dual purpose of providing for a complete education for those not now proceeding to higher education and a preparatory course for those who will.

The jockeying for position of various disciplines within schools in America is subject to the varying interests and perceived needs of society at large and decision-making bodies. This same phenomenon can be seen in the history of American education (Brandwein, 1981; Eisner and Vallance, 1974; Ravitch, 1983). Westbury (1988) reports that there are more amateur and professional musicians and artists than many other occupations that occupy more prominent positions within the precollege curriculum. He asks (Westbury, 1988: 180): "Why do they [the arts] receive less attention in the rising mound of literature expressing concern for the curriculum than do, say, foreign languages?" That schools are political and well as social institutions and that schooling in America is a political issue can be easily observed in communities throughout America. Thomas F. Green (1980) has sketched the broad parameters within which the school functions as a political institution. Social critics such as Ivan Illich (1972), Michael Apple (1979, 1982), and Paolo Friere (1970, 1985) have been writing for some time about the hidden curriculum and political agendas of schooling in America.

Education for Twenty-First Century Citizens

A prominent place for science education within the school curriculum seems assured given the fact that we live in a world dominated by science and technology. The political climate outside schools has brought open acknowledgement of this fact as reflected in the report of the National Commission on Excellence in Education (1982: 11). It recommended the humanities be "harnessed to science and technology if the latter are to remain creative and humane, just as the humanities need to be informed by science and technology if they are to remain relevant to the human condition."

The fact that there is a crisis in science education—although certainly not the crisis about which the national reform reports pontificate—can be seen in either a positive or negative manner. Surveying the history of science education in America, Rodger Bybee (1977a: 360) is hopeful when he points out:

> crisis is a turning point; it is the point of improvement or deterioration; it is a time of change; it is the difficult period of simultaneously recognizing the problem and seeking a solution. Crises can be seen as danger resulting in personal despair; they can also be perceived as opportunity and inspire activity. I believe that science educators should grasp this opportunity for improvement, not only for us but for our students and future generations of students...science education has experienced many trends at different times and for a variety of reasons; but it must always be realized that direction is not destiny, and we have the opportunity and responsibility for a different direction of science education in our third century.

What kind of changes should be made if science education is going to meet the demands of a world shaped and profoundly influenced by the twin cultures of science and technology? Paul Hurd (1985) has described an acceptable science curriculum for pre-college levels that he believes has cultural as well as scientific and technological validity. He identifies the following elements as essential for the reformation of science education: (1) yearly required instruction in science for all K–10 students; (2) organization of courses in a social context rather than special disciplines; (3) a balance of science and technology with an emphasis on interrelationships between and among them, values, and society at large; (4) concentration on responsible decision-making and critical-thinking skills; and (5) development of courses around persistent social problems that have underlying health, environmental, and technological aspects.

Too frequently in schools we have engaged in behavior described so eloquently by a distinguished African educator, Joseph Elstgeese from Lesotho (Lewis and Kelly, 1987: 9): "We gave them answers and kept the confidence in ourselves. We gave them memory and kept thinking to ourselves. We gave them marks and kept the understanding to ourselves. This must change."

Cecily Selby, formerly of New York University, believes that "The way that mathematics and science have been described and taught has not been 'user friendly' to many segments of the student population including most of our female, Hispanic and Black students and teachers. These subjects are generally taught in abstract terms: linear, rational, 'cold'—not human—centered" (Selby, 1988: 5).

Project Synthesis recommended the following content emphases to prepare students for a world in which science, technology and society interact on a continual basis (Harms and Yager, 1981):

1. Energy problems from a personal perspective.
2. The role of energy in population dynamics.
3. Emerging problems in human engineering.
4. Aspects of environmental quality and their differential impact.
5. The various accomplishments of the space and national defense programs.
6. The sociology of science.
7. Effects of hard and soft technology on individuals and society.
8. The background necessary to understand, critically consider, and take responsible action on issues arising from the above areas and other social issues which are science and technology laden.

Additional lists of recommendations can be found in several chapters of the Project Synthesis Final Report (Anderson, 1981; Harms, 1981; Hurd, 1981; Piel, 1981; Welch, 1981).

Peter Fensham (1986) argues that science education as practiced generally in our nation's schools is vocational preparation for those heading for careers in science. He suggests we use other criteria for determining what should go on in science curriculum including: "1) aspects of science that students will very likely use in a relatively short time in their daily lives outside of school; and 2) aspects of natural phenomena that exemplify easily and well to the students the excitement, novelty, and power of scientific knowledge and explanation" (Fensham, 1986: 22).

"Science for All" has become Fensham's motto for the science education efforts needed for the future (Fensham, 1985, 1986, 1987). Unfortunately this phrase frequently results in such courses being seen as dumping grounds for less academically able students. It could also lead to higher ability students missing relevant dimensions of science learning for their future lives. Westbury (1988) believes the only way out of this dilemma is to require a core curriculum with elements that all students must take in order to graduate from our high schools. Whether such a proposal would, in fact, be implemented and enforced is still an open question. The recent Education Summit of the White House