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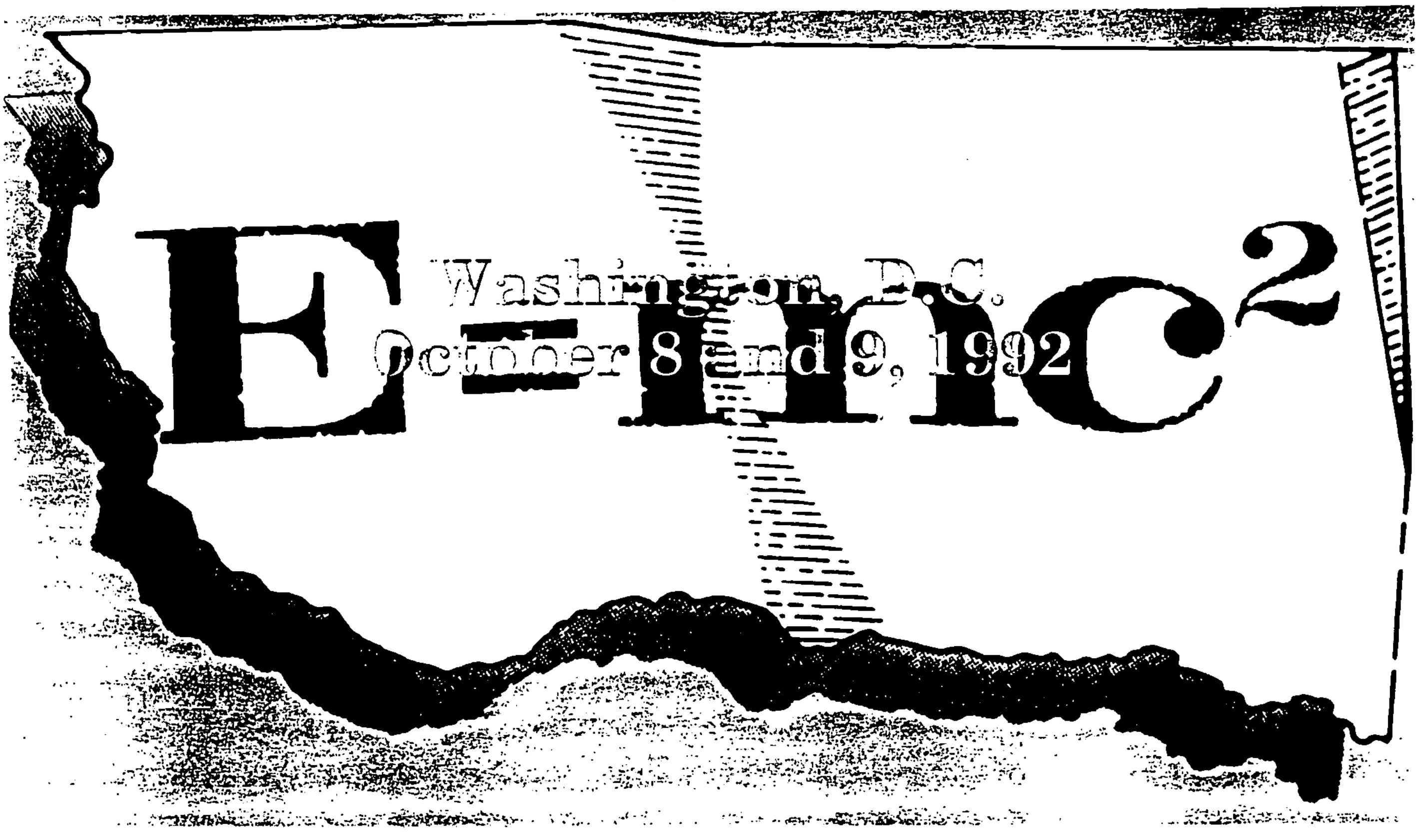
ABSTRACT

This document contains materials from the Secretary's Conference on Improving Mathematics and Science Education, the purpose of which was to bring together leaders from across the nation to consider ways of improving the teaching of these disciplines. It is a compilation of papers and other documents which include examples of effective and dynamic instructional programs. Sections include: (1) Standards; (2) Professional Development; (3) Instructional Resources; (4) Math and Science; (5) Related Material; (6) Participants; and (7) Demonstrations and Exhibits. (JRH)

The Secretary's Second Conference on Math and Science



Washington, D.C.
October 8 and 9, 1992

Office of Educational Research and Improvement

U.S. Department of Education

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The Secretary's Second Conference on Math and Science

Improving Math and Science Teaching

To be "...first in the world in science and mathematics..."

Office of Educational Research and Improvement

U.S. Department of Education

UNITED STATES DEPARTMENT OF EDUCATION

OFFICE OF THE ASSISTANT SECRETARY
FOR EDUCATIONAL RESEARCH AND IMPROVEMENT

THE ASSISTANT SECRETARY

October 8, 1992

Dear Conference Participant:

Welcome to the Secretary's Conference on Improving Mathematics and Science Education. The purpose of this conference is to bring together leaders from across the nation to consider ways to improve the teaching of these important disciplines. We have worked hard to bring together a selection of the most effective and dynamic instructional programs that we are aware of. Obviously, we haven't been able to identify all of them; you may know of good programs in math and science in your own community or state, and we hope that you will talk about them and bring them to the attention of everyone here and the U.S. Department of Education.

Our intention is to stimulate progress towards our fourth national education goal: "By the year 2000, American students will be first in the world in math and science." We know what a daunting challenge this is, but we meet today in Washington committed to the proposition that we can work wonders by working together.

In order to achieve the goal, we know that we have to raise everyone's expectations: students', teachers', and parents'. We have to set new and higher standards, and we have to change many parts of the educational system to support those high standards. We must improve professional development; teacher education; textbooks; instructional materials; classroom technology; and assessments. And above all, we must accept the challenge to educate all students. Neither race, nor gender, nor social class should be a barrier to full participation and achievement in the study of math and science.

Math educators have taken the lead in setting standards for curriculum, teaching, and assessment, and this model has inspired work in other subject areas. Science educators are now engaged in a consensus building process to develop voluntary national standards. The project is being led by the National Academy of Sciences with funding from the U.S. Department of Education.

I hope you enjoy this conference and that you find it to be stimulating and informative.

With regards,

Diane Ravitch

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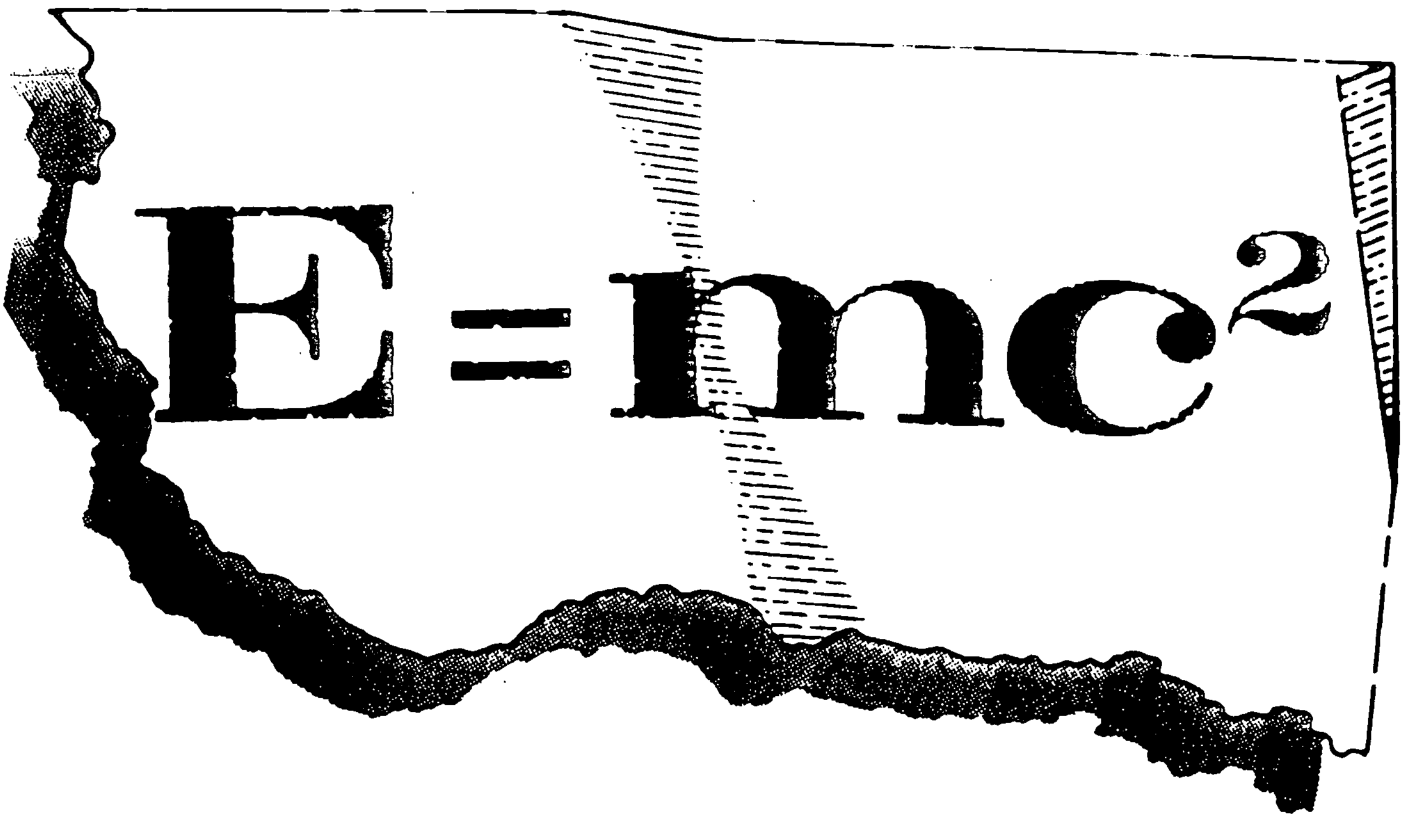
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Developing National Standards in Education

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Delivered to the
American Sociological Association Annual Meeting
August 22, 1992

I told Jim Coleman that my subject this evening would be "Developing National Standards in Education." I am not a sociologist but a historian, and in my estimation, the prospect of national standards represents a historic change in the way that our far-flung and highly decentralized educational system works.

Before getting into the subject at hand, I would like to offer some background. I have been an Assistant Secretary of Education for slightly more than a year. I came to Washington to run the Office of Educational Research and Improvement--or OERI.

OERI was born some two decades ago; it was originally called the National Institute of Education. In preparing to speak tonight, I reviewed testimony delivered by Daniel Patrick Moynihan to a Congressional subcommittee that was considering the creation of the NIE in 1971. Professor Moynihan appeared before the Subcommittee on Education of the House Education and Labor Committee to describe the need for the new NIE. We can easily date Mr. Moynihan's remarks because he begins by apologizing for the typos in his testimony, which he admits he typed by hand.

In retrospect, there are four striking points to be made about Mr. Moynihan's testimony:

First, he was remarkably optimistic about what could be expected from an investment in educational research. He claimed that there had been "a significant influx of men of large ability" into the field, as a consequence of the intellectual ferment created by the Coleman report of 1965. He predicted that educational researchers were on the verge of major breakthroughs; that within a decade, say by 1981, education researchers would be ready to explain how learning occurs, to identify "what goes on in the chemistry of the brain when a child learns something." "Something happens," he said, "They [the researchers] feel they are going to get it."

Second, Mr. Moynihan suggested that federal expenditures for educational research might begin at about $250 million a year and rise--by 1980--to *not less* than $1.1 billion a year.

Third, Mr. Moynihan believed, as a result of his participation in a reanalysis of the Coleman report of 1965, that "traditional measures of school quality, such as pupil-teacher ratios [and] levels of educational expenditure" had "very little educational effect." He insisted that educational research would help identify what needed to be done to improve educational outcomes. He said, "We have learned that things are far more complicated than we thought. The rather simple input-output relations which naively, no doubt, but honestly, we had assumed to obtain in education simply, on examination, do not hold up . . . we confront school systems that are seemingly increasingly chaotic, even anarchic, and which are widely perceived as failing. It may just be that this is partly a result of the expectations induced by the rather simple faith that went into such legislation as the Elementary and Secondary Education Act of 1965. Or the reasons may be altogether unrelated to anything done or tried in the past. But the facts are there. Things aren't very good, or don't seem very good to a great many persons, including a great many students."

And fourth, he asserted that the essential purpose of a National Institute of Education was to aim not just for equality of opportunity but for "parity of educational outcomes" among different social groups. His exact words were, "We must master the art of education to the point that achievement is more or less evenly distributed among the different groups in our society and not too enormously varied within such groups."

As a historian, it is my habit to return to original intentions, and it is necessary therefore to note that the federal funding for education research never materialized. After I became Assistant Secretary for OERI, I learned to my dismay that there is virtually no support in Congress for educational research nor has there been for the past 20 years. By using the term "virtually," I fear that I have exaggerated the degree of support for educational R&D. A recent study of our agency by the National Academy of Sciences concluded that funding for educational R&D has declined by 82 percent in constant dollars since 1973. While federal support for R&D has grown steadily in every other field, while the Department of Education's budget has grown steadily, support for educational R&D has declined with monotonous regularity. Today, the Department of Education spends about $58 million for R&D, a laughable amount. The Department's request for an increase for R&D in 1993 was again rejected, although the amounts involved are so small as to be mistaken for a rounding error in the federal budget.

Thus, there has been no significant federal investment in studying how children learn or how to improve teaching, at least not by the Department of Education. The "men of large ability" to whom Dr. Moynihan referred some 21 years ago did not produce the great breakthroughs in educational research that presumably required a large infusion of federal dollars. The woeful description of the schools that he offered has a contemporary ring; many things have changed in these past two decades, but we continue to lament the condition of learning, and for good reason.

What is clear today is that the investment in educational research that was anticipated did not occur. However, our national investment in providing education did continue to grow over these past 21 years. Indeed, our investment in education--the total for all public and private expenditures, from kindergarten through universities--has grown from $263 billion to $425 billion in constant 1991-92 dollars. During this period, the K-12 enrollment has actually declined, from 51 million students to 46 million students, while enrollments in higher education have increased from 8.5 million to 13.5 million. It might interest you to know that higher education, which grew by nearly 60 percent, increased its expenditures in constant dollars by 72 percent, while K-12--where enrollments declined by 10 percent--increased its expenditures by 61 percent.

But we obviously have not achieved "parity of outcomes." We continue to see large discrepancies among groups in educational outcomes.

This is the context in which I wish to discuss the movement to develop national standards. The main impetus for standards, I believe, is the same one that animated the creation of the NIE some two decades ago. It stems from our nation's continuing effort to identify the outcomes that we seek in schooling; it stems, furthermore, from our search for an effective means to provide what Senator Moynihan referred to in 1971 as "parity of outcomes." We cannot, after all, pursue parity of *outcomes unless* we have a sure sense of what those outcomes are.

The movement for national standards has three sources, I believe. First is the impetus that comes from disappointment with American students' performance in international assessments, particularly in mathematics and science.

A second source of this movement emerges from the participation of governors, business leaders, and visionary educators in school reform during the past decade. Those men and women who understood the idea of strategic planning, who knew that a change process must begin by identifying goals, found that education was not accustomed to goal-setting. Those who tried to set goals and to determine appropriate outcomes met resistance and institutional inertia; they realized very quickly that the schools are accustomed to having a multitude of unordered priorities, a multitude of roles, and a plethora of outcomes, none more important than the others. Those who went seriously about the question of reform discovered that American education is characterized by a lack of consensus on desired outcomes and goals. You might even say that there has been a consensus that no need has precedence over any other need; and that this broad receptivity to bearing all burdens and accepting all social responsibilities has served to unfit the schools for achieving any of its ends.

A third reason for the movement for national standards is the example created by the National Council of Teachers of Mathematics, which has successfully developed voluntary national standards over the past several years.

These three causes could be seen at work in the establishment by Congress last year of the National Council on Education Standards and Testing, which issued its report in January 1992, calling for the creation of voluntary national standards and a system of national examinations.

If I may, I would like to go through this scenario in closer detail.

First, the international assessments. Over the past 25 years, the United States has participated in half-a-dozen international assessments of student achievement. More often than not, our students rank below the mean, sometimes quite near the bottom. The most recent international assessment of mathematics and science was released earlier this year. It compared 9-year-old and 13-year-old students in 20 countries. Of these countries, 15 tested representative samples. Thirteen-year-old American students ranked 13th out of 15 in science, and 14th out of 15 in mathematics.

Critics of these assessments have been quite vocal, claiming that the tests are invalid and the rankings are insignificant. As I understand them, they have three basic complaints. First, that it is not fair to compare our students to students from cultures where education is valued. I would argue, to the contrary, that we should learn to value education, or continue to pay the consequences in low student achievement.

A second criticism is that it is unfair to compare our students to their counterparts from nations that have a strong coherent curriculum in mathematics and science. Again, the critics miss the point. The test is not at fault for having discovered the price that we pay for <u>not</u> having a strong coherent curriculum in mathematics and science. If anything, the lesson from these international assessments is that you learn what you study, and you can't learn what you don't study. Indeed, American students are not on a level playing field when they are matched with students from countries that offer a program of studies that is coherent, cumulative, and thoughtful.

A third criticism one hears is that our country teaches everyone and tests everyone, unlike every other country in the assessment. This is simply not true, although its frequent repetition has caused many people to think it is true. In the last international assessment of science and math, for example, 15 of the 20 participating countries tested comprehensive populations, and in all 15 of those nations, 90 percent or more of the age-eligible children are in school.

So, the international assessments laid the groundwork for those who felt that something was fundamentally wrong in our educational system. The momentum for change was picked up by those governors, educators, and business leaders who became involved in school reform after the publication of *A Nation at Risk* in 1983. For a decade, the states sought to reform their schools. They began by raising graduation requirements, initiating merit pay and career ladders, and trying a host of other reforms; recently they have promoted school-based management and a variety of other efforts to restructure the social organization of schools.

Many reformers came to believe that such changes were too piecemeal, too uncoordinated, too incremental. So, in recent years, we have heard more about the need for *systemic* change, for changes that essentially alter the entire system of education. And systemic reformers characteristically step back to look at the system as a whole and to see how they can intervene in a way that makes the system more coherent and to focus attention on improvement of educational *outcomes*. Bill Honig, the State Superintendent in California, was the first to launch systemic reform focused on outcomes; he focused first on changing *what* children learn, by revising the state's curriculum frameworks; and he then changed *how* students are assessed, so that what is taught in the best classrooms is the same as what is tested by the state. Fortunately, there is good research to support systemic reform, such as the work done by the federally-funded Center for Policy Research in Education at Rutgers University.

Goal-setting went national in 1989, when the President invited the nation's 50 governors to Charlottesville, Virginia, where they agreed on the importance of national goals for education. Of particular note here are goals three and four, which states that all students will demonstrate competency in challenging subject matter, including mathematics, science, English, history, and geography. Goal four somewhat redundantly emphasizes the importance of achievement in math and science. The two goals together have become the basis for much of the broad and bipartisan support to establish national standards in subject areas.

For the fact is that you cannot achieve goal three or goal four unless a consensus is established about what students are expected to learn.

In the absence of a consensus about *what* children should learn, the educational system is inherently incoherent:

o Teacher education prepares would-be teachers for indeterminate roles, to carry a variety of social burdens, without any clear definition of *what* they are to teach.

o Textbooks base their content on the combined dictates of 22 states that formally adopt textbooks and on the idiosyncratic demands of large city school districts, not on the content that has been shaped thoughtfully and purposefully by the teachers and scholars who know the field best.

o Assessments are prepared by commercial test-makers who seek to provide national norms, and these national tests are not based on what is specified in the curriculum or taught in the classroom. Over time, teachers have been "teaching to the test," so that these tests eventually shape the curriculum, instead of the curriculum determining the tests.

o In many states, staff development had no connection to the curriculum, because of the absence of a consensus about what was to be taught.

So how in this highly decentralized nation--a nation of 15,000 school districts and 50 state educational authorities, each jealous of its domain--how in this contentious and individualistic nation were we to derive a consensus about what students *should* learn?

Fortunately, the math teachers came to the rescue and pointed the way. In the mid-1980s, the National Council of Teachers of Mathematics (known as the NCTM) began the arduous process of standard-setting on its own. Having experienced the failure of the New Math, which was criticized for being too abstract, and having watched with dismay as the nation's schools went back to basics with a vengeance, the math teachers deliberated about what they could do to change the teaching of math for the better. The math teachers were helped in their deliberations by good educational research, in this case the work of the federally-funded National Center for Research in Mathematical Sciences Education at the University of Wisconsin, proof that even a small investment in good research has been worthwhile.

After many meetings and much discussion, they hit upon the answer: they decided to develop national standards. They devised an elaborate consensus and review process that ultimately involved thousands of math teachers. By 1989, they were able to publish national standards that represented a dramatic change in the teaching of mathematics.

Instead of computation and memorization of abstractions, the new standards emphasize problem-solving, hands-on activities, use of manipulatives, and the development of mathematics as a way of thinking and reasoning.

The new standards encourage the introduction of elements of algebra, geometry, probability and statistics in the elementary grades.

The new standards set high expectations for all children, instead of dividing children into those who are bound for college and those who are not.

The NCTM standards have been widely accepted by math teachers and by educational leaders in districts and states. Consequently, they have had a dynamic effect on the entire educational system. The NCTM standards are changing teacher education, because new teachers will be expected to learn to teach to them. The NCTM standards have changed teacher training in 41 states, which use them as their basic standard. The NCTM standards have changed the way mathematics textbooks are written, with more attention to problem-solving and real-world situations. The NCTM standards are changing the nature of assessments, reinforcing the move away from standardized multiple-choice tests and toward performance assessments that probe for students' explanations, interpretations, decisions and understanding.

I have seen the NCTM standards at work in a variety of settings. At Mission High School in San Francisco, I saw inner-city students working on a fascinating problem that required them to use algebra and geometry to find a solution. These were youngsters who would ordinarily be tracked into remedial math or consumer math. Every one of those students discovered that they could learn more and use their minds well. The NCTM standards caused a change in instructional methods, a change in materials, a change in teacher training, and a raising of expectations.

What the NCTM standards demonstrate is the power of standards. Good standards establish a goal; they create a consensus about what the educational outcomes *should* be. It now seems obvious that in the absence of such a consensus, we are left with the unsatisfactory goal of getting high scores on standardized tests of basic skills and allowing students to believe that learning is nothing more than a guessing game, a game that they can win by mastering test-taking techniques.

It seems clear to a growing number of people, at the federal, state, and local level, that good national standards have the power to create a coherent system, to promote purposeful and constructive changes in the system, to establish clear goals for learning, and to raise the overall quality of education.

When Lamar Alexander was appointed Secretary of Education, he determined that one of his goals would be to begin the development of voluntary national standards. Towards that end, he joined with Congress in creating the National Council on Education Standards and Testing, to examine the feasibility and desirability of setting standards and creating a national examination system. That panel, co-chaired by Governors Carroll Campbell of South Carolina and Roy Romer of Colorado, issued its report earlier this year, which strongly endorsed both national standards and a national system of assessment.

At the Department of Education, we have worked to implement the recommendations of the standards and testing panel. Last fall, the Department made a grant to the National Academy of Sciences to develop content standards in science, that is, what American students should know and be able to do in science. This summer, the Academy has gathered representatives from every science education organization, along with teachers and scholars, to work on the consensus-building process.

Also last fall, the Department made a grant, in collaboration with the National Endowment for the Humanities, to the National Center for History in the Schools, based at UCLA to develop voluntary national standards in American history and world history. The Center has brought together every organization concerned with history, social studies, and social sciences in elementary and secondary education and will engage in a broad review process involving thousands of teachers and scholars and members of the public.

This spring, the Department, with support from other federal agencies, has made grants to develop national standards in the arts, in civics, and in geography. It is our hope that before long we will be able to announce a grant in the field of English. In each case, funding went to professional, scholarly organizations that demonstrated the ability to bring the field together to work in concert on the difficult task of building a consensus about what children from kindergarten through 12th grade should know and be able to do.

The purpose of standard-setting, it should be clear, is two-fold: to promote equality of educational opportunity and to raise the academic achievement of all children.

The small federal investment in educational R&D fortunately has included support for a sturdy program of statistics and data-collection. From the valuable work of the National Center for Education Statistics, we known that there are wide disparities in course-taking in our schools. For example, we learn from NELS:88 (National Educational Longitudinal Study) that curricular tracking can be detected as early as the eighth grade, where children get very different exposure to algebra, for example. Only 18 percent of the children whose parents did *not* graduate high school take Algebra I, compared with 43 percent of the children whose parents graduated college, and 59 percent of children of Ph.D.s, M.D.s, and other professionals. Not surprisingly, the same skewing can be found when one looks at family income or race/ethnicity. In the latter category, it is Asian students who are likeliest to take algebra in eighth grade (46.8 percent), followed by white students (33.9 percent), then by black, Hispanic and Native American students (about 25 percent for each group).

By 11th grade, looking now at transcript studies drawn by the National Assessment of Educational Progress, we can see the effects of curricular tracking in public schools. By that time, only 63 percent of the students whose parents did not finish high schools have taken Algebra I, compared with 91 percent of the students whose parents graduated from college.

Does this disparity have to exist? Is it a necessary part of schooling in America? Consider the same two groups of students enrolled in Catholic schools. The figures for Catholic school 11th graders are as follows: of those students whose parents did not graduate from high school, 96 percent have taken Algebra I, compared with those whose parents graduated college: 97 percent.

Why is there so much disparity in the public schools, and so little in the Catholic schools? I suggest it is because the Catholic schools did not ask anyone if they wanted to take Algebra I. In other words, they have standards that apply to everyone, and these standards provide a guarantee of educational opportunity and equity.

All of the standard-setting projects are concerned about equity. The math teachers want to break the connection between coursetaking and such factors as socioeconomic status, parent education, income, and ethnicity. They believe that students can learn much more, and that expectations can be raised much higher for all students. Similarly, the leading science organizations want to build knowledge of science and curiosity about natural phenomena throughout the K-12 curriculum.

Each of these professional groups wants to break the iron grip of tracking and to expose more and more children to a rich diet of inquiry, exploration, problem-solving and active learning. There is general agreement among them that we do not need to ration educational experiences and that we can instead make available to all children the opportunity for a full and rich curriculum.

The first critically important step, then, is the creation of a national consensus among teachers, scholars, and the educational community about what students need to know and be able to do. This is beginning to happen. It will succeed to the extent that the products of these consensus-building activities are accepted by the professional field. If the standards are powerful, they will be embraced, as the NCTM standards have been. If they are not, they will be rejected and ignored. They will stand or fall based on professional review, not by any legal mandate.

What must happen next is implementation, and this depends on actions taken by the states, where most educational authority resides. Many states regularly design curriculum frameworks. Some states, notably California, have used the curriculum process to build high standards for the state's educational system; indeed, the highly regarded California curriculum frameworks are a model for the nation. The National Science Foundation has made sizable grants to 21 states to stimulate systemic reforms, including the development of state curriculum frameworks. Over the next few years, the Department of Education hopes to provide funding for state curriculum frameworks in every important subject area. Over time, the state curriculum frameworks will both reflect and influence the continually evolving national standards.

If the NCTM standards serve as a model, we can expect that the development of high national standards will influence assessments and will drive out the mechanistic standardized tests that have been so long lamented. What will emerge, and what is already emerging in a number of states, is a commitment to constant improvement in assessment, and a commitment to discover ways to gauge student performance that are better than current tests. Of course, we need R&D to encourage the evolution of improved assessments. My agency requested $5 million to invest in such research in 1993, but have thus far not received any support from Congress. States will be hard-pressed to pay for what is rightfully a federal responsibility.

We still need federal support of R&D to achieve the ends we seek. We must continue to work to persuade the Congress that funding is needed in order to understand the consequences of our policies. In the meanwhile, events have moved to bring us to a historic turning of the road through the effort to set voluntary national standards. Perhaps, 20 years from now, someone else will stand before you and assess these efforts harshly. I certainly hope not.

At a recent meeting of the Asia-Pacific nations in Washington, 14 countries--including Japan, Korea, China, Taiwan, Thailand, New Zealand, Canada, Australia, and the U.S.--discussed standards for the 21st century. Every one of the members was either setting or had already established national standards for what students should learn. When asked why they had set these standards, all gave the same answer: first, to raise academic achievement for all students; and second, to provide equal educational opportunity for all students.

It seemed perfectly obvious to those who had done it. We still must persuade many in our country that standards do not mean standardization; that they do not mean setting the bar so high that more children will fail; that they do not mean more reliance on standardized tests. What they do mean is that children, teachers, and parents will understand what is expected to succeed; that textbooks and educational technology will be based on that understanding; that assessments will be based on the curriculum and on what children have been taught, rather than what has been standardized; and that teachers will learn what they are expected to teach.

As a historian, I know where good intentions lead. I know, too, how seldom we achieve what we set out to do. And I understand how often unintended consequences prevail. Yet try we must.

As we promote the development of national standards, we seek the purpose that Senator Moynihan so aptly described in 1971: parity of educational outcomes. To quote the Senator once again: "We must master the art of education to the point that achievement is more or less evenly distributed among the different groups in our society and not too enormously varied within such groups."

Perhaps it is policy, not research, that must lead the way. To be sure, we need both.

Standards for the Preparation and Certification of Teachers of Science, K-12

This position statement identifies the type of training, background, and undergraduate experiences that a preservice teacher must have to be qualified to teach science. The text is divided into three parts: (1) Standards for Elementary Science Teachers, (2) Standards for Middle/Junior High School Science Teachers, and (3) Standards for High School Science Teachers. Each section provides complete and comprehensive statements which can be applied during and for teacher training program assessment.

The NSTA standards have been adopted by the NSTA Board of Directors (1984, 1987), the National Council for Accreditation of Teacher Education (NCATE), and the Association for the Education of Teachers of Science (AETS). NCATE has been using these standards when working with institutions across the nation that apply for accreditation approval of their teacher education program since January, 1985. A committee of NSTA science educators under the direction of NCATE conducts the process.

In addition to these standards for the preservice preparation of teachers, NSTA offers inservice teachers certification in their speciality. To become NSTA certified, a teacher must meet specific standards of education and experience based on the grade level and/or subject he or she teaches. A teacher is eligible to apply for certification after completing three years of full-time teaching. Applications are available from NSTA headquarters.

NSTA offers certification in the following categories:

- Elementary Science Teacher
- Middle/Junior High Science Teacher
- Secondary Biology Teacher
- Secondary Chemistry Teacher
- Secondary Physics Teacher
- Secondary Physical Science Teacher
- Secondary Earth and Space Science Teacher
- Secondary General Science Teacher

—Adopted by the NSTA Board of Directors in July, 1987.

Standards for the Preparation And Certification of Elementary Teachers of Science

I. Science Content Preparation

Programs should require a minimum of 12 semester hours of laboratory or field-oriented science including course work in the biological, physical, and earth sciences. These courses should be selected or designed specifically to serve the needs of preservice elementary school teachers. They should provide the preservice teacher with

- a knowledge of science content selected for its application to elementary school classrooms;
- competency in using the processes of science common to all scientific disciplines, including skills of investigating scientific phenomena, interpreting findings, and communicating results;
- positive attitudes toward science and the teaching of science;
- competency in selected laboratory and field skills;
- an understanding of the relationship between science, technology, society and human values; and
- decision-making and value-analysis skills for use in solving science related problems in society.

II. Science Teaching Preparation

The program should require at least 3 semester hours of course work in elementary school science methods. This course should be scheduled after the science content courses have been completed and just prior to student teaching.

The elementary science methods course should prepare preservice teachers to teach science processes, content and attitudes to elementary school children with a wide range of abilities and socio-economic and ethnic backgrounds. The course should model desired teaching behavior and include experiences with

- hands-on activities selected to promote process skill development;
- the selection of science content appropriate for the elementary student;
- the design of classroom experiences that promote positive attitudes toward science;
- the selection and use of a variety of instructional strategies and materials;
- the development of techniques for evaluating student learning; and
- activities that develop the ability to identify, establish and maintain the highest levels of safety in the classroom and other areas used for science instruction.

III. Classroom Experience

There should be continuous opportunities to teach science to children throughout the program. Classroom experiences in science should begin with supervised observation and tutoring and progress through to small and large group instruction.

Student teaching must include frequent experiences in planning and teaching science lessons. Ideally, this might involve teaching at least six weeks of science that reflects the nature of science knowledge and process.

IV. Faculty Preparation

Faculty assigned to teach science content and methods courses for preservice elementary teachers should have the qualifications, experience, and interest to provide high quality instruction.

Individuals who teach science methods courses should have elementary school science teaching experience. Elementary science teachers should be involved as resource persons in the science methods course.

V. Faculties, Equipment, and Materials

Preservice elementary teachers should receive their instruction in science laboratories and educational facilities that include equipment, instructional materials, and library resources that promote science learning. Students should gain experience with resources typically found in elementary classrooms. Appropriate microcomputer and other technologies should be used so that teachers will know how and when such technologies can be used most effectively in science teaching.

VI. Professional Orientation

The program should include experiences that

- develop both the capacity and the motivation for continued learning in science and the teaching of science;
- foster an appreciation for the value of science in the total curriculum and in the lives of the children; and
- provide information about professional organizations, publications and other resources and their respective roles in the continuing education of science teachers.

Standards for the Preparation And Certification of Middle or Junior High School Teachers of Science

A separate, specific teacher certification program should be established for either middle or junior high school science. A junior high school teacher education program typically focuses on in-depth preparation in a subject area like science where teaching of that particular content area is the primary objective; a middle school teacher education program often focuses on preparation in two subject matter areas like science and mathematics and overtly subscribes to a philosophy which stresses the nature of the early adolescent learner and how schooling should be designed to facilitate his/her development. Both programs should emphasize science content, methodology, field experience and professional orientation activities designed specifically for the middle or junior high school science teacher.

I. Science Content Preparation

Junior High School Science Content Preparation

A minimum of 45 semester hours of science should be required of all preservice junior high school science teachers. This coursework should include at least 8-10 hours each in the biological, physical (physics and chemistry), and earth-space sciences. If specific physical science courses are not available, 4-5 semester hours each in chemistry and physics should be required. The remaining 15-21 hours should include electives from among the major science disciplines.

Middle School Science Content Preparation

In programs that prepare teachers specifically for middle schools and require two teaching fields, a minimum of 24 semester hours of science content should be required and should include 8-10 semester hours each in the biological, physical and earth sciences. These courses should be broad, interdisciplinary and encompass the primary area within each of these disciplines. If specific physical science courses are not available, 4-5 semester hours each in chemistry and physics should be required. These requirements are based on the expectation that an equal number of hours will be required in a second content field.

The programs and courses should be designed to develop a breadth of scientific literacy that will provide the preservice teacher with

- positive attitudes toward science and an accompanying motivation to be a lifelong learner in science;
- competency in using the processes of science common to all scientific disciplines, including the skills of investigating scientific phenomena, interpreting the findings, and communicating results;
- competency in a broad range of research, laboratory and field skills;
- knowledge of scientific concepts and principles and their applications in technology and society;
- an understanding of the relationship between science, technology, society and human values; and
- decision-making and value-analysis skills for use in solving science related problems in society.

II. Science Teaching Preparation

Middle and junior high school science teachers should have at least one

3-5 semester-hour teaching methods course, and preferably more, emphasizing the unique intellectual, physical and social-emotional development of the early adolescent. The course should model desired teaching behavior and develop a wide variety of teaching-related skills, including those that help preservice teachers to

- teach science processes, attitudes, and content to learners with a wide range of abilities and socio-economic and ethnic backgrounds;
- become knowledgeable of a broad range of school science curricula, instructional strategies, and materials, as well as how to select those best suited for a given teaching-learning situation;
- become proficient in constructing and using a broad variety of science evaluation tools and strategies; and
- become knowledgeable about the learning process, how early adolescents learn science, and how related research findings can be applied for more effective science teaching.

III. Classroom Experience

Field Experience

Prospective middle or junior high school science teachers should have opportunities for classroom observation and participation in early adolescent science classes taught by qualified teachers. These experiences should begin early in the program with emphasis on observation, participation and tutoring and progress to small and large group instruction with consistent supervision provided by appropriate educational personnel.

The Student Teaching Experience

The student teaching experience should be full-time for at least 10 weeks. There must be ample time and opportunity to plan and provide instruction for students in a middle or junior high school science classroom supervised by a qualified science teacher. The program should give prospective teachers experience with a full range of in-school activities and responsibilities. Supervision by a qualified science educator should include regular visits and seminars.

IV. Supportive Preparation in Mathematics and Computer Use

The middle or junior high school science teacher should also have a minimum of 9 semester hours in mathematics and computer science instruction.

V. Faculty Preparation

Faculty members assigned to teach the science content and methods course should have the qualifications, experience, and motivation to provide instruction relevant to the needs of middle or junior high school science teachers. Individuals who teach science methods courses and supervise student teachers in science at this level should have middle or junior high science teaching experience. Middle or junior high school science teachers should be involved as resource persons in the science methods courses.

VI. Facilities, Equipment and Materials

Preservice middle or junior high school science teachers should receive their instruction in science laboratories and educational facilities that include equipment, instructional materials, and library resources that promote science learning. Students should gain experience with resources typically found in middle or junior high school science classrooms. Appropriate microcomputer and other technologies can be used most effectively in science teaching.

VII. Professional Orientation

The middle or junior high school science teacher preparation program should

- provide experiences that will engender professional pride, dedication, and commitment to the early adolescent student and early adolescent instruction; and
- develop both the capacity and the motivation for continued learning in science and the teaching of science.

Standards for the Preparation And Certification of Secondary School Teachers of Science

I. Science Content Preparation

The program for preparing secondary school teachers of science should require specialization in one of the sciences (i.e. preparation equivalent to the bachelor's level) as well as supporting course work in other areas of science. The programs should require a minimum of 50 semester hours of course work in one or more of the sciences and additional course work in related content areas such as mathematics, statistics, and computer applications to science teaching. The programs and courses should be designed to develop a breadth of scientific literacy that will provide the preservice teacher with

- positive attitudes toward science and an accompanying motivation to be a lifelong learner in science;
- competency in using the processes of science common to all scientific disciplines, including the skills of investigating scientific phenomena, interpreting the findings, and communicating results;
- competency in a broad range of research, laboratory and field skills;
- knowledge of scientific concepts and principles and their applications in technology and society;
- an understanding of the relationship between science, technology, society and human values; and
- decision-making and value-analysis skills for use in solving science-related problems in society.

Overall, the programs should be designed for the unique needs of secondary school science teachers.

II. Science Teaching Preparation

Science Teaching Methods and Curricula

The program should prepare preservice teachers in the methods and curricula of science. Method courses should model desired teaching behavior in the secondary classroom. These experiences should develop a wide variety of skills, including those which help preservice science teachers to

- teach science processes, attitudes, and content to learners with a wide range of abilities and socio-economic and ethnic backgrounds;
- become knowledgeable of a broad range of secondary school science curricula, instructional strategies and materials, as well as how to select those best suited for a given teaching and learning situation;
- become proficient in constructing and using a broad variety of science evaluation tools and strategies; and
- become knowledgeable about the learning process, how people learn science, and how related research findings can be applied for more effective science teaching.

The program should include *at least* one separate course (3-5 semester hours), and preferably more, in science teaching methods and curricula.

Communication Skills and Classroom Management Techniques

The program should prepare preservice teachers to speak and write effectively and demonstrate effective use of classroom management techniques when teaching laboratory activities, leading class discussions, conducting field trips, and carrying out daily classroom instruction in science.

Preparation in Research Skills

The program should prepare preservice teachers to conduct or apply, understand, and interpret science education research and to communicate information about such research to others (e.g., students, teachers and parents).

Safety in Science Teaching

The program should require experiences that develop the ability to identify, establish, and maintain the highest level of safety in classrooms, stockrooms, laboratories, and other areas used for science instruction.

Other Educational Experiences

Courses in other educational areas, including general curricula and methods, educational psychology, foundations and the special needs of exceptional students, should be a part of the program in order to complement the science education components described above.

III. Classroom Experience

Field Experience

Field experiences in secondary school science classrooms are essential for the thorough preparation of preservice teachers of science. The field experience of preservice teachers should begin early with an emphasis on observation, participation, and tutoring, and should progress from small to large group instruction.

The Student Teaching Experience

The student teaching experience should be full-time for a minimum of 10 weeks. The program should require student teaching at more than one educational level (such as junior high school experience combined with that of working in the high school) or in more than one area of science (i.e., biology and chemistry) if certification is sought in more than one area. The program should give prospective teachers experience with a full range of in-school activities and responsibilities.

Day-to-day supervision of the student teacher should be done by an experienced, master science teacher(s). University supervision should be provided by a person having significant secondary school science teaching experience. Responsibility for working with student teachers should be given only to highly qualified, committed individuals, and close and continuing cooperation between school and university is imperative.

IV. Supportive Preparation in Mathematics, Statistics, and Computer Use

The program should require competencies in

- mathematics as specified for each discipline;
- scientific and educational use and interpretation of statistics; and
- computer applications to science teaching, emphasizing computer tools such as: (a) computation, (b) interfacing with lab experiences and equipment, (c) processing information, (d) testing and creating models, and (e) describing processes, procedures, and algorithms.

V. Faculty Involved in Preservice Teacher Education in Science

Faculty members assigned to teach the science content and methods courses should have the qualifications, experience, and motivation to provide instruction relevant to the needs of secondary school science teachers. Individuals who teach science methods courses and supervise student teachers in science should have secondary school science training experience. Secondary school science teachers should be involved in teaching the science methods courses and designing and supervising the student teaching experience.

VI. Facilities, Equipment, and Materials for Preservice Teacher Education in Science

Preservice secondary teachers should receive their instruction in science laboratories and educational facilities that include equipment, instructional materials, and library resources that promote science learning. Students should gain experience with resources typically found in secondary school science classrooms. Appropriate microcomputer and other technologies should be used in the training program of prospecitve science teachers so that they will know how, and when, such technologies can be used most effectively in science teaching.

VII. Professional Orientation

The program should develop both the capacity and the motivation for continued learning in science and the teaching of science. Students should gain a basic understanding of the goals and objectives of American education and how science education relates to these broader purposes. The preservice teacher should learn about professional organizations, publications, and other resources, and their respective roles in the continuing education of science teachers.

Standards for Each Secondary Discipline

Biology

I. The program in biology should require broad study and experiences with living organisms. These studies should include use of experimental methods of inquiry in the laboratory and field and applications of biology to technology and society.

II. The program would require a minimum of 32 semester hours of study in biology to include at least the equivalent of three semester hours in each of the following: zoology, botany, physiology, genetics, ecology, microbiology, cell biology/biochemistry, and evolution; interrelationships among these areas should be emphasized throughout.

III. The program should require a minimum of 16 semester hours of study in chemistry, physics, and earth science emphasizing their relationships to biology.

IV. The program should require the study of mathematics, at least to the pre-calculus level.

V. The program of study for preservice biology teachers should provide opportunities for studying the interaction of biology and technology and the ethical and human implications of such developments as genetic screening and engineering, cloning, and human organ transplantation.

VI. The program should require experiences in designing, developing, and evaluating laboratory and field instructional activities, and in using special skills and techniques with equipment, facilities, and specimens that support and enhance curricula and instruction in biology.

Chemistry

I. The program of specialization in chemistry should require systematic and quantitative study of the fundamental principles of chemistry, interrelated and illustrated with descriptive and historical perspectives, as well as applications of chemistry in society.

II. The program should require a minimum of 32 semester hours of study including organic, inorganic, analytical, physical, and biochemistry, and their relationships with each other.

III. The program should require a minimum of 16 semester hours of study in physics, biology, and earth science emphasizing their relationships to chemistry.

IV. The program should require the study of mathematics to include a working knowledge of the calculus.

V. The program of study should provide prospective chemistry teachers with opportunities to study the health, ethical, and human implications of such developments/issues as effects of synthetic molecules and food additives on life systems, and the disposal of toxic chemical wastes.

VI. The program should require experiences in designing, developing, and evaluating demonstration and laboratory instructional activities, and in using special skills and techniques with equipment and facilities that support and enhance curricula and instruction in chemistry.

Earth Science

I. The program in earth science should require study that develops the prospective teacher's ability to view and present earth science as an interdisciplinary science involving the study of the lithosphere, atmosphere, hydrosphere, space, and their relationships to humans and their environment.

II. The program should require a minimum of 32 semester hours of study in the earth sciences and should require specialization in one of the earth sciences (astronomy, geology, meteorology, and/or oceanography) and supporting work in each of the other three.

III. The program should require a

minimum of 16 semester hours of study in biology, chemistry, and physics emphasizing their relationships to earth science.

IV. The program should require the study of mathematics at least to the level of introductory calculus.

V. The program should require study and experiences that examine the impact of technologies on the lithosphere, atmosphere, hydrosphere, and conservation of humans in their environment. Also, the programs should emphasize the conservation of natural resources and the environment.

VI. The program should require experiences assuring a mastery of techniques and strategies for using the local environment as a teaching/learning laboratory and competency for doing field and in-school laboratory demonstrations, experimentation, and research.

General Science

I. The program in general science should require study and experiences in each of the major science disciplines and their applications in society. The program of study should provide a broad but coherent and comprehensive understanding of the sciences. It is intended to prepare/certify candidates to teach general, comprehensive, and/or interdisciplinary science courses and not intended as a "Broad-field" preparation for certification in one or more of the major science fields.

II. The program should require at least 8 semester hours of study in each of the basic fields of biology, chemistry, physics, and earth science.

III. The program should require a minimum of 16 additional hours from the science disciplines which would both broaden and strengthen each individual's program of study.

IV. The program should require the study of mathematics at least to the level of introductory calculus.

V. Special emphasis should be given to studying the relationship between science and technology and to the impacts of science/technology upon humans and their environment.

VI. The program should require experiences in designing, developing, and evaluating field, demonstration, and laboratory instructional activities and in using special skills and techniques with equipment and facilities that support and enhance curricula and instruction in all science fields.

Physical Science

I. The program in physical science should require study and experiences in each of the major physical science disciplines with an emphasis on their applications in society. The program should provide a broad but coherent and comprehensive understanding of the physical sciences. It is intended to prepare/certify candidates to teach general, comprehensive, and/or interdisciplinary science courses and not intended as a "Broad-field" preparation to teach either chemistry or physics.

II. The program in physical science should require at least 30 semester hours of study in chemistry and physics reflecting a balance between the two and, at least 12 semester hours of study in the earth sciences, including at least three of the following areas: astronomy, geology, meteorology, oceanography, and physical geography.

III. The program should require the study of introductory biology and emphasize the relationships among physics/chemistry, earth science, and biology.

IV. The program should require the study of mathematics at least to the level of introductory calculus.

V. The program should develop an understanding of how the physical sciences integrate with each other and with technology, and their implications for humans and their environment.

VI. The program should require experiences in designing, developing, and evaluating field, demonstration, and laboratory instructional activities, and in using special skills and techniques with equipment and facilities that support and enhance curricula and instruction in the physical science.

Physics

I. The program in physics should require systematic and quantitative study of the fundamental topics of physics, interrelated and illustrated with descriptive and historical content and the applications of physics in society.

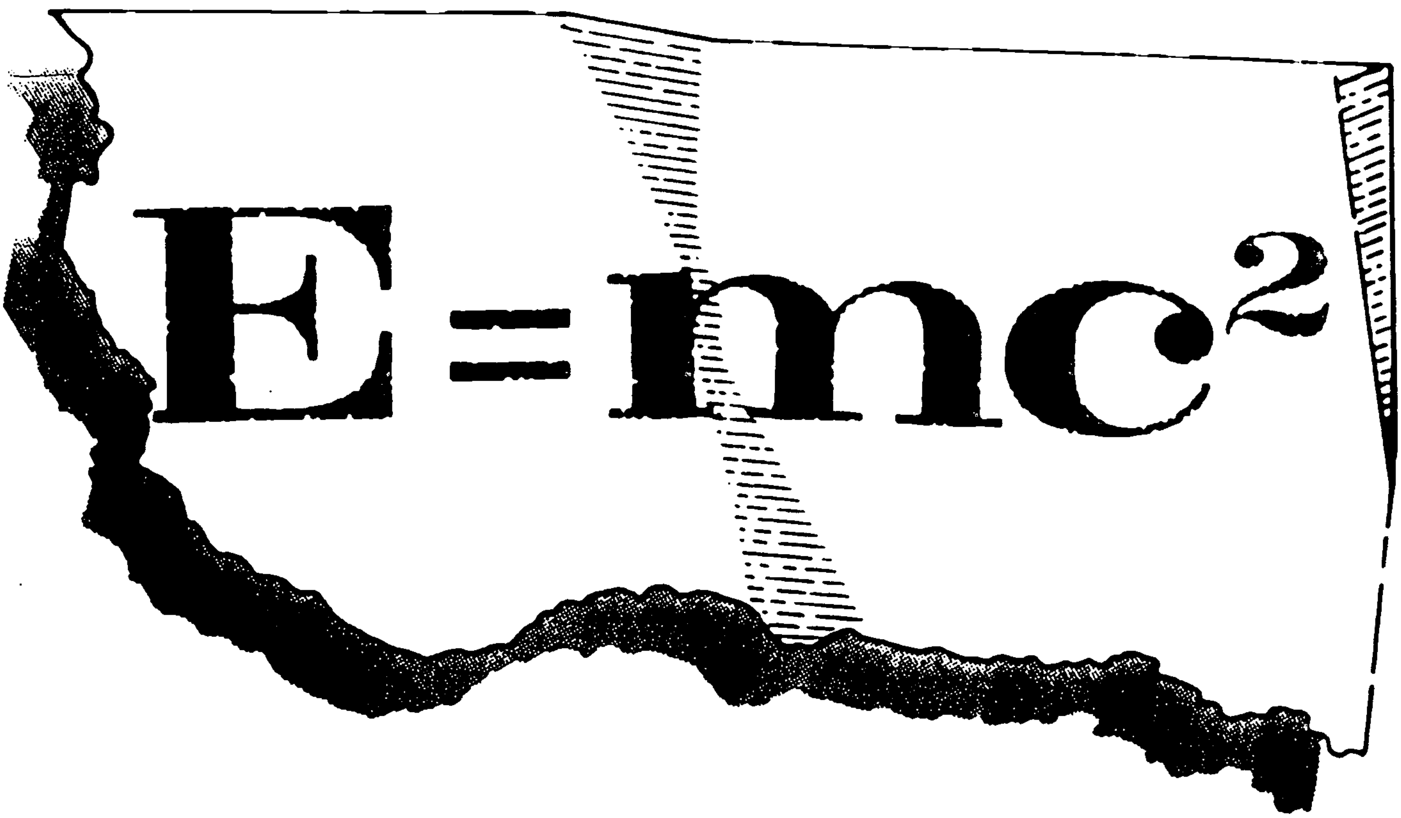
II. The program should require a minimum of 32 semester hours of intensive study in those areas of physics which are specifically relevant to high school courses, including classical mechanics, electricity and magnetism, heat and thermodynamics, waves, optics, atomic and nuclear physics, radiation and radioactivity, relativity, and quantum mechanics.

III. The program should require a minimum of 16 semester hours of study in biology, chemistry, and earth science emphasizing interrelationships among them.

IV. The program should require the study of mathematics through the calculus, including an introduction to differential equations.

V. The program of study should provide prospective physics teachers with opportunities to study the ethical and human implications of such contemporary issues as nuclear power plant siting and waste disposal, long-range energy policies, and the effects of radiation on living systems.

VI. The program should require experiences in designing, developing, and evaluating field, demonstration, and laboratory instructional activities, and in using special skills and techniques with equipment and facilities which support and enhance curricula and instruction in physics. For example, the study of practical electronics, including instrument repair, is highly recommended.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Science Teachers as Learned Professionals

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So we went alone for our walk in the woods. But mothers were very powerful in those days as they are now, and they convinced the other fathers that they had to take their own sons out for walks in the woods. So all fathers took all sons out for walks in the woods one Sunday afternoon. The next day, Monday, we were playing in the fields and this boy said to me, "See that bird standing on the wheat there? What's the name of it?" I said, "I haven't got the slightest idea." He said, "It's a brown-throated thrush. Your father doesn't teach you much about science."

I smiled to myself, because my father had already taught me that that doesn't tell me anything about the bird. He taught me "See that bird? It's a brown-throated thrush; but in Germany it's called a halzenflugel, and in Chinese they call it a chung ling and even if you know all those names for it, you still know nothing about the bird. You only know something about people; what they call that bird."

"Now that thrush sings, and teaches its young to fly, and flies so many miles away during the summer across the country, and nobody knows how it finds its way," and so forth. There is a difference between the name of the thing and what goes on.

Richard P. Feynman (1966)[1]
Nobel Laureate in physics, late

Within the past decade a clear consensus has emerged on the issue of mathematics and science education reform, embodied in Feynman's remarks: *no more learning by rote*. Students must learn to ask probing questions, not passively receive superficial answers; to investigate deeply, not just take perfunctory notice; to communicate, not regurgitate. These sentiments resound in celebrated documents written by our nation's most eminent scholars.[2]

But, these reports are quick to point out, institutionalizing this way of thinking about mathematics and science education requires not only a new vision of learning but also a new vision of teaching. We need versatile teachers who are effective facilitators of investigation, not didactic agents of authority; teachers who understand well not only the sources of subject matter knowledge but also the intricate dynamics of the learning process. In addition, such teachers need access to intellectual resources -- instructional materials -- that promote wonderment, exploration, and discovery.

The theme of this conference is the improvement of mathematics and science teaching through teacher education and the design of exemplary instructional materials. This paper addresses this theme by describing what effective science teachers know and are able to do, in a manner that illustrates why science teaching (and by extension mathematics teaching and teaching in general) is a rich and complex discipline worthy of characterization as a learned profession. Such a characterization has implications for teacher development, instructional materials development, and school restructuring policies that strive to improve mathematics and science teaching in a manner that is consistent with the vision set forth in recent calls for reform.

A Model for Effective Science Teaching and Learning

The California State Board of Education introduces its 1990 Science Framework for grades K–12 with the assertion that "thematic teaching, coupled with active learning, is the best way to provide students with the education they will need as voters, consumers, and parents in the future."[3] Other recent frameworks and reports echo similar conceptions.

Thematic teaching involves the development of ideas that extend beyond individual facts and concepts and which transcend disciplinary boundaries. Themes such as change, systems, diversity, chance, and cause and effect emerge through the study of ecology, aeronautics, finance, geography, and biochemistry. Through thematic teaching facts become relevant -- and memorable -- in the context of ideas. Thematic teaching broadens students' conceptions of the world as it sharpens their ability to discern the general from the particular.

Active learning is the antithesis of learning by rote. Rather than accepting statements at face value, students are encouraged to always ask "How does it work?" "What's the evidence?" and "How can I find out?" They learn to answer these questions by observing, experimenting, analyzing, reflecting, and communicating with each other. As California State Superintendent Bill Honig aptly describes it, active learning occurs when students "grapple with the ideas of science as they learn the inner workings of the counterintuitive universe." In so doing, students build on what they already know by "regularly making new associations between new ideas and their previous conceptions of how the world works" -- a key feature of the active learning process.[4]

Characteristics of Effective Science Teachers

Thematic teaching and active learning are good theoretical prescriptions. But to translate such theories into practice, teachers need to have a broad repertoire of professional knowledge and skills. As validation, consider just a few aspects of what effective teachers do to facilitate learning:

Effective science teachers create the need to know. It is a truism that the more one wants to learn something, the more likely one is to expend the effort to learn it. Subjects that relate to students' personal lives or those of their friends are far more compelling than abstractions taken out of context. Antibodies may be a rather dull subject to most students when introduced in a textbook chapter that lists basic principles of immunology. The subject is likely to become far more interesting in the context of a discussion about AIDS. It becomes more compelling still when students are given an opportunity to use antibodies to assay for the presence of a particular protein and to then discuss how such an assay relates directly to the design of blood tests for the presence of the AIDS virus and to experiments that scientists do when they study AIDS. There are many ways to create a need to know, including demonstrations, puzzles, videos, experiments, projects, or even just an intriguing question or two; the choice of which ones to use will depend on many factors. *Effective science teachers weigh these factors and consistently draw on resources that translate a curriculum into motivating contexts and activities that will cultivate and nourish their students' natural curiosity.*

Effective science teachers teach from the concrete to the abstract. Abstractions certainly are among the major outcomes of scientific work, but concrete experiences are its principal building blocks. This should also be true of *learning* science. Thus, for example, a teacher might give students a mechanical toy, prompt them to ask what makes it move, and then let them discover for themselves that it involves the unwinding of a spring that pushes a gear around.[5] A discussion about the complex abstraction that scientists call "energy" can come later, once students have achieved an intuitive grasp of the idea from experience. *Effective science teachers understand how to choose appropriate resources and activities that gradually develop abstract concepts using concrete, "hands-on" experiences.*

Effective science teachers relate new ideas to what students already know. As science educators Bruce Watson and Richard Konicek point out, "learners bring their idiosyncratic and personal experiences to most learning situations. These experiences have a profound effect on the learner's view of the world and a startling effect on their willingness and ability to accept other, more scientifically grounded explanations of how the world works."[6] For example, many children believe that articles of clothing such as sweaters are sources of heat rather than thermal insulators. Cognitive research has shown that simply *telling* the "right" answer to children does little to change their conceptions. As an alternative approach, a teacher could have children roll up a thermometer inside a sweater, take temperature readings over the course of minutes, hours, and days, and then confront their conceptions in a group discussion -- perhaps prompting additional experiments.[7] *Effective science teachers are able to diagnose the preconceptions or misconceptions that students have about particular subject matter and then use this* *information to devise or adapt appropriate strategies that help reorient and expand their students' thinking.*

Effective science teachers create opportunities to practice, provide constructive feedback, and instill confidence in their students. Like the development of athletic skills, science learning takes practice. As articulated in the American Association for the Advancement of Science's publication *Science for All Americans*, "students cannot learn to think critically, analyze information, communicate scientific ideas, make logical arguments, work as part of a team, and acquire other desirable skills unless they are permitted and encouraged to do these things over and over in many contexts."[8] Moreover, a desire to practice, even if not nourished by ambition, is usually motivated by a feeling of achievement or success. However, skilled coaching is often necessary for a novice to achieve success consistently and move forward. Good coaches set high but reasonable expectations for their players, regularly assess performance, and know how to motivate improvement with both substantive praise and tempered criticism. *Effective science teachers know how to design and adapt challenging activities and resources that provide ample occasion for their students to try and succeed. Moreover, these teachers are skilled coaches who regularly assess their students' progress and interact with them in a manner that maximizes their learning potential.*

A Professional Knowledge Base for Science Teaching

These characteristics of effective science teaching, which are by no means exhaustive, clearly suggest that skilled science teachers possess a rich, complex, and dynamic knowledge base. This base consists not only of subject matter knowledge and knowledge about learners, curriculum, and assessment, but also of a melding of these whereby content, psychology, and curriculum are transformed into a special form that is inherently *teachable*. Lee Shulman, who has been immersed in the study and improvement of teacher education, has called this special form *pedagogical content knowledge*, "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding."[9]

And yet these aspects of the knowledge base tell only part of the story because a professional science teacher's responsibilities, while directed towards the classroom, extend well beyond it. Professional science teachers communicate with each other and with other professionals to share ideas, insights, and experiences; they regularly help to mentor and induct new teachers into the profession; they participate in the design of instructional materials; and they are charged with high level school management responsibilities and help to direct school policy. Indeed, given the broad domain of a professional science teacher's responsibilities, it is little wonder that Shulman has written, "our question should not be, is there really much one needs to know in order to teach? Rather, it should express our wonder at how the extensive knowledge of teaching can be learned at all during the brief period allotted to teacher preparation."[10]

Implications

The view of effective science teachers as learned professionals (in the sense described in the previous section) has broad implications for discussing the processes of teacher development, instructional materials development, and school restructuring, among others. Brief sketches of just a few of these implications help to illustrate why this is so:

<u>Professional science teachers need education for professionals.</u> The view that effective science teachers are learned professionals suggests that a rigorous educational program should be a prerequisite for practice, as it is for other learned professions. Such a program would require prospective teachers to attain a solid foundation in science content and child development. It would also require the completion of a structured, professional course of study that gradually develops skill in the teaching of science. Such a program would instill within future practitioners a lifelong commitment to the enhancement of practice and the creation of learning communities -- cultures with

capacity for continuing improvement, both individually and organizationally.[11] As experienced professionals who best understand the nature of effective practice, members of such communities would then be vested with responsibility for actively participating in the refinement and enforcement of high and rigorous standards for entrance into the profession.

Professional teachers need professional tools. As learned professionals, effective science teachers use texts and other resources as sophisticated tools of instruction, not as instruction manuals to direct their practice. Such teachers regularly choose prudently among various alternative resources, based on many criteria. These might include how well a resource promotes inquiry–based development of a theme; how accurate the resource is in presenting particular content; or how motivating a resource is for introducing a new idea. Because effective teachers choose resources based on sound pedagogic judgments, they create demand in the marketplace for instructional materials that clearly promote thematic teaching and active learning. Such demand extends to all types of resources that professional teachers ought to have at their disposal, such as laboratory kits and equipment, texts, videos, computers, and interactive multimedia. Materials developers should strive to meet this demand by creating innovative resources that complement effective teachers' pedagogic objectives. Indeed, the development of exemplary resources ideally should involve an interplay between developers and teachers, often involving active collaboration in both the design and field–testing stages.

Professional teachers need professional environments. As do other skilled professionals, effective science teachers should work in an environment that holds professionals in high regard and which provides them with flexible schedules, adequate facilities, and staff support. In essence, schools where teachers are viewed as learned professionals are dynamic organizations in which teachers have autonomy and significant professional responsibility. As described in the Carnegie Task Force report *A Nation Prepared: Teachers for the 21st Century*, such schools are places where teachers have "the ability to make -- or at least strongly influence -- decisions concerning such things as the materials and instructional methods to be used, the staffing structure to be employed, the organization of the school day, the assignment of students, the consultants to be used, and the allocation of resources available to the school."[12] The staff in such schools work collaboratively, and take collective responsibility for student progress.

Concluding Remarks

Improving mathematics and science teaching is clearly a formidable task that will require the sustained commitment and collective efforts of many individuals working at multiple levels. Schools need adequate resources to improve their facilities for teaching math and science. Exemplary instructional materials that promote thematic teaching and active learning need to become the classroom standard. And, in general, schools and communities need to work together to improve both the social conditions and the pedagogic policies and practices that affect learning. As this paper has attempted to convey, we also need effective teachers, who, as learned professionals, understand best how to maximize the utility of facilities and resources by transforming them into professional tools with which to construct truly effective learning environments for all students. As such, effective teachers may be among our most effective agents of reform.

Notes

1. Feynman, R. (1969) "What is Science?" *The Physics Teacher* 7 (6):313–320. Originally presented as an address at the Fourteenth Convention of the National Science Teachers Association in 1966.

2. See, for example: The National Science Board Commission on Precollege Education in Mathematics, Science and Technology (1983): *Educating Americans for the 21st Century* (National Science Foundation, Washington, DC); American Association for the Advancement of Science (1989): *Science for All Americans* (Washington, DC); The National Center for Improving Science Education (1989): *Science and Technology Education for the Elementary Years: Frameworks for Curriculum and Instruction* (Washington, DC), and other publications from the Center.

3. California State Board of Education (1990) *Science Framework for California Public Schools: Kindergarten Through Grade Twelve* (Sacramento, CA).

4. Honig, B. Forward to *Science Framework for California Public Schools: Kindergarten Through Grade Twelve*.

5. Feynman, R. "What is Science?"

6. Watson, B. and Konicek, R. (1990) "Teaching for Conceptual Change: Confronting Children's Experience" *Phi Delta Kappan*. 71 (9):680–685.

7. Watson, B. and Konicek, R. "Teaching for Conceptual Change: Confronting Children's Experience."

8. American Association for the Advancement of Science, *Science for All Americans (p146)*.

9. Shulman, L. (1987). "Knowledge and Teaching: Foundations of the New Reform" *Teachers, Teaching, & Teacher Education*. In: Harvard Education Review, Okasawa–Rey, M., Anderson, J., and Traver, R., editors. pp. 313–334. (Cambridge, MA).

10. Shulman, L. "Knowledge and Teaching: Foundations of the New Reform."

11. National Center for Improving Science Education (1989) *Developing and Supporting Teachers for Elementary School Science Education* (Washington, DC). The report describes three distinct phases of teacher development.

12. Carnegie Forum on Education and the Economy (1986). *A Nation Prepared: Teachers for the 21st Century*. The report of the Task Force on Teaching as a Profession. (New York, NY).

What Research Has To Tell Us About Improving Mathematics Teaching

by

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Reform in the content, assessment, teaching, and learning of mathematics is called for if we are to meet world class standards in mathematics achievement. Current research on how mathematics should be taught and learned indicates that teachers should facilitate student "construction" of knowledge. Accompanying this research is the theory that teacher educators should help in- and pre-service teachers construct their own pedagogical practices. The NCTM Professional Standards for Teaching Mathematics calls for major shifts in the teaching of mathematics. These shifts should move

- o toward classrooms as mathematical communities--away from classrooms as simply a collection of individuals;
- o toward students seeking evidence to verify conjectures--away from the teacher as sole authority of the right answer;
- o toward mathematical reasoning--away from merely memorizing procedures;
- o toward conjecturing, inventing, and problem solving--away from an emphasis on mechanistic answer-finding;
- o toward connecting mathematics and science, their ideas and applications--away from treating mathematics and science as bodies of isolated concepts and procedures; and
- o toward the use of manipulatives, and computer simulation to introduce concepts--away from emphasis on formal, abstract representation of concepts. (National Council of Teachers of Mathematics, 1991)

Such profound shifts require massive changes in teacher beliefs and practices and in what the public expects and is willing to support.

Helping children construct their own mathematics understanding demands different roles for both teacher and student. The teacher must become a facilitator. The teacher can no longer "preach to the seats"; she/he must be a "guide at the side." The student can no longer be the passive recipient of knowledge; she/he must be actively engaged in the acquisition of knowledge. The concern that this process is exceedingly time consuming is offset by research that indicates that the mathematical understanding that students construct themselves is deep and enduring--that students taught this way score as well as their peers on low-level mathematics skill items and better on problem solving and conceptual items. Orchestrating the major mathematical concepts that students should understand and eliminating from deep coverage less significant items is a difficult new role for teachers.

Note: This piece is part of a larger report, What Research Has to Tell Us About The Reform of Mathematics Education. For a copy of the complete report, write Hunter Moorman, OERI, Rm 502C, U.S. Department of Education, 555 New Jersey NW, Washington, DC, 20208.

"Direct instruction" is undoubtedly still the pedagogical practice used by most mathematical teachers today. But a growing body of evidence indicates that direct instruction may not provide an adequate basis for student development of and use of higher order thinking skills. Finding the appropriate balance among student-centered activity, direct instruction, and other pedagogical practices is a complex issue. At this time we lack sufficient research on this matter.

Research on the relationship of teacher knowledge of mathematics to student learning is not definitive. However, case studies of teachers who have a good background in mathematics indicate that there is a richness to the lessons they teach, that they involve students extensively in mathematical dialogue, and that they capitalize on student questions and discussions to weave and extend mathematical relationships. Research indicates further that an interplay of teacher knowledge of mathematics, of content-specific knowledge, of how children think about mathematics -- as well as teacher beliefs about mathematics and about how children learn mathematics -- affect teacher classroom behavior.

Current requirements for the preparation and certification of teachers in mathematics, particularly at the elementary and middle school levels, fall far short of what is envisioned in the mathematics reform. In A Call for Change, the Mathematical Association of America (MAA) proposes standards for the preparation of mathematics teachers at all levels that would enable teachers to

- view mathematics as a system of interrelated principles;
- communicate mathematics accurately, both verbally and in writing;
- understand the elements of mathematical modelling;
- understand and use calculators and computers appropriately in the teaching and learning of mathematics; and
- appreciate the development of mathematics both historically and culturally.

Current classroom teachers also need enriched education. Two successful research projects that build upon this constructivist concept are Cognitively Guided Instruction (CGI) (Carpenter & Fennema, University of Wisconsin) and Project IMPACT (Pat Campbell, University of Maryland). Teacher enhancement projects that involve multi-week summer workshops followed by year-long implementation, follow-up activities, and classroom visitations have proven effective. Two such projects are SummerMath, an inservice program for elementary and secondary teachers focusing on problem-solving from the constructivist approach to learning (Schifter, Mount Holyoke College); and Improving the Mathematical Performance of Low-Achieving Middle School Students, a collaborative teacher-centered staff development model (Ruopp, EDC, Newton, MA).

There is an assumption in the field that short-term inservice is ineffectual in producing lasting change. However, hypermedia is beginning to be used successfully as a tool for helping teachers and those preparing to teach to construct their own pedagogical practices. This is done by preserving the complexity of the classrooms of exemplar teachers on video and augmenting this video classroom view with comments from the teachers and from other mathematics educators. One such video is Changing Practice: Teaching Mathematics for Understanding (Kirsner, National Center for Research on Teacher Learning, Michigan State University).

What Research Has To Tell Us about Improving Science Teaching

by

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A comprehensive science education reform movement is underway in the United States at the national level, in the states, in schools, and in individual classrooms. Teachers -- as well as parents, administrators, and policymakers -- have a vital role to play in furthering reform in their communities. To truly change science education, a widespread effort is required.

Several overall shifts in our view of science education have occurred that provide the context for reform.

- All of our children and young adults, not just those preparing to be professional scientists, must have science knowledge and understand scientific ways of thinking in order to function in an information age.

- Research from the cognitive sciences and from science education have produced insights into how children learn science. The view has shifted from one of the student absorbing knowledge to one of the student constructing knowledge (the "constructivist approach"). While research continues on the meaning of constructivism for the curriculum or its context, there has been a conceptual shift in what students should be expected to learn and how it is taught.

- The curriculum emphasis has moved from amassing facts to more indepth understanding of basic science concepts, from an emphasis on acquiring information to an equal emphasis on ways in which knowledge can serve individuals.

- The teacher has changed from being the dispenser of knowledge to being the facilitator of learning. The student is more active in acquiring his or her own knowledge. The teacher provides a rich learning environment by selecting engaging materials, arousing students' curiosity, and encouraging discourse on science phenomena.

Research influencing science instruction focuses on the nature of thinking and how students learn. All students can become competent thinkers. But the learner must construct his or her own knowledge rather than knowledge being transmitted to a passive student. Learners come to new situations with preconceived notions. Students' ideas may make sense to them, but they are often "incorrect responses" and "wrong from a scientific perspective." It is only through exploring these naive conceptions and integrating them with new understandings that new knowledge can be developed. If misconceptions are not addressed, new material is not meaningful to the student. While good students may learn to memorize material and thus produce a correct response, they lack understanding of the concepts. Worse yet, students learn to dislike science. Interest in science declines beginning in the middle school grades.

Note: This piece is drawn from a larger report, Improved Science Teaching and Learning for the 21st Century: Research-Based Perspectives on Reform. For a copy of the complete report, write Hunter Moorman, OERI, Rm 502C, U. S. Department of Education, 555 New Jersey Avenue NW, Washington, DC 20208.

If we are to teach for conceptual understanding, less material will be covered. But, "less is more." Rather than memorize facts and vocabulary, which are soon forgotten, students should develop more indepth understanding of fewer topics. This is difficult to do; the current science curriculum is filled with so many facts, often without connections. Both the American Association for the Advancement of Science's Project 2061 and the National Science Teachers Association's Scope, Sequence and Coordination Project call for fewer topics in greater detail and for the building of connections between the science disciplines.

Teaching for conceptual change, or "teaching for understanding" as it is called, is problem-centered and requires use of concrete materials in an inquiry mode. Teachers need to continually diagnose student concepts and consider where they are in the process of conceptual change. Student misconceptions need to be addressed through discussion and other strategies. Materials are needed that will encourage students' exploration and provide concrete, relevant and varied experiences with a particular science phenomenon.

While there is more to be learned about teaching strategies that best promote teaching science to diverse students, it is known that the inquiry approach to teaching is a way of promoting understanding. And there is agreement that traditional didactic teaching, in which teachers primarily organize and present content through the textbook and lecture and expect students to study and learn, will not lead to conceptual change. Rather, students remain committed to their alternative conceptions while memorizing new material. They often do well on tests, but without any real understanding of a concept. And without knowing underlying concepts, they cannot go on to deeper concepts.

To assume a new role as facilitator of knowledge, teachers must have a firm grasp of the subject matter and teaching strategies so that they can encourage students to follow an inquiry approach, asking questions and proposing solutions. Additionally, teachers will need skills in managing the physical and social organization of the classroom required for small-group problem solving. Career-long professional development is needed. Inservice education is an important ingredient in supporting the kind of teaching called for by the reform agenda. Some guidelines for developing teacher enhancement programs are:

o Teachers need to know the discipline, to understand the key ideas and their relationships to each other. Knowledge of the discipline is essential to effective instruction. The National Science Teachers Association recommends that elementary teachers have at least one course in the biological sciences, one course in the physical sciences, and one course in the earth/space sciences as well as a course in the methods of teaching elementary science. Yet only about one-third of current classroom teachers meet these standards.

o There is a need to change the way teachers think about teaching science. Through altering beliefs and views about the classroom, teaching can change.

o Teacher inservice should be conducted in such a way that it serves as a model of the teaching and learning that will take place in the classroom.

Studies indicate that teachers teach to the test. Assessment and instruction are closely linked. As we change the goal of science instruction to one of developing understanding and the ability to solve problems and apply science concepts in new situations, we need to develop assessments that more closely measure this goal. The most important consideration is that assessment measure the goal of the instruction rather than assessment driving the curriculum toward unconnected facts and discrete pieces of information.

U.S. DEPARTMENT OF EDUCATION
OFFICE OF EDUCATIONAL RESEARCH AND IMPROVEMENT

ACHIEVING WORLD CLASS STANDARDS: THE CHALLENGE FOR EDUCATING TEACHERS STUDY GROUP RECOMMENDATIONS

The need for systemic change in education was a dominant theme of the Study Group meeting: Achieving World Class Standards: The Challenge for Educating Teachers held by the Office of Educational Research and Improvement in Washington, D.C., March 22-24, 1992. The 58 participants represented a cross-section of educators, policy makers, association representatives, and others interested in improving teacher education. Discussions centered on the kind of teaching needed to achieve world class standards; problems and issues in educating teachers for higher subject matter standards; and the potential for current reforms in bringing about needed change.

Participants emphasized that reforming teacher education must occur simultaneously with the process of reforming schooling. Moreover, in order to sustain the process of renewal we will need collaboration and innovation, as well as a "moral stewardship" of educators for providing excellent education.

The Study Group recommended changes in those components of the education system with primary responsibilities for the ongoing education of teachers -- state education agencies, local districts and schools, institutions of higher education and professional organizations. They also recommended needed research on issues in educating teachers and ways in which the U.S. Department of Education could facilitate the process of systematic change.

Recommendations for State Education Agencies

- Facilitate consensus among educators and the public on world class standards and their implications for teaching.
- Organize consortia for sharing information on higher standards and related assessments and on teacher certification and licensing.
- Support networks and systems that assist teachers in using new standards.
- Revise licensing processes to emphasize strong content knowledge as well as the ability to teach.
- Require teachers to develop portfolios demonstrating their teaching abilities in connection with continuing their licenses to teach.
- Support teacher education programs that emphasize collaborative relationships among university and school staffs and clinical teaching experiences with diverse student populations.
- Support efforts to improve the quality of teaching in institutions of higher education, especially in programs related to the preparation of teachers.

- Support initiatives that include teachers as members of research teams.
- Require external reviews of schools of education in conjunction with a nationwide system of standards for accreditation.

Recommendations for Districts and Schools

- Promote shared understandings and a community of learning among parents, and education professionals on issues in achieving world class standards.
- Develop internal agreement within the district, and within each school on instructional objectives and purposes of assessment.
- Support mentor programs that strengthen teachers' knowledge of content as well as pedagogy.
- Provide resources - space, time expert consultants - to help teachers learn and collaborate about ways of achieving world class standards.
- Support professional development, including leadership skills for administrators to enable them to implement new standards.
- Support participation by teachers in the creation of ongoing professional development programs.
- Strengthen the process for selecting new teachers by:
  - developing criteria that reflect high standards, especially for subject matter areas, and
  - involving school level administrators and teachers from the content area or grade level in which the person will teach
  - publicizing selection criteria in order to "market for quality."

Recommendations for Institutions of Higher Education

- Develop strong liberal arts programs as prerequisites for teacher education.
- Involve arts and science faculty in improving teacher education through:
- Promoting better connections between general education programs and content and methods courses in teacher education.
- Integrating ideas for teaching within specific disciplines into the disciplinary courses themselves.

- Providing incentives for faculty to become involved in educating teachers; for example, by defining scholarship to include research and theories on the teaching of a specific discipline.

- Re-thinking current distinctions in subject matter preparation of elementary school and secondary school teachers, e.g. some elementary school teachers may need to be specific subject matter specialists.

- Improve the quality of teaching throughout higher education by:

- Promoting peer review of college teaching, including examination of course syllabi and teaching portfolios.

- Systematically evaluating teaching performance and using the results to improve the quality of instruction.

- Improve professional development components of teacher education programs by:

- Supporting the continued professional development of teacher education faculties.

- Providing supervised clinical experiences beyond student teaching to extend professional development after graduation.

- Encouraging in prospective teachers a sense of responsibility for important decisions in schools and districts.

- Encouraging continued contact with the University, for example, through auditing of courses by classroom teachers.

- Organizing learning experiences to develop collegiality among college faculty and classroom teachers.

Recommendations for Professional Organizations

- Involve teachers in critical aspects of education reform by:

- Establishing standards and assessments of student and teacher performance at school, state and national levels.

- Restructuring of schools to facilitate, encourage, and ensure high standards.

- Participating in decisions affecting preservice, and inservice education, mentor, and advanced professional development.

- Encouraging local teachers associations to support restructuring of schools and to develop rewards and incentives to support change.

- Supporting subject area associations' efforts to establish standards-related teacher education and licensing programs.

- Lead and encourage collaborative efforts to reform teacher education, including:
- Collaborating across professional organizations to develop general and subject-specific pedagogical methods.
- Collaborating with other education stakeholder to achieve consensus and consistency of policy and message on educating teachers for higher student achievement.
- Encouraging collaboration among education and government, business, parents, the community, researchers, subject area specialists, and others on issues related to educating teachers.
- Working with textbook publishers and other suppliers of educational materials to develop tools and resources for teaching to world class standards.
- Encouraging politicians to coordinate and work together across their various interests for the improvement of education.
- Utilizing new technologies for educating and encouraging collaboration among teachers.

Recommendations for the U.S. Department of Education

- Provide support for networking, communication, and collaboration among various levels and parts of the education system for purposes of improving the education of teachers including:
- Facilitating collaboration on standards and instruction among content-area specialists, teacher educators, and classroom teachers.
- Providing forums for discussing world class standards among the public, policymakers, and the education community.
- Establishing an electronic network on education that is easily accessible by schools and teachers.
- Support innovative efforts for individuals and agencies working to overcome resistance to change on the part of educators.
- Support projects that establish and study the effectiveness of professional development schools.
- Support efforts to develop professional teaching standards for initial licensure and for advanced certification of teachers.
- Support and disseminate research on the connection between new subject area standards and assessment of student learning.

Recommendations for Researchers

- Conduct research to test the influence of world class standards on improving teacher education, teaching and student achievement, including:

- Research on how teachers, students, parents, and university faculty come to understand and to implement the standards.

- Scholarly analysis of the content and standards selected in new subject area frameworks and their relationships to existing student and teacher assessment procedures.

- Conduct research on characteristics of excellent teacher education, of excellent teaching and of high levels of student achievement, in order to better define needed reforms including:

- Research on successful teachers and how they become educated.

- Research on models of productive collaboration among arts and science and education faculty to distinguish between real barriers and those that are myths.

- Research on the " language" -- metaphors, images, representations -- that disciplinary experts use to communicate with each other in order to facilitate communication across disciplinary boundaries.

CONSORTIUM FOR POLICY RESEARCH IN EDUCATION
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Policy Coherence Between Colleges of Education and Colleges of Arts and Science: Who is Responsible for Teacher Education?

Frank B. Murray

The separateness of the faculties of education and liberal arts and the lack of coherence between the scholarship and curricula of teacher education and arts and science is seen by many policymakers as the root cause of the American teacher's alleged low level grasp of the subject matter and the failure of pupils to understand the school curriculum at competitive levels. **Project 30** is a group of institutions of higher education who have pledged to work on the reform of the relationship between faculties of education and arts and science. This group addresses five themes which need to be settled in any teacher education program:

(1) **Subject matter understanding.** How should teachers acquire a thorough knowledge of the discipline(s) they are licensed to teach? Within **Project 30** six general approaches are pursued to improve the acquisition of subject-matter understanding for prospective elementary and secondary school teachers:

- the interdisciplinary major, which is a collection, in the case of the elementary school teacher, of reworked minors in the areas of the school curriculum;
- the philosophy of subject matter approach, in which the underlying coherent principles or structures that hold academic disciplines together are the subject of the courses themselves;
- the text approach or "great books" major, which entails a course of study containing a close reading of seminal texts in each area coupled with an examination of school textbooks for the assumptions they make about the discipline in question;
- the genetic epistemology option, which entails the study of the developmental psychological literature from the perspective of the development of the concepts that make up the curriculum so that students learn the relevant developmental constraints on the pupil's acquisition of the curriculum while laying out the nature of the subject itself;
- the cognitive psychology major, in which subject areas would be approached from the perspective of how we think about and know the content in question; and
- the pedagogical content knowledge minor, which focuses on the way teachers transform their knowledge into a teachable subject which is appropriate to their students' understanding, and uses this transformation to structure the academic disciplines.

(2) **General and liberal knowledge.** The decade's educational reform reports all make the unchallenged claim that teachers need to be well schooled in the liberal arts. How, in fact, is the teacher's or the pupil's education served by the teacher's knowledge of the liberal arts as opposed to other forms of knowledge? What is it about the liberal education that makes it so valuable to teacher education? The liberal arts component of the teacher education program should deliver at least three things: (a) the subject matter knowledge for which the teacher is responsible in the classroom; (b) the general education knowledge that defines what the well-educated person knows, apart from the knowledge and information that the teacher is

responsible for directly conveying to the students; and (c) a set of attitudes and dispositions that allow a teacher to go beyond mere information or knowledge — to search out and construct truth, to question assumptions rather than simply accepting them, to value knowledge for its own sake, and to be true thinkers rather than simply receptacles and transmitters of facts.

(3) **Pedagogical content knowledge.** How do teacher education students learn to convert their knowledge of the subject matter into a teachable subject for a wide range of pupils? Discussion in this area centers on appropriate ways of organizing information and knowledge in order to take each pupil well beyond what can be held together through rote memorization. Pedagogical content knowledge is fundamentally about those structures that confer some appropriate level of understanding, and it is ultimately about those structures that actually advance our understanding.

(4) **Multicultural, international, and other human perspectives.** How can we make the curriculum accurate with respect to current scholarship on matters of race, gender, ethnic and cultural perspectives? The study of minority issues or the study of global or international issues will fail, as they have in the past, if they are not anchored in the core values of the academy.

(5) **Recruitment into teaching.** How can the numbers and proportions of under-represented persons be increased for the right reasons and on a principled basis?

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REVOLUTION IN ONE CLASSROOM

(or, then again, was it?)

BY DAVID K. COHEN

AS MRS. Oublier sees it, her classroom is a new world. When she began six or seven years ago, she was a thoroughly traditional teacher. She reported that she followed the mathematics text. Her second graders spent most of their time on worksheets. Learning math meant memorizing facts and procedures. Then Mrs. O found a new way to teach math. The summer after her first year of teaching, she took a workshop in which she learned to focus lessons on students' understanding of mathematical ideas. She found ways to relate mathematical concepts to students' knowledge and experience. And she learned how to engage students in actively understanding mathematics.

Mrs. O's story is a timely one. I encountered her in the late 1980s, as reformers once again began trying to change mathematics teaching and learning from mechanical drill and memorization to reasoning and understanding. Since the early twentieth century, mathematicians and math educators had intermittently insisted that students should learn to reason mathematically, to apply mathematical ideas to everyday situations, and to understand the conceptual basis of mathematics. But in the 1980s, state and national education leaders, chagrined about reports of weak school performance and worried about America's economic situation, gave new force to demands for reform.

These are revolutionary aspirations, at least judged by current classroom practice. But the new ambitions are being taken quite seriously. The National Council of Teachers of Mathematics has formulated an ambitious new set of standards for teaching and curriculum, which have received favorable attention in many quarters, including the secretary of education and the president. Several states are trying to realize the new ideas. For instance , since 1985, California's department of education has been pressing a remarkable program of reform in mathematics teaching and learning. The state issued a new curriculum framework. It then required publishers to re-orient math textbooks to conform more closely to new ideas about instruction. It also began to re-write the state testing program so that it assesses students' understanding and reasoning. And it has been offering workshops and other assistance to teachers.

Mrs. O teaches in California and sees her work as part of the changes that the state is trying to promote. Her story is engaging, and so is she. She is considerate of her students, eager for them to learn, energetic, and attractive. These qualities would stand out anywhere, but they seem particularly vivid in her school—a drab collection of one-story concrete buildings that sprawl over several

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acres. Though clean and well managed, her school has none of the familiar signs of classy education. It has no legacy of experimentation or progressive pedagogy, or even of heavy spending on education. Only a minority of children come from well-off families. Most have middling or modest incomes, and many are eligible for Chapter 1 assistance. A sizable minority are on welfare. The school district is situated in a dusty corner of southern California, where city migrants are turning a rural town into a suburb. New condominiums are sprouting up all over the community, but one still sees pick-up trucks with rifle racks in their rear windows. Like several of her colleagues, Mrs. O works in a covey of tacky, portable, prefab classrooms, trucked into the back of the schoolyard to absorb growing enrollments on the cheap.

Mrs. O's story seems even more unlikely when considered against the history of American educational reform. Great plans for educational change are familiar in that history, but so are reports of failed reform. John Dewey and others announced a revolution in pedagogy just as our century opened, but apparently it fizzled, for classrooms changed only a little (Cuban, 1984). That also seems to have been the fate of the earlier "new math" in the 1950s and 1960s and of related efforts to improve science teaching (Welch, 1979). Since then, many studies of instructional innovation have embroidered these old themes of great ambitions and modest results (Gross, et al., 1971; Berman and McLaughlin, 1977; Rowan and Guthrie, 1989; Cohen, 1988).

Some analysts attribute these results to teachers' resistance, saying that entrenched classroom habits defeat reform (Gross, et al., 1971). Others report that many innovations fail because they are so poorly adapted to the classroom that even teachers who avidly desire change can do little (Cuban, 1984; Cuban, 1986). Mrs O's revolution looks particularly appealing against this background. She eagerly embraced change, rather than resisting it, finding new ideas and materials that worked in her classroom. Mrs. O sees her class as a success for the new mathematics Framework. She reports that her math teaching has wound up where the Framework wants it to be.

SOMETHING OLD AND SOMETHING NEW

One prominent feature of Mrs. O's teaching is her use of innovative instructional materials and activities designed to help students make sense of mathematics. But she used these new activities and materials quite traditionally, as though mathematics contained only right and wrong answers. Similarly, while she had revised the class organization and activities to help students understand math, she managed the discourse in ways that discouraged exploration of students' understanding.

In fact, Mrs. O's lessons were quite mixed. They contained some important elements that reformers embraced, but others that they branded inadequate. Her classes present an extraordinary *mélange* of tradition and novel approaches to math instruction, which is one reason that they deserve attention. For such mixtures are quite common in instructional innovations, though little noticed. As teachers and students try to find their way from familiar practices to new ones, they cobble new

Students' number sentences were accepted if correct, and written down on the board. But they were turned down if incorrect, and not written on the board. Right answers were not explained, and wrong answers were treated as unreal.

ideas together with old practices. Teachers' ingenuity is remarkable, but the mixtures raise fundamental questions. Can we say that an innovation has made much progress when it is tangled up with many traditional practices? What might it take to help teachers continue to learn and change? These questions have a special urgency just now, as reformers urge teachers to radically revise their work in math and other subjects.

New Materials, Old Mathematics

From one angle, the curriculum and instructional materials in this class looked just like what the new California math Framework invited. For instance, Mrs. O regularly asked her second graders to work on "number sentences." In one class that I observed, students had just done the problem: 10+4=14. Mrs. O then asked them to generate additional "number sentences" about 14. They volunteered various ways to write addition problems about fourteen—that is, 10+1+1+1+1=14, 5+5+4=14, etc. Some students proposed several ways to write subtraction problems—that is, 14-4=10, 14-10=4, etc. Most of the students' proposals were correct. Such work could make mathematical relationships more accessible, by coming at them with ordinary language rather than working only with bare numbers on a page. It also could unpack mathematical relationships, by offering different ways to get the same result. It could illuminate the reversible relations between addition and subtraction. And it could get students to do "mental math," i.e., to solve problems in their heads and thereby learn to see math as something to puzzle about and figure out, rather than just a bunch of facts and procedures to be memorized.

These are all things that the new Framework celebrated. It exhorted teachers to help students cultivate ". . . an attitude of curiosity and the willingness to probe and explore . . . " (California State Department of Education [CSDE], 1985, p.1). It also called for classroom work that helps students ". . . to understand why computational algorithms are constructed in particular forms . . ." (CSDE, 1985, p.4).

But Mrs. O conducted the entire exercise in a thoroughly traditional fashion. The class recited in response to the teacher's queries. Students' sentences were accepted if correct, and written down on the board. But they were turned down if incorrect, and not written on the board. Right answers were not explained, and wrong answers were treated as unreal. The Framework made no such distinction, arguing instead that understanding how to arrive at answers is an essential part of helping students figure out how mathematics works—no less important than whether the answers are right or wrong. The Framework criticized the usual algorithmic approach to mathematics, and the usual search for the right answer. It called for class discussion of problems as an important part of figuring out mathematical relationships (CSDE, 1985, pp. 13-14). But no one in Mrs. O's class was asked to explain his or her proposed number sentences, whether correct or not. No student was invited to demonstrate how he or she knew whether a sentence was correct or not. The teacher used a new mathematics curriculum, but used it in a way that conveyed a sense of mathematics as a fixed body of knowledge of right answers rather than as a field of inquiry.

The mixture of new mathematical ideas and materials with old mathematical knowledge and pedagogy showed up elsewhere in Mrs. O's work. She used concrete materials and other physical activities extensively to represent mathematical concepts in forms that are vivid and accessible to young children. She opened every day with a calendar activity in which she and the students gathered on a rug at one side of the room to count up the days of the school year. She used this activity for various purposes. During my first visit, she was familiarizing students with place value, regrouping, and odd and even numbers. As it happened, my visit began on the thirty-ninth day of the school year, and so the class counted to thirty-nine. They used single claps for most numbers but double claps for ten, twenty, etc. Thus, one physical activity represented the "tens" and distinguished them from another physical activity that was used to represent the "ones." The idea was that fundamental distinctions among types of numbers can be represented in ways that make immediate sense to young children and that will easily familiarize them with important mathematical ideas.

Mrs. O's class abounds with such activities and materials, and they are very different from the bare numbers on worksheets that would be found in a traditional math class. Her approach seems nicely attuned to the new Framework. For instance, that document argues that "many activities should involve concrete experiences so that students develop a sense of what numbers mean and how they are related before they are asked to add, subtract, multiply, or divide them (CSDE, 1985, p. 8). And it adds that "concrete materials provide a way for students to connect their own understandings about real objects and their own experiences to mathematical concepts. They gain direct experience with the underlying principles of each concept" (CSDE, 1985, p.15).

But it is one thing to embrace a doctrine of instruction and quite another to weave it deeply into one's practice. For even rather monotonous teaching comprises many different threads, and any new instructional element is somehow related to many others already there. The new thread can simply be dropped onto the fabric, and everything else left as is. Or new threads may be somehow woven into the fabric. Mrs. O introduced new threads but only slightly re-adjusted the old ones. Hence the novel materials and activities were infused with traditional messages about what mathematics was and what it meant to understand it.

These mixed qualities were vividly apparent in a lesson that focused on addition and subtraction with regrouping. The lesson occurred early in an eight-or ten-week cycle concerning these topics. Like many of Mrs. O's lessons, it combined a game-like activity with the use of concrete materials. She hoped to capture children's interest in math while helping them to understand it. Mrs. O introduced this lesson by announcing: "Boys and girls, today we are going to play a counting game. Inside this paper [holding up a wadded-up sheet of paper] is the secret message. . . ." Mrs. O unwadded the paper and held it up: "6" was inscribed. The number was important because it would establish the number base for the lesson: Six. In previous lessons, they had done the same thing with four and five. So part of the story here was exploring how things work in different number bases, and one reason for that, presumably, was to get some perspective on the base-ten system that we conventionally use. Mrs. O told the children that, as in the previous games, they would use a nonsense word in place of the secret number. This time they selected "cat's eye" to stand in for six.

With this groundwork laid, Mrs. O had "place-value boards" given to each student. She held up her board: It was roughly eight by eleven; one half was blue, the other white. She said: "We call this a place-value board. What do you notice about it?"

Cristie Smith, who turned out to be a steady infielder on Mrs. O's team, said: "There's a smiling face at the top." Mrs. O agreed, noting that the smiling face needed to be at the top at all times [that would keep the blue half of the board to everyone's left]. Several kids held theirs up for inspection from various angles, and she admonished them to leave the boards flat on their tables at all times.

"What else do we notice?" she inquired. Sam said that one half is blue and the other white. Mrs. O agreed and went on to say that "... the blue side will be the cat's eye side. During this game we will add one to the white side, and when we get a cat's eye, we will move it over to the blue side." With that, each student was given a small plastic tub, which contained a handful of dried beans and half a dozen small paper cups, perhaps a third the size of those dispensed in dentists' offices. This was the sum total of pre-lesson framing—no other discussion or description preceeded the work.

There was a small flurry of activity as students took their tubs and checked out the contents. Beans present nearly endless mischievous possibilities, and several of the kids seemed on the verge of exploring their properties as guided missiles. Mrs. O nipped off these investigations, saying: "Put your tubs at the top of your desks, and put both hands in the air." The students complied, as though in a small stagecoach robbery. "Please keep them up while I talk." She opened a spiral-bound book, not the school district's adopted text but *Math Their Way*. This was the innovative curriculum guide that had helped to spark her revolution. She looked at it from time to time as the lesson progressed but seemed to have quite a good grip on the activity.

Mrs. O got things off to a brisk start: "Boys and girls [who still were in the holdup], when I clap my hands, add a bean to the white side."

She clapped once vigorously, adding that they could put their hands down. "Now we are going to read what we have: What do we have?" (She led a choral chant of the answer.) "Zero cat's eye and one." She asked students to repeat that, and everyone did. She clapped again, and students obediently added a second bean to the white portion of the card. "What do we have now?" she inquired. Again she led a choral chant: "Zero cat's eye and two." So another part of the story in this lesson was place value: "Zero cat's eye denoted what would be the "tens" place in the base-ten numbering, and "two" is the "one's" place. Counting individual beans and beans grouped in "cat's eye" would give the kids a first-hand, physical sense of how place value worked in this and other number bases.

In these opening chants, as in all subsequent ones, Mrs. O performed as much as a drill sergeant as a choir director. Rather than establishing a beat and then maintaining it, she led each chant and the class followed at a split-second interval. Any kid who didn't grasp the idea needed only to wait for her cue or for his table-mates. Students were never invited or allowed to count on their own. Thus, while the *leitmotif* in their second chant was "zero cat's eye and two," there was an audible minor theme of "zero cat's eye and one." That several students repeated the first chant suggested that they did not get either the routine or its point.

Mrs. O moved right on nonetheless, saying that it "... is very important that you read the numbers with your hands." This was a matter to which she returned many times during the lesson, reminding children to put their little paws first on the beans in the white square and then on the little cups on the blue square as they incanted the mathematical chants. She seemed to feel it essential that they manipulate the concrete materials. Whenever she spotted a child who was not palpitating beans and cups, she walked over and moved their arms and hands for them.

Mrs. O led the bean adding and chants up to five. Then, with five beans down on everyone's card, she asked: "Now think ahead; when I clap my hands this time, what will you have on the white side?"

Reliable Cristie Smith scooped it up and threw smoothly to first: "Cat's eye."

Mrs. O led off again: "When you get a cat's eye, put all the beans in a paper cup and move them over." She clapped her hands for the cat's eye and then led the following chant: "Put the beans in the cup and move them over."

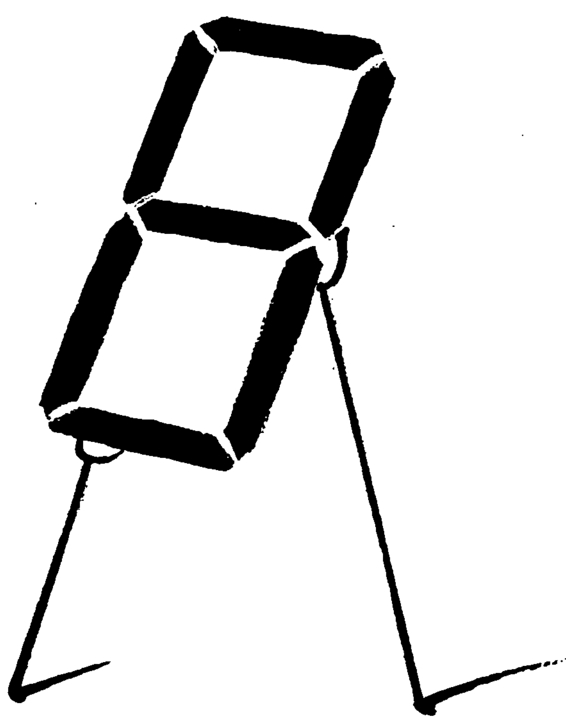
"Now let's read what we have." The chant rolled on: "One cat's eye and zero." A puzzling undercurrent of "one cat's eye and one" went unattended. She then led the class through a series of claps and chants, leading up to two cat's eyes. And then, with a methodical monotony, up to five cat's eyes and five. By the time they got to five cat's eyes and five, her claps had grown more perfunctory, and many kids had gotten the fidgets. But Mrs. O saw this chanting and bean-pawing as the high road to mathematical understanding and tenaciously drove her team on.

"Now, how many do we have?" "Five cat's eyes and five beans," came the chant. "Now we will take away one bean" (from the "ones" side of the board). "How many do we have?" Again the answering chant, again led by her, a fraction of a second earlier: "Five cat's eyes and four."

This was a crucial point, for the class was moving from a representation of addition with regrouping to a representation of subtraction with regrouping. It would have been an obvious moment for some such comment or discussion, at least if one saw the articulation of ideas as part of understanding mathematics. But Mrs. O did not comment or explain. She took an activity-based approach, as though all the important ideas were implicit, and better that way.

Thus the class counted down to five cat's eyes and zero. Mrs. O then asked, "What do we do now?" Jane responded: "Take a dish from the cat's eye side and move it to the white side." No explanation was requested or offered to embroider this response. Mrs. O simply approved the answer, clapped her hands, and everyone followed Jane's lead. With this, Mrs. O led the class back

Her inspiration for all this was* Math Their Way, *on which Mrs. O relied heavily.



through each step, with claps, chants, and reminders to "read" the beans with their hands, down to zero cat's eye and zero beans. Everyone was flagging long before it was done, but not a chant was skipped or a movement missed.

Why did Mrs. O teach in this fashion? In an interview following the lesson, I asked what she thought the children learned from the exercise. She said that manipulating the materials helped them to understand what goes on in addition and subtraction with regrouping. She seemed convinced that these physical experiences caused learning, that mathematical knowledge arose from the activities.

Her inspiration for all this was *Math Their Way*, on which Mrs. O relied heavily. This increasingly popular book, a system of primary grade math teaching, announces that it will help ". . . to develop understanding and insight of the patterns of mathematics through the use of concrete materials" (Baratta-Lorton, 1976: xiv). Concrete materials and physical activities are crucial because they are believed to provide real experience with mathematics. The book sharply distinguishes between mathematical symbols and concepts and criticizes teaching with symbols. Symbols—that is, numbers— ". . . are not *the concept* [emphasis in original], they are only a representation of the concept, and as such are abstractions describing something which is not visible to the child. Real materials, on the other hand, can be manipulated to illustrate the concept concretely, and can be experienced visually by the child. . . . The emphasis throughout this book is making concepts, rather than numerical symbols, meaningful" (Baratta-Lorton, 1976: xiv).

Math Their Way fairly oozes with the belief that physical representations are much more real than symbolic ones. This idea is a recent mathematical mutation of the idea, at least as old as Rousseau, Pestalozzi, and James Fenimore Cooper, that experience is a better teacher than books. For experience is vivid, vital, and immediate, while books are all abstract ideas and dead formulations. *Math Their Way* also claims that concrete materials are developmentally desirable for young children. Numbers are referred to many times as an "adult" way of approaching math. That idea leads to another, still more important: If math is taught properly, it will be easy. Activities with concrete materials, the book insists, are the natural way for kids to learn math: ". . . if this foundation is firmly laid, dealing with abstract numbers will be effortless" (Baratta-Lorton, 1976: 176).

Stated so baldly, that seems a phenomenal claim. Simply beginning with the proper activities and materials ensures that math will be understood well and easily. But the idea is quite common. Pestalozzi might have cheered it. Many other pedagogical Romantics, Rousseau and Dewey among them, embraced a version of this view. Piaget is commonly thought to have endorsed a similar idea. So when *Math Their Way* argues that the key to teaching math for understanding is to get children to use the right sorts of activities and materials, it is in one of the main lines of modern educational thought and practice.

The book's claim also helps to explain why it gives so little attention to the explanation of mathematical ideas. For the author seems convinced that it is superfluous.

Appropriate materials and activities alone will do the trick. Students will "understand" math without any need to question or explain mathematical ideas. This made *Math Their Way* an appealing package, for it enabled Mrs. O to whole-heartedly embrace teaching math for understanding, without considering or reconsidering mathematics. She was keen that children should understand math and worked hard at helping them. But she placed nearly the entire weight of this effort on concrete materials and activities. Her use of the materials, insisting that all the children actually feel them and perform the same prescribed physical operations with them, suggests that she endowed them with enormous, even magical, instructional powers. The lack of any other ways of making sense of mathematics in her lessons was no oversight. With *Math Their Way,* she simply saw no need for anything else.

In what sense was Mrs. O teaching for understanding? The question opens up a great puzzle. Her classes exuded traditional conceptions of mathematical knowledge and were organized as though explanation and discussion were irrelevant to mathematics. But she had changed her math teaching quite dramatically. She now used a new curriculum specifically designed to promote students' understanding of mathematics, as opposed to simple memorization. And her students worked with materials that represented mathematical relationships in the concrete ways that the Framework and many other authorities endorse.

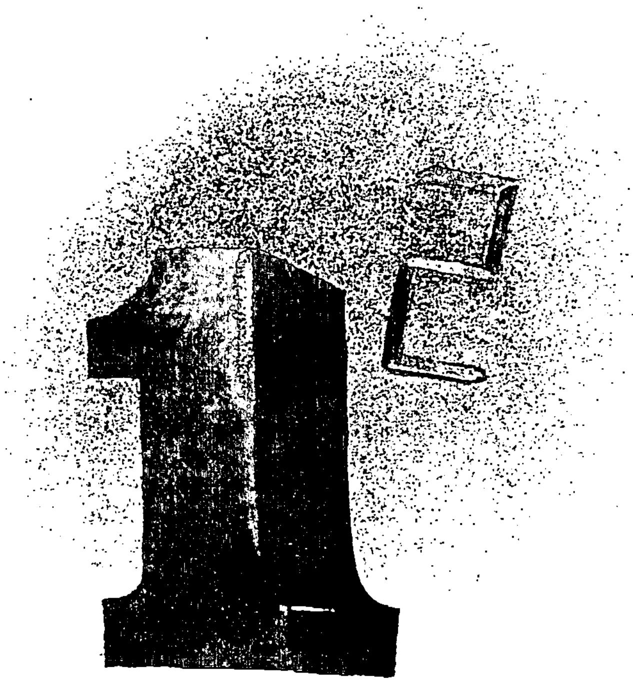
New Topics and Old Knowledge

The puzzle was apparent in other features of Mrs. O's teaching. For instance, she taught several topics that would not have been covered in many traditional math classes, among them estimation. She told me that estimation is important because it helps students to make sense of numbers by making educated guesses and figuring out why some guesses are better than others. She reported that she dealt with estimation recurrently in her second-grade classwork, for it could not be learned by doing it once or twice, and is useful in many different problem-solving situations. Her reasoning on this matter seemed to accord with the Framework's call for "guessing and checking the result" as an important element in mathematical problem solving (CSDE, 1985, p. 14).

But the teaching that I observed did not entirely realize these ambitions. In one lesson, Mrs. O asked the class to estimate how many large paper clips would be required to span one edge of her desk. Two students were enlisted to stand near the desk and hold up the clips. They were near enough to visually gauge its width in relation to the clips, but all the other students remained at their tables, scattered around the room. None had any clips, and few could see the edge of the teacher's desk that was in question, for it was a side edge, away from most of the class. Seated at the back with many of the kids, I could see that they were the large sort of clip, but even then they were barely visible.

So only two members of the class had real contact with the two key data sources in the problem—visible, palpable clips and a clear view of the desk edge. Hence only two members of the class had any solid basis for deciding if their estimates were mathematically reasonable. Even Mrs. O was seated too far away to see the edge well.

Her use of the materials, insisting that all the children actually feel them and perform the same prescribed physical operations with them, suggests that she endowed them with enormous, even magical, instructional powers.



The problem was sensible and could have been an opportunity to make and discuss estimates of a real puzzle. But it was set up in a way that frustrated mathematical sense making.

Mrs. O did not seem aware of this. She asked the students to estimate how many clips it would take to cover the edge and to write down their answers. Then she took estimates from most of the class, wrote them on the board, and asked class members if the estimates were "reasonable." Not surprisingly, many of the answers lacked mathematical discrimination. Estimates that were close to three times the actual answer, or one-third of it, were accepted by the class and the teacher as "reasonable." Indeed, no answers were rejected as unreasonable, even though quite a few were far from the mark. Nor were some estimates distinguished as more or less reasonable than others. Mrs. O did ask the class what "reasonable" meant, and one boy offered an appropriate answer, suggesting that the class had some previous contact with this idea.

I could see nothing that led inexorably to this treatment. Mrs. O had many clips. If eight or ten had been passed around, the kids would have had at least a bit of direct access to one element in the estimation problem. She also could have pointed to the desk edge that the class could see, rather than the far edge that was obscured from their view. Alternatively, she could have invited them to estimate the length of their own desk edges, which were all the same standard-issue models. Either or both would have given them much more direct contact with the elements of the problem and more of a basis to consider how reasonable their estimates were.

Why did Mrs. O not set the problem up in one of these ways? In an interview after the class, she displayed no sense that anything had been wrong, in response to my queries. She seemed to understand the broad purpose of teaching and learning estimation, but she taught as though she lacked the mathematical and pedagogical infrastructure—the knowledge of mathematics, and of teaching and learning mathematics—that would have helped her to set the problem up so that the crucial mathematical data were available to students. And despite her earlier comments, Mrs. O presented estimation as a topic in its own right rather than as a part of solving problems that came up in the course of studying mathematics. It was as though she thought that estimation bore no intimate relation to solving the ordinary run of mathematical problems. In contrast, the Framework argued that "... estimation activities should be presented not as separate lessons but as a step to be used in all computational activities" (CSDE, 1985, p.4).

I wondered what students made of this. They appeared to accept the lesson as reasonable. No one complained about the lack of comprehensible data, which they might have done if they were used to such data. No one said that they had done it differently some other time and that this didn't make sense. That could mean that the other lessons on estimation conveyed a similar impression, or it could mean that students were doing as they had been told because they had so often been told to do so, or because they had a visitor. Or it may mean only that students took nothing from the lesson. Schools present many mystifying examples of adult behavior that children learn to simply accept, and this may have been such a case.

Was this teaching math for understanding? From one angle, it was. Mrs. O taught a novel and important topic, specifically intended to promote students' sense-making in arithmetic. It may have done that. But from another angle it was not. For the problem was framed so that many students could not bring mathematical evidence to bear on it and had little basis for making reasonable estimates. These alternatives are not mutually exclusive. This bit of teaching could have promoted more understanding of mathematics along with more misunderstanding.

New Organization and Old Discourse

Mrs. O's class was organized to promote "cooperative learning." The students' desks and tables were gathered in groups of four and five so that they could easily work together. Each group had a leader to help with various chores, and instructional materials often were managed by groups rather than individually. The new Framework approved: "To internalize concepts and apply them to new situations, students must interact with materials, express their thoughts, and discuss alternative approaches and explanations. Often, these activities can be accomplished well in groups of four students" (CSDE, 1985, p.16).

Hence cooperative learning groups are seen as vehicles for a new sort of instructional discourse, in which students would do much more of the teaching. Students would learn from their own efforts to articulate and explain ideas, and they would learn from their mates' ideas. The Framework explains: "Students have more chances to speak in a small group than in a class discussion; and in that setting, some students are more comfortable speculating, questioning, and explaining concepts in order to clarify their thinking" (CSDE, 1985, pp. 16-17). Mrs. O's class was spatially and socially organized for such learning, but the class was conducted in a highly structured and classically teacher-centered fashion. The exchanges were either between the teacher and one student or choral responses to the teacher's questions. No student ever spoke to another about mathematical ideas, as part of the public discourse of the classes that I observed. Nor was such conversation ever encouraged by the teacher. Indeed, Mrs. O specifically discouraged students from speaking with each other in her efforts to keep the class orderly and quiet.

Still, the small groups were used for some instructional purposes. In one class that I observed, Mrs. O announced a "graphing activity" about mid-way through the math period. She wrote across the chalk board, at the front of the room, "Letter to Santa?" Underneath she wrote "Yes" and "No." Then she told the children that she would call on them by groups to answer the question. If she had been following the Framework's injunctions, she might have asked each group to tally its answers to the question, asked each group to figure out whether it had more "yes" than "no" answers, or the reverse, and asked each group to figure out how many more. Then she might have had each group contribute its totals to the chart at the front of the room. This would not have been the most challenging group activity, but it would have meaningfully used the small groups as agents for working on this

(Continued on page 44)

(Continued from page 23)

bit of mathematics.

But Mrs. O used the groups only to call on individual children. She asked individuals from each group to come to the front and put their entry under the "Yes" or "No" column, exhausting one group before going on to the next. The groups were used in a socially meaningful way, but there was no mathematical discourse within them.

Was this teaching for understanding? Mrs. O did use a new form of classroom organization that was designed to promote collaborative work and broader discourse about academic work. She did employ the small groups consistently during my visits. The children seemed quite familiar with procedures and worked easily in this organization. She also used the groups to distribute and collect instructional materials and to dismiss the class for lunch and recess (she let the quietest and tidiest group go first). Moreover, she referred to her classwork as "cooperative learning" and used the organization for some regular features of classroom work. When I mentally compared her class with others I had observed in which students sat in rows and in which there was only whole group or individual work, her class seemed really different. But she filled the new social organization with old discourse processes that effectively frustrated the sort of cooperative learning that the Framework's authors had envisioned. I asked if she ever used the groups for discussions and that sort of thing; she said that mostly she worked in the ways I had observed.

REPRISE

I have emphasized certain tensions within Mrs. O's classes, but these came into view partly because I crouched in her class with one eye on the Framework. Other observers might not have noticed them, for Mrs. O's lessons went quite smoothly. She and her students were well used to each other, and the contrary elements of instruction that I have highlighted did not jar the class. On the contrary, students and teacher acted as though these lessons made perfect sense. Features of instruction that seemed at odds analytically appeared to co-exist nicely in practice.

One reason for this lay in the classroom discourse. Mrs. O never invited or permitted broad participation in mathematical discussion. She held most exchanges within a recitation format; she initiated nearly every interaction, and the students responded. They complied. After all, most second graders want to please their teacher, and compliance is easier than initiation. In consequence, the discourse was very familiar to members of the class, almost ritually so. The calendar exercises that I observed were so familiar that students often gave the answers before she asked the questions. Most of the class participated, but they did so on a narrow track in which she maintained control of direction, content, and pace.

In contrast, the Framework argued that children need to express and discuss their ideas in order to understand the material on which they are working (CSDE, 1985, pp. 14, 16). But the discourse in Mrs. O's class discouraged students from reflecting on mathematical ideas or from sharing their puzzles with the class. Attention was focused instead on successfully managing a highly structured set of activities. This restricted even the questions and ideas that could occur to students, for thought is created, not merely expressed, in social interactions. Mrs. O employed a curriculum that sought to teach math for understanding, but she kept evidence about what students understood from entering the classroom discourse. The discourse remained smooth partly because so much possible roughness was choked off at the source.

Another reason for the lesson's smoothness lay in Mrs. O's knowledge of mathematics. Though she plainly wanted her students to understand this subject, she did not know mathematics deeply or extensively. She had taken one or two courses in college, and reported that she had liked them; but she had not pursued the subject further. Moreover, Mrs. O knew mathematics as a fixed body of truths, rather than as a particular way of framing and solving problems. Questioning, argument, and explanation seemed quite foreign to her. She worked hard to make the fixed truths accessible to her students,

Mathematically she was on thin ice.

using a new curriculum that promised to embody mathematical ideas and operations in concrete materials and physical activities. This struck her (and many other teachers today) as a great improvement on words and sheets of numbers. But neither Mrs. O nor *Math Their Way* saw mathematics as a source of puzzles, as a terrain for argument, or as a subject in which questioning and explanation were key elements of learning—all ideas that are plainly featured in the Framework (CSDE, 1985, pp.13-14). Lacking a sense of importance of explanation in mathematics, she simply slipped over many opportunities to elicit it, unaware that they existed. Because her conception of mathematical understanding was so limited, she could "teach for understanding," with little sense of how much remained to be understood, how much might be incompletely or naively understood, and how much might still remain to be taught. Working as she did near the surface of the subject, many elements of understanding and many pedagogical possibilities remained invisible. Mathematically she was on thin ice. But she did not know it and so skated smoothly on with great confidence.

In a sense, then, the tensions that I observed were not there. Though real enough in my view, they did not enter the public arena of the class. For they were kept hidden by the nature of the class itself. Mrs. O's modest grasp of mathematics, her limited conception of mathematical understanding, and her close management of classroom discourse simply obliterated many potential sources of roughness in the lessons. Had Mrs. O known more math and constructed a somewhat more open discourse, her class would not have run so smoothly. Some of the tensions that I noticed would have become audible and visible. Things would have been rougher, potentially more fruitful, and vastly more difficult.

PRACTICE AND PROGRESS

Is Mrs. O's mathematical revolution a sign of progress or confusion? Does it signal an advance or a setback for the latest new math? It probably is unwise to sharply distinguish progress from confusion when considering such deep change in instruction as reformers press today. For the teachers and students who try to carry out such change cannot simply shed their old ideas and practices like a shabby coat and slip on something new. Inherited ideas and practices are all that teachers and students know, even as they begin to know something else. As they reach out toward a new instruction, they do so with their old instructional practices. Their past is their only path to the future. Mixed practice and confusion, therefore, seem essential to progress.

This point often goes unnoticed by those in the throes of change, as well as by those who promote it. The changes in Mrs. O's teaching that seemed paradoxical to me seemed revolutionary to her, and I do not think she was deluded. She saw certain crucial limits of her early emphasis on computation and memorization and was convinced that her classes have greatly improved. She contended that her students now understood and learned much more math than their predecessors had a few years ago. She even asserts that this has been reflected in their achievement test scores. I have no direct evidence of these claims. But when I mentally compared this class with others that I have seen, in which instruction consisted only of rote exercises in manipulating numbers, her claims seemed entirely plausible. Many traditional teachers viewing her classes today would also think they were revolutionary.

But all revolutions preserve large elements of the old order as they invent new ones, if only because everything cannot change at once. One continuing element in Mrs. O's practice was a conception of mathematics as a fixed body of knowledge. Another was a view of learning mathematics as getting the right answers. She said that math had not been a favorite subject in school and that she had only learned to do well at it in college. When I asked her how that had happened, she said, ". . . I found that if I just didn't ask so many 'why's' about things that it all started fitting into place. . . ." Mrs. O learned to do well at math by avoiding exactly the sort of questions that the Framework associates with understanding mathematics. She noted that her view of math has not changed since college.

Another persistent element in her practice was "clinical teaching," that is, the California version of Madeline Hunter's Instructional Theory Into Practice (ITIP). This approach stresses the importance of structure in lessons and is associated with a rigid, sonata-form pedagogy, close teacher control, brisk pacing, and highly structured recitations. ITIP appears to have played an important part in Mrs. O's own education as a teacher, and she has been encouraged to persist with it. Both her principal and assistant principal at the time were devotees of Hunter's method and vigorously promoted it in the school. I asked all three of them whether clinical teaching worked well with the Framework. None saw any inconsistency, saying emphatically that the two innovations were "complementary." Yet as ITIP was realized in Mrs. O's class, it cut across the grain of the Framework. For she took clinical teaching as a license to rigidly limit discourse, to closely control social interaction, to focus the classroom on herself, and to hold instruction to relatively simple objectives.

Is Mrs. O's mathematical revolution a sign of progress or confusion?

If Mrs. O's past affected the changes in her practice, it also affected how she saw them. In the spring of 1989, I asked where her math teaching stood. She thought that her revolution was over. Her teaching had changed definitively: She had arrived at the other shore. In response to further queries, Mrs. O evinced no sense that there were areas in her math teaching that needed improvement. Nor did she seem to want guidance about how well she was doing or how far she had come.

There is an arresting contrast here. From an observer's perspective, especially one who had the new Framework in mind, Mrs. O looked like a teacher in transition. On this view, she might be imagined near the beginning of growth toward new math teaching. But the matter looked quite different to Mrs. O, who considered things in light of her past work. She saw herself as a teacher who had made a great transition and mastered a new practice.

Which perspective is most appropriate—Mrs. O's or the hypothetical observer's? This is a terrific puzzle. One wants to honor this teacher, who has made a serious and sincere effort to change, and who has changed. But one also wants to honor efforts to achieve greater intelligence and humanity in mathematics instruction.

We might begin by noticing that Mrs. O had only one perspective available. No one had asked how she saw her math teaching, in light of the Framework, nor had she been offered opportunities to view other sorts of teaching. If no one in California education had seen fit to ask her the question and help her to figure out answers, could we expect her to have asked and answered it all alone?

If math teaching is half as deficient as reformers say, then few teachers would know enough to raise many fruitful questions about their practice. Mrs. O's own lessons quite effectively protected her from experiences that might have provoked such questions. But even if such questions were somehow raised for Mrs. O and other teachers, would they know enough to frame appropriate answers? How could teachers be expected to assess their own progress in inventing a new sort of instruction if their teaching is half as dismal as reformers suggest?

One can imagine arrangements that would help teachers to learn more about math teaching and how to think about it. But California's budget for professional development is painfully modest just now. Lacking such assistance, could teachers assess their progress as though they had access to thoughtful commentary, when in fact most had none?

Even if Mrs. O had had such assistance, she would still have had to build on her past practices as she changed, like any practitioner. Hence her view of how much she had accomplished would be tied to her subjective experience of change. Teachers whose practice is very traditional would most likely think that their first steps—that would seem small to an observer—were quite large. For from a perspective still rooted mostly in a traditional practice, such modest changes would be immense. Such teachers might come to regard them as small only if they

From this perspective, Mrs. O's progress seems remarkable.

took some larger steps later on and consequently gained a different perspective. Of course, we might expect more from teachers who had a good deal of help in thinking about teaching in some active discourse about their work, in which questions were asked and answered from a variety of perspectives. For those teachers would have more resources for change, unlike colleagues who had been left to figure things out for themselves.

What would it take to make such assistance available to teachers? And to help teachers pay constructive attention to it? Neither query has been given much attention, either in efforts to change instruction or in efforts to understand such change. But without such help, it is difficult to imagine how Mrs. O and many other teachers could make the changes that reformers now invite.

POLICY AND PRACTICE

Mrs. O's math classes suggest a paradox. On the one hand, policy is the key to changing practice. For new instructional policies illuminate deficiencies in teaching and learning and provide impetus for change. From this perspective, teachers are the problem, for it is their mechanical and modest knowledge of mathematics that impedes progress. But teachers also are the chief agents of any new instruction, because few students will learn a new mathematics unless teachers teach it. The new policy seeks great changes in knowledge, learning, and teaching, yet these are intimately held human constructions. They cannot be changed unless the people who know, teach, and learn want to change, take an active part in changing, and have the resources to change.

How can practice be improved if the chief change agents are also are the problem to be corrected? This puzzle is worth noticing partly because so much instructional policy making seems to ignore it. Many policies that seek fundamental instructional reform look as though their authors believed that students and teachers would change if they simply were told to do so. New goals are articulated, and exhortations to pursue them are issued. Sometimes new materials are provided. Another reason to notice the paradox is that the instructional changes reformers seek are immense. If the recent reforms are to succeed, students and teachers must not simply absorb a new "body" of knowledge. Rather, they must acquire a new way of thinking about knowledge and a new practice of acquiring it. They must cultivate strategies of problem solving that seem to be quite unusual among adult Americans. They must learn to treat knowledge as something they construct, test, and explore, rather than as something they absorb and accumulate. Additionally, and in order to do all of the above, they must un-learn much of what they know, whether they are second graders or veteran teachers. Their extant knowledge may be naive, but it often works. A few can learn these things easily, and some even seem to pick it up on their own. But many very able learners have great difficulty, and so prefer the traditional sorts of learning that reformers reject.

Learning a new mathematics is much more formidable for teachers than students, for they must learn how to teach anew while relearning what to teach. And they must un-learn the mathematics and teaching practices that they have used for decades.

Mrs. O was not taught about the new Framework in a way that recognized these difficulties. Instead, the California state education department taught her about the new math using roughly the same traditional pedagogy that it criticized in the Framework. Like students in many traditional math classrooms, she was told to do something. She was told that it was important. And a synopsis of what she was to learn was provided in a text. The state advanced an instructional revolution, but it used an old pedagogy to do so. If, as the Framework argues, it is implausible to expect students to understand math simply from telling it to them, why is it any less implausible to expect changes in teaching to result simply from telling teachers to change? From this perspective, Mrs. O's progress seems remarkable.

What more might it take to support major instructional change? It is no answer to the question, but I note that few people in Mrs. O's vicinity seemed to be asking that question, let alone taking action based on some answers.

This is no argument against the changes that reformers press. The revised California Mathematics Framework offers a bold and ambitious vision of mathematics instruction, one that took imagination to devise and courage to pursue. Yet this admirable initiative has done little to augment teachers' capacities to realize the vision. The new Framework, for instance, had barely been announced in her school. She knew that it existed but was not sure that she ever had read it. She knew that the principal had a copy and that the new text series had been written in light of the Framework. She had attended a publisher's workshop on the new text and found it informative. She also had studied the text and the teacher's guide. But like many teachers in her district, she used the new book only a little, preferring *Math Their Way.* The state education department also supported a network of teacher development projects, mostly in universities, that offered math workshops for teachers. But there are only a handful of these projects compared with the tens of thousands of teachers in California, and most workshop sessions are brief. A few project staffers follow teachers back into school and offer support for change, but most do not. To the extent that there was support or guidance for change in Mrs. O's practice, it was local, but there was precious little of that.

Hence the changes in Mrs. O's practice were at best weakly guided and supported by the new policy. From one angle, this seems admirable. Mrs. O has had considerable discretion to change her teaching, and she has done so in ways that seem well adapted to her school. Though I call attention to the mixed quality of her teaching, her superiors celebrate her work. But if we take seriously reformers' arguments about the importance of mathematics and the need for a new mathematical pedagogy, then Mrs. O's situation is troublesome. When I observed what I report here, there seemed little chance that she would be helped to struggle through to a more complex knowledge of mathematics and a more complex practice of teaching mathematics. And if she cannot struggle through, how can she better help her students to do so? The recent reform movement has vastly expanded Mrs. O's obligations in teaching mathematics, without much increasing her resources for meeting those obligations. Ambitions for reform have continued to escalate as state and local budgets contract.

That collision between ambitions and resources may turn out to be crippling. Researchers and other commentators on education have begun to appreciate how difficult it is for many students to achieve deep understanding of a subject. This appreciation is at least occasionally evident in the rhetoric of reform. But so far, there is little appreciation of how difficult and costly it will be for teachers to learn new practices in which students are competently guided toward deeper understanding. □

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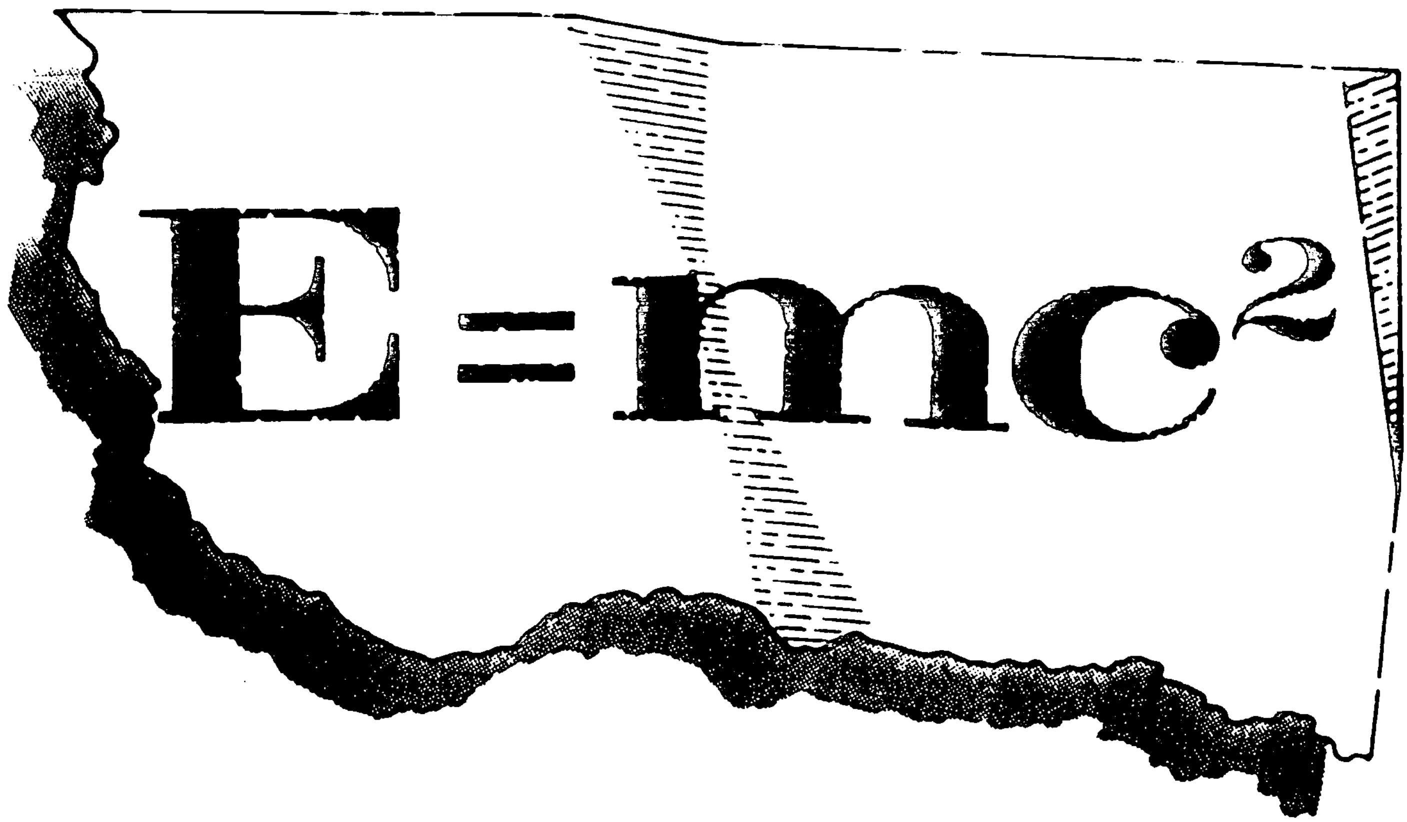
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Instructional Technology

While middle-level schools continue to acquire microcomputers and similar technologies, research indicates that teachers make little use of the equipment to enhance their instruction. Typically, science students spend fewer than 15 minutes per week working with computers. Over 85 percent of students in middle-level schools never use computers. Moreover, research indicates a need to study ways to improve education in science through information technologies (Bybee and Ellis, 1989; Weiss, 1987; Educational Technology Center, 1988; Cawelti, 1988; Alexander and McEwin, 1989; Mullis and Jenkins, 1988).

Technology pervades the students' world, and can be used selectively to enhance the learning process. There are several functions of technology for instruction in the classroom, including the use of computers for organization, presentations, simulations, and data collection. Computer technology also can help the teacher to simplify grade books, to produce posters and banners, to provide access to word processing, and to deal with other classroom management problems. Middle-level schools need to budget for the use of technology in the classroom. First, staff development must be paid for. Second, someone must keep track of the hardware and software, as well as evaluate new products and recommend purchases. Third, the cost of hardware repairs and service contracts must be budgeted for.

Most middle-level schools have technologies consisting of chalkboards, overhead projectors, movie and slide projectors, and televisions. While taking these technologies into account, the proposed framework should accommodate the newer technologies, such as computers, video/VCR, and camcorders. In addition, the curriculum should be ready to incorporate the newest technologies, such as hypermedia references, interactive video, and microcomputer-based laboratories (MBL).

Bybee and Ellis (1989) have outlined recommendations for the appropriate use of information technologies in elementary science programs that are also appropriate for middle-level schools. The recommendations are divided into two categories: microcomputer courseware and video courseware.

Microcomputer Courseware

There are several types of courseware, depending upon its instructional purpose. Below are descriptions of the major types.

Information Processing. Here, students use the microcomputer to enter, store, revise, and print hard copy of text. An information processor should have the extended abilities to process and present both tabular, graphics, and audio information; to insert figures, charts, pictures, graphs, text, and audio into a computer program; and to accept text, data, graphics, and audio from other utilities (for example, scanner, video disc, and microcomputer-based laboratories). The information processor should include the functions typically found in spreadsheet, database, statistical analysis, and graphing programs.

Hypermedia. The recent development of Apple's HyperCard™ and IBM's LinkWay™ provides students with the opportunity to seek and obtain information on numerous and varied topics. In the future, HyperCard and LinkWay could easily replace textbooks as sources of information (both print and visual) in the middle-level classroom.

Microcomputer-Based Laboratory (MBL). With an MBL, students can use the microcomputer to gather, store, display, manipulate, and analyze data. MBL software and hardware packages will process data collected through probes and sensors. The students can measure temperature, sound, light, pressure, distance, resistance, voltage, heart rate, blood pressure, and electro-dermal activity. The microcomputer can store and display all data the students gather from the probes and sensors. Data gathered by the MBL package can control the operation of the system modelers, interactive videodisc, and simulation packages described below.

Telecommunications. This involves transferring information from one site to another using microcomputers linked via cables, telephone lines, satellite communication systems, or a combination of the three. The telecommunications package should enable students to search large databases and information networks (for example, CompuServe) and to share information about their own investigations (for example, National Geographic Kids Network). By participating in the social enterprise of science, students can enhance their understanding of the collaborative nature of science.

Systems Modeler. A systems modeler should be available to enable students and teachers to express their ideas about how systems work. The user can construct a structural diagram of the components of a single system and define the interrelationships among the components. System modelers can teach cause-and-effect relationships and the systems approach in modeling such phenomena as food webs, population growth, digestion, sexually transmitted diseases, and soil erosion. In some cases, the systems modelers will present students with a simulation of a system and its model. The students can then manipulate the inputs and explore the relationships among the components of the system.

Simulations. Microcomputer courseware should also include simulations for imitating imaginary or real phenomena. The students have opportunities to provide input, perhaps from a list of options, or to manipulate objects that the program graphically represents on the screen. The input requested of the student simulates the activities that scientists do and actively involves the students in learning science.

Tutorials. An intelligent tutor should be a component of the information processors, microcomputer-based laboratories, telecommunications package, system modelers, and simulations packages. An effective tutor can engage the student in learning activities by asking questions, giving directions, providing clues, and giving feedback.

Programming and practice represent two additional uses of the microcomputer in the classroom. Not all school districts will choose to acquaint middle-level students with a computer language, but when it is offered, LOGO, or a similar language, should be used. Drill-and-practice computer programs should be part of an overall instructional package.

Video Courseware

A technology-oriented classroom can include three types of video presentations: sequential, archival, and interactive. Sequential video can present motion segments, still frames, and time lapse segments to engage the students and dynamically present new information.

Interactive video gives the students the chance to explore concepts in depth and to control the learning experience. The students can use two kinds of interactive video — an archive of still and motion frames and an interactive package that uses motion and still images. With the archive video, the student is in control and can explore the collection of images while seeking to understand a topic. With interactive instruction, an intelligent tutor guides the student through a series of interactions with the video program. The video segments are stored on laser-read discs, such as videodiscs and compact discs, so that retrieval of information is easy and efficient. A microcomputer controls the presentation.

Much work has yet to be done on the appropriate use of technologies for instruction, but we are already learning much about their promise. A long-term study of the use of new technologies to enhance student understanding is underway at the Educational Technology Center (ETC) of the Harvard Graduate School of Education. The group's Weight/Density and Heat/Temperature projects use a hybrid of direct instruction and episodes of inquiry to explore the use of computer-implemented interactive models that help students achieve conceptual change in science. Preliminary findings indicate that the approach helps students advance their conceptual model of weight and density. The ETC's Nature of Science Project, which uses software that includes multiple visual representations, has been successful in increasing ratio and proportional reasoning in upper elementary students who failed with more traditional methods (Educational Technology Center, 1988).

Facilities and Equipment

To teach science and technology in the middle-level classroom requires plenty of space, tables or desks with ample surface area, running water, and electrical outlets. When these things are not in the classroom, teachers need to make the most of the resources that are available within the school and community, including the physical plant, surrounding grounds, and human services.

A teacher who uses the proposed frameworks for curriculum and instruction will depend on a well-maintained facility. The availability and maintenance of equipment, media, and supplies should be adequate to support the program's requirements. Systems should exist to provide materials, collect and replenish materials for the next use, and offer assistance in getting unusual materials for interested students and teachers. The school should have allocations for a reasonable collection of science-related books in the school library.

Each classroom should allow for flexible seating arrangements. Within the school, there should be space that allows for display of science activities, storage of materials and unfinished projects, and interest centers on science topics under study (Pratt, 1981).

Outside the school, creative teachers can compensate for the lack of facilities and equipment. The concepts of the proposed framework can be applied to any setting; a teacher does not need a designated natural area near the school to teach change, diversity, or systems. In urban settings, the teacher may emphasize technology over the natural world to make the curriculum more relevant to the students' lives.

Communities have resources, such as people, museums, nature centers, zoos, industries, and farms. Middle-level teachers who use these resources must make an extra effort to make the experience meaningful, but the cooperation from community groups is usually obtained easily and the rewards for the students are substantial.

Instructional Materials

Science textbook series designed for the junior high school are the dominant instructional materials in middle-level schools. Textbooks focus on learning about science rather than encouraging active involvement by students. Subjects reflect the disciplines of life, earth, and physical sciences. Textbooks emphasize description, explanation, and identification, and generally neglect higher order processes, such as interpretation, evaluation, analysis, and synthesis (Blosser. 1986; Boyer, 1988; Jacobson, 1986; Weiss, 1978 and 1987).

The use of materials in the proposed program will encompass a variety of resources usually overlooked in middle-level science classrooms. The orientation of the program requires both reusable and consumable materials. Many of these materials will have multiple uses and benefits across the curriculum, including art, social studies, health, and other disciplines. The program will likely require some unusual materials. Students who are using the program will interact physically with instructional materials through handling, operating, or practicing: the materials will provide greater realism or concreteness (Holdzkom and Lutz, 1984). The program will help the teachers integrate manipulative and visual stimuli with printed matter.

The use of materials will require attention to classroom management, school and district-wide inventory, and financial support. The school budget should provide money for materials, equipment, and books in sufficient quantities to enable all students to have hands-on experience. Teachers should have access to petty cash funds to buy consumable materials. Also needed are funds for staff development in science, transportation costs for trips into the community, and resources for replacing science supplies on a regular basis. Schools should look to science centers and other regional resources to help promote student interaction with exhibits and laboratory experiences that cannot be duplicated in the classroom.

The creative use of both formal and informal instructional resources should be a part of the middle-level curriculum. Educational TV programs or films, for example, can be used as topic introductions, surveys, or motivating extensions.

Note: This piece was extracted from *Science and Technology Education for the Middle Years: Frameworks for Curriculum and Instruction*. Washington, D.C.: The National Center for Improving Science Education, 1990.

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Policy Making about Textbooks in the 1990s

No doubt, to many educators, textbooks seem an insignificant feature of the education enterprise and not one around which important policy issues arise. It is with textbooks, however, that American values, big market forces, and the dispersed powers of the education enterprise converge. In the past, Americans' beliefs that textbook purchases provided opportunities for the misuse of public funds and that what children read in school is what they will grow up believing have led to policy controversy. Policies intended to make the process of textbook selection free from graft and conflict of interest and subject to the influence by the majority culture yet sensitive to the impact of special interest groups from a broad spectrum of the American populace have resulted (Cody, 1990). It is not surprising, therefore, that many policy makers and most of the public will think of these areas of controversy when they think of textbooks—if they think of them at all. During the last decade, however, textbooks and the policies surrounding them have become the subject of new interest for several reasons, reasons very central to policy makers' efforts to improve schools.

First, in the late 1970s and 1980s, it become clear to many policy makers that the public's expectation for improved reading achievement was the new political reality. That reality created an interest in the findings of research which indicated that some reading achievement problems resided not with the reader, but with the material to be read. Scholars analyzed the factors about text that impact on readability and textbooks' ability to bring about learning: the instructional design, the style of writing, the use of illustration, the content, and so on (Cole and Sticht, 1981; Anderson, Osborn, and Tierney, 1984). Using these factors to study and evaluate textbooks, researchers found many books lacking, and a movement to improve the quality of textbooks used in classrooms took hold among farsighted policy makers (Cody, 1986).

Efforts to improve the books available for purchase must confront a complex market system and the loosely linked system by which books are selected. Publishers respond to market demands transmitted in large part by the selection process (Squire and Morgan, 1990). But since educators find it difficult to be cynical about the beautiful books presented and since the areas in which the new research-based stan-

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dards are important are difficult to evaluate, we often send the wrong messages to publishers. Time and expertise are often missing from the selection process; selectors often use proxies such as renowned authorship, recent copyright date, attractive presentation, easy-to-use manuals, and the like as indicators of quality. There are no shortcuts for choosing quality books, and when the best books presented are not chosen, we lessen the chance that books will improve. Publishers assure us that they will provide what the market demands; policy makers are challenged, therefore, to construct selection processes that will result in books that justify readers' efforts.

The second reason that policy makers must take another look at textbook policy has to do with efforts to tighten the linkage between what is taught and what is tested. This tenet of the effective schools movement leads many policy makers to look at the textbook as a mechanism important to the reform movement. The idea that the textbook is the de facto curriculum and the teacher's manual the major pedagogy gives encouragement to efforts to change books in order to change teaching.

Tightening the linkage has taken two forms. First, many school districts have created curriculum specifications for textbooks that are designed to ensure that books presented by publishers for consideration will cover the curriculum of the district. Increasingly, computer programs have permitted publishers to create correlation studies to demonstrate to selection committees on what pages specific curriculum objectives are covered. Such computer studies look important and bring much comfort to selectors, but instructional design is more complicated than such studies would indicate. No study can evaluate the quality of content on a topic or its appropriateness for teaching and learning.

Influential states that have used curriculum specifications to influence what is included in books have met with some success—sometimes improving the quality of books available to all districts; such efforts, however, are appropriate for only the most influential purchasers and their influence is not always positive. Correlation studies required by many jurisdictions throughout the country, however, have created new pressures on the editors of textbooks that often result in books designed to include everything and please everyone. No longer is it likely that a working educator or a professor can invest a lifetime of experience in writing a textbook; it is more likely that editors will develop an outline based on the curriculum specifications of important constituencies and hire a professional writer who can write with such a formula in mind. Since the books will be marketed throughout the country, there is pressure also to homogenize the books so they will meet as many guidelines as possible and satisfy teachers on the selection committees. High standards for content, quality of writing, and instructional design are difficult to maintain under such a formula (Tyson-Bernstein, 1988).

Using the textbook to tighten the linkages in decision making has also had its impact on teaching and teachers. The use of the textbook to bring about standardization of teaching takes several forms. Many school districts have advocated centralized decision making about what books will be used throughout the district. Such decisions are seen to have several advantages: negotiating with a single publisher increases the likelihood that an advantageous purchasing package can be worked out to include free materials and training programs; a single book used throughout the system permits students to move from school to school without "loosing their place"; and using a single book facilitates distribution of textbooks in times when school populations fluctuate. A single book also makes the instructional supervisor's job easier. Instructional leadership can concentrate not on the complexities of teaching, but on monitoring the efficient use of the materials. Some districts have gone so far down the standardization route as to prescribe what chapter a teacher should be on during any week during the year. Teachers, on the whole, have not complained. Some, feeling at risk, have welcomed clear directives about what and how they should teach.

The use of the textbook as the program of instruction has often meant that a criterion for the selection of the book often has been the ability of the weakest teacher to use the book and follow the manual. The teachers' manuals that accompany textbooks have differed from decade to decade (Woodward, 1986). In some periods of educational history, the manual has been a resource guide for teaching and has contained discussions of professional issues and research; in other periods, manuals have avoided challenging new ideas or even ideas at all and have been characterized by scripted questions for teachers to read for which acceptable answers are given. In recent decades, schools have experimented with the textbook-delivered "teacher proof" programs, and manuals have attempted to make teaching effortless and thoughtless. Current textbooks come in packages that include not only manuals, but materials and teaching aids that in better times teachers would have used their professional knowledge and creativity to prepare. Publishers have invested a great deal in the development of such programs, perhaps at the expense of the books themselves. To use such programs, the teacher becomes a technician, needing only to follow the directions; critic Michael Apple (1986) has described this trend as "deskilling" the teacher. It is tempting to believe that a district could adopt a textbook that would do all this—ensure the curriculum is taught, improve instruction, and so on. In the next decade, policy makers will have to address the issues, pro and con, of using textbook policy to standardize curriculum, teachers, and teaching.

A third movement is at work in the United States in the 1990s, and it speaks to a countermovement and teacher empowerment. Frustration with the lack of success with previous reform movements has brought many policy makers to a point wherein teacher professionalism and increased decision making at the school level seem promising as a reform strategy. They seek to bring to life professional prerogatives and to involve teachers in the reform of the schools in which they teach. In all jurisdictions, legislation and policy require that teachers dominate the textbook-selection process. In states that have a centralized process by which they create a list of approved books for purchase with state funds, teachers have the votes on the state committees as they do at the local level. In states that have no state level process, teachers also dominate the process, either as members of selection committees or as individuals when all-teacher vote is the selection process (California State Department of Education, 1984; Education Research Service, 1976).

A recent study of teacher decision making in the various states released by the Carnegie Foundation for the Advancement of Teaching found that of all the decisions made in schools, teachers feel the most involved in textbook selection. In the Gallup poll published in the June 1989 *Kappan*, when asked how much and in what areas teachers should have control in the educational process, sampled teachers responded that they should have control of "selecting textbooks to be used in class" at the level of 4.2 on a 5.0 scale. When asked "How much control teachers in your school actually have" on the selection process, teachers indicated 3.1. Clearly, in the minds of many teachers, selection of textbooks is an area of clear professional prerogative; they feel involved at present and would seem to want to be more involved. It is also clear that teachers are selecting the books now in use—the books so often found lacking.

The three movements—to improve the quality of books, to use textbooks to ensure that the curriculum is delivered, and to involve teachers in increased professional decision making—provide an interesting conundrum. Textbooks need to be improved. It is the belief of many scholars that requiring textbooks to deliver the curriculum—its content and its pedagogy—is having a detrimental effect on the quality of textbooks. It is a loosely linked system; the people who develop the specifications are not the people who select the books. Teachers select the textbooks and feel it is an important professional prerogative. It is also believed that increased professionalization of teachers and their involvement in choosing textbooks are not congruent with efforts to control teaching by the use of books, and it is clear that present less-than-adequate books that are designed to be selected by teacher committees do not merit the faith of administrators who cannot resist the efficiencies of standardization and centralization.

The new decade provides a challenge for policy makers. Policy makers in large jurisdictions must create mechanisms for designing specifications for school books that focus not on the shortcuts, but on the quality features of books. Policy makers in all jurisdictions must challenge publishers and convince them that textbooks must continue to improve to meet the highest standards research can provide us. Policy makers must design processes that can result in the selection of the best books, thereby encouraging publishers to market excellent books; policy makers must send the message to teacher selectors that they must not be distracted by the glitz of textbook programs, but must look long and hard for excellent content and instructional design that address the best pedagogy available. In addition and even more basic, it is this author's opinion that textbook policy is one area where policy makers should resist the temptation to use textbooks to centralize and standardize; decisions about how to use textbooks are best made by teachers—perhaps even at the school level. Centralization, as irresistible as its efficiencies may seem, has high risks and a negative impact on the quality of books available and on the quality of teachers and teaching. No doubt, policy makers have some important decisions to make as they think strategically about textbooks and school improvement in the 1990s.

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Mathematics Framework for California Public Schools

Kindergarten through Grade Twelve

Version of 20 August 1991

Introduction

The 1985 *Mathematics Framework for California Public Schools, K–12* established the goal of mathematical power for all students—the ability to discern mathematical relationships, reason logically, and use mathematical techniques effectively. Since 1985, a number of influential publications have affirmed and enhanced this goal; they include *Everybody Counts* (National Research Council, 1989), the *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics, 1989), *Reshaping School Mathematics* (National Research Council, 1990), the *Mathematics Model Curriculum Guide, Kindergarten Through Grade Eight* (California Department of Education, 1987), and the *Professional Standards for Teaching Mathematics* (National Council of Teachers of Mathematics, 1991). A number of multi-year projects for primary through graduate education have begun to address the challenges outlined in these documents.

As a result of national, state, and local initiatives, evidence of change is accumulating. In many schools throughout the country and in California, teachers emphasize problem solving, providing students with hands-on, highly interactive learning experiences. Students are not limited to learning arithmetic and algebra; they study all of the different strands of mathematics, including measurement, statistics, and logic. Computers and calculators are becoming common classroom tools. Innovations in student assessment—such as open-ended questions and portfolios—are finding their way into classroom, district, and state assessment programs. Reform in mathematics education has direction, coherence, and momentum.

It is also necessary. Under our current programs, too few young people leave school mathematically powerful. In order to address this problem, this Framework asks all of us to raise our expectations for ourselves and for our students, and to expand our vision of what can happen in a mathematics classroom and what can appear in mathematics instructional materials. *All* students are capable of the level of work described here; it will take time, hard work, and courage to make this vision a reality.

What's new in 1991?

The 1991 Framework reinforces the momentum toward reform. Building on its predecessor, this Framework elaborates the concepts and recommendations of 1985. It also draws these concepts into a comprehensive vision for mathematics education, one which serves the larger purposes of schooling: to equip students with the reasoning tools they need as good citizens; to prepare students for successful work lives; and to develop students' personal capacities to enjoy and appreciate mathematics.

Mathematical Power

"Mathematical power, which involves the ability to discern mathematical relationships, reason logically, and use mathematical techniques effectively, must be the central concern of mathematics education and must be the context in which skills are developed."

—*California Mathematics Framework*, 1985, p. 1[1]

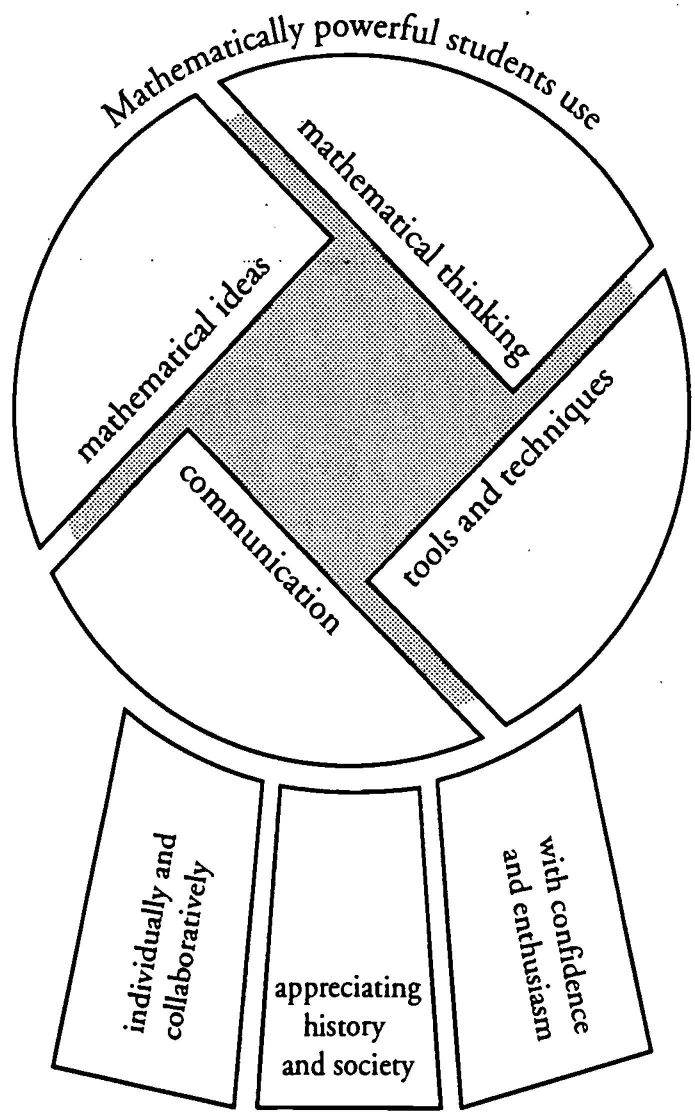
Echoing the 1985 Framework, this document reasserts the goal of mathematical power for all students, and emphasizes the phrase "for all students." Many of the recommendations here are motivated by a concern for equity: giving every student in California fair access to mathematics education.This includes females and males; rich, poor, and middle class; descendents from the old world, the new world, the third world; speakers of Mandarin, English, Arabic, Spanish, and each of the other more than 200 first languages of US citizens.

How do we recognize mathematical power? Part I describes it this way: **Mathematically powerful students think and communicate, drawing on mathematical ideas and using mathematical tools and techniques.**

[1] Complete citations for all quotations and other references appear in Appendix E, "References," page 132.

What do those words mean in this context?

- *Thinking* refers to intellectual activity. Thinking includes classifying, planning, comparing, investigating, designing, inferring and deducing, making hypotheses and mathematical models and testing them.[2]
- *Communication* refers to coherent expression of one's mathematical processes and results.
- *Ideas* refers to content: mathematical concepts such as addition, proportional relationships, geometry, counting, and limits.
- *Tools and techniques* extend from literal tools such as calculators and compasses—and their effective use—to figurative tools such as computational algorithms and making visual representations of data.



Mathematically powerful students use these four components—the dimensions of mathematical power—to do something meaningful for them. That is, *mathematically powerful work is purposeful.* This purpose need not be utilitarian; students may be motivated by curiosity or whimsy—as long as the purpose is theirs, not ours.

We have three additional expectations for students: that students work successfully both individually and with others; that they come to appreciate mathematics in history and society; and that they exhibit positive attitudes towards mathematics, working with confidence, persistence, and enthusiasm.

[2] The NCTM *Curriculum and Evaluation Standards* characterize thinking in three of the first four standards: *reasoning, problem solving,* and *making connections.*

Performance

But what about performance? How well do we expect students to learn mathematics? We expect student work to demonstrate mathematical power in all its dimensions. This is a broad demand; it requires us to create a program that supports the students without wavering in its insistence on good thinking, clear communication, proficiency with tools, and deep understanding of the mathematical content. Students must show that they can use mathematics to do something meaningful. The program's support includes clear standards and high expectations, adequate preparation for sophisticated work and time to work on it, a developing tradition of draft and revision, and, finally, tasks that are worthy of the kind of work that demonstrates mathematical power.

Large Pieces of Work

Creating assignments that encompass all the dimensions of mathematical power has two important implications. First, many assignments will have to be larger than those of the past. Students may have to work for days or weeks to complete them. Second, since the assignments will be so large, students will have to work on them outside of class time, once they are old enough. This document calls these larger projects *investigations*, which are a natural extension of the situational lessons called for in 1985.

That is not to say that exercises or smaller problems should be eliminated, or that we expect students to discover everything themselves. Teachers and curriculum developers are expected to use their creativity and experience to provide students a balanced diet of different types of work: short exercises, interesting problems, collaborative tasks, and larger, long-lasting projects. The program will also benefit from varied instructional modes: teachers will enable and facilitate as well as demonstrate and instruct. Achieving a balance requires that we move from exercises towards large projects and from direct instruction towards facilitating. Exercises will therefore be embedded in larger projects where possible, and instruction will more often help students learn specifically what they need to finish a large piece of work.

Completeness

Traditionally, students worked in only one dimension—with tools and techniques. Occasionally we evaluated students' thinking (how did she analyze this problem?) or ideas (how well does he understand sampling?) independent of right answers. And we almost never worried about clear communication beyond format and legibility.

Now, when a student successfully finishes a large-scale project that demonstrates all the dimensions of mathematical power, we will call it *complete* mathematical work. Grades might be based on complete work rather than on tasks (such as computational exercises and word problems) that, by their nature, do not demonstrate all of the dimensions.

The word "complete" is crucial because it implies not only the scope of the work but its mutability. If a student's work is not up to standards, it is simply incomplete. Students are expected to revise their work until it meets quality standards. This policy shows respect for students, rewards persistence, and eliminates early failures that convince so many that math is not for them.

Content

What will the mathematical content of this complete work be?

The 1985 Framework identified seven strands: number, measurement, geometry, patterns and functions, statistics and probability, logic, and algebra. This document endorses these strands and adds another: *discrete mathematics*.[3] Adding an eighth strand is part of the natural evolution of the mathematics curriculum. In addition, this document expands Logic to *Logic and Language*, acknowledging the importance of language in presenting mathematical ideas unambiguously; and changes *Patterns and Functions* to *Functions*, recognizing that patterns are part of every strand. (Patterns are promoted to an even more important role in the curriculum, discussed below under "unifying ideas.")

"The reader should bear in mind that the division into strands is somewhat arbitrary, that more or fewer strands could be named, and that the strands frequently overlap."

—*California Mathematics Framework*, 1985, p. 8

Strands help us evaluate whether the mathematical subject matter of a curriculum is broad enough and well-balanced at all grade levels. But by themselves they don't help us identify the most important ideas or plan the daily flow of the curriculum. This Framework provides guidance here through two additional ways to look at mathematical content: by *unifying idea* and by *domain*.

[3] This formidable title includes things teachers at all grade levels have been doing for years. The word "discrete" implies emphasis on separate (discrete) entities, rather than on measures of continuous quantities. At third grade, for example, we can ask how many ways Boris can dress if he has three shirts and two pairs of pants (six); at seventh grade, we can ask students to design a tournament. This is discrete mathematics. It includes topics such as combinatorial counting principles (how to count permutations and combinations for probability problems) and discrete structures (such as networks and trees).

A resource for teachers is *Discrete Mathematics in the Curriculum, K–12*—the NCTM Yearbook for 1991.

> [Proportional relationships play] a key role in many basic subjects often studied in middle school: ratio, rate, "per," percent quantities and per-unit quantities, proportional parts, slope, similarity, scale relationships, linear functions, and probability.... For example, in a sloped straight line, the "rise" is proportional; to the "run" and their ratio is the slope of the line; in a scale drawing, real distances are proportional to distances in the drawing; in a class of similar figures, any two lengths in one figure are in the same proportion as the corresponding two lengths in any other figure; when an event has a certain probability it means that, approximately, the event happens that proportion of the time; and so on.
>
> —this Framework, pp. 90–91

Unifying ideas focus understanding on a few very important and deep mathematical themes. They are present at all grade levels but have special relevance at a particular grade range. For example, *proportional relationships* is a unifying idea for the middle grades. Elementary students work with proportions, as do high schoolers. But it is at the middle grades when students will focus most intently on this as a mathematical principle that unifies a broad range of concepts and applications. Another unifying idea is *patterns*, which begin to play a role in the elementary grades, and whose role extends in middle school to include generalizations of many kinds.

> "...students should come to understand and appreciate mathematics as a coherent body of knowledge rather than a vast, perhaps bewildering, collection of isolated facts and rules."
>
> —NCTM, *Curriculum and Evaluation Standards for School Mathematics*, p. 91

Unifying ideas allow us to focus on mathematical themes that bridge many strands. *Proportional relationships*, for example, draw from virtually every strand: scale drawings from *measurement*; sampling from *statistics*; percent and ratios from *number*; linear relationships from *functions*; solution of proportions from *algebra*; and similarity from *geometry*. Unifying ideas bind the curriculum together through the year and give a focus to understanding.

Although both are essential perspectives on mathematical content, neither unifying ideas nor strands give enough guidance to help us design specific pieces of instruction. Unifying ideas are too general and abstract. Strands are incomplete if they appear one at a time; they are most effective when they interweave. So we need a third way of dividing up the content—one that serves as a guide for designing units of instruction. This third perspective looks at content in terms of mathematical *domains*.

You can read more about domains in Part I, p. 20 and in Part III p. 67.

Domains[4] are coherent aggregates of subject matter that serve as arenas for specific mathematical work at a particular grade level. For example, at the middle grades, student work might be organized around domains such as: *objects, shapes, and containers; maps and scale drawings; coordinate systems; growth;* and *similar figures*.

Domains typically incorporate more than one unifying idea as well as several strands. For example, *growth* bridges the unifying ideas of *proportional relationships* and of *patterns and generalization*. Some domains are more concrete and real-world—like *the mathematics of growth*—while others are more abstract—such as *coordinate systems*. Some domains support others by providing elements of mathematics other domains require; domains can also overlap. Instruction based on domains provides all students entry into mathematical ideas and places for them to use mathematics.

[4] This use of the word is unrelated to its use in formal functions, as in "domain and range."

Units

How will strands, unifying ideas, and domains appear in the program's instructional materials? In order to avoid breaking up large mathematical ideas into disconnected bits, and in order to make room for more opportunities for complete work, materials will be organized into large chunks called ***units***. Each unit integrates strands and develops unifying ideas—and is typically based on a domain.

While other countries have concept-sized lessons, often lasting weeks, the U.S. has lesson-sized concepts, lasting one day plus homework.

—adapted from McKnight, *The Underachieving Curriculum*, p. 89

Units will typically last from one to six weeks, depending on the mathematics content and on the age of the students. Units will have several opportunities (e.g. investigations) for students to produce complete mathematical work. In addition, materials for units will have exercises and smaller problems to give students different perspectives on the ideas contained in them as well as relevant practice. Work on units is not limited to exploring and investigating; teachers and students will naturally need to demonstrate straightforward mathematical tools, explain conventions and notation, and summarize. But the unit is coherent: its content and assignments relate to the domain; the direct instruction and demonstration support the large assignments; and the activities relate to one another through a common context or through well-designed summary lessons.

An example: suppose there were an eighth-grade unit on *Games of Chance* that focused on the mathematics of *fairness*. It would have classroom activities about probability, of course, and problems and experiments for students to do—individually and in groups, both in and outside of class. But there may be one or more larger, organizing projects in the unit. For example, students might invent, create, and write intelligible rules for a game and analyze its fairness using mathematical insight about chance. They would write about the mathematics behind their game and the ***mathematical*** reasons for choices they made in its design.

In producing the game and its accompanying literature, students would demonstrate all of the dimensions of mathematical power: their thinking (design, conjecture, analysis); their use of ideas (proportions in game probabilities); their use of tools and techniques (computation, simulation); and their ability to communicate (rules and justification). The unit itself is based on a domain (*the mathematics of fairness*); it develops several unifying ideas (*proportional relationships* and *multiple representations*); and it interweaves material from several strands (*number, logic and language,* and *statistics and probability*).

Assessment

"We must ensure that tests measure what is of value, not just what is easy to test. If we want students to investigate, explore, and discover, assessment must not measure just mimicry mathematics."

—National Research Council, *Everybody Counts*, p. 70

How can we tell whether student work demonstrates mathematical power?

A traditional test is a snapshot of a student's ability to recall facts or procedures. By itself, it gives only a limited picture of a student's mathematical power—usually focusing his or her mastery of mathematical tools and techniques and memory of facts rather than on mathematical thinking, understanding, and skill at communicating.[5]

We need new assessment tools that help us evaluate the powerful work we expect of students. Instructional materials aligned with this Framework and the NCTM *Curriculum and Evaluation Standards* should embed appropriate assessment materials and include examples of student work.

The reader can learn more about what the California Assessment Program has done and see examples of student work in *A Sampler of Mathematics Assessment*. Sacramento: California Department of Education, 1991.

But what do we mean by appropriate? There have been advances in mathematics education that let us see assessment alternatives. The California Assessment Program (CAP) has been changing from reliance on prestructured answers to performance assessment techniques including open-ended items and portfolio assessment. National tests are moving in the same direction. Teachers throughout California are having students present and write more; they are observing their students work in groups; they are learning to manage portfolios of student work. And they are finding that they know more about student thinking and understanding than ever before.

In general, mathematics assessment in the 1990s will be more formative, that is, focusing more on work in progress. We can also focus more on assessing large pieces of work than on smaller efforts. We can integrate assessment with instruction more effectively. We can raise standards and expectations, asking thoughtful questions that allow for thoughtful (and unexpected) responses. Students can become more involved in the assessment process; teachers and students alike can learn to evaluate work holistically using quality standards. Most important, we can learn to assess student work rather than the student, and focus on what students know rather than on what they don't. This shift of emphasis will free students from the stigmata of past failures and facilitate their taking responsibility for their own learning. All of these issues are elaborated in Part II, pages 53–56.

[5] The reason is not only that bubble-tests are one-dimensional and don't measure mathematical thinking. Their scores also fail to give students advice about what to do to improve their work. A score of 78% is easy to average, but hard to react to constructively. Far more useful is the concrete feedback of a peer or a teacher. Without that, the numerical score is as mysterious as it is demoralizing.

A Framework for Change

This Framework is not a blueprint for immediate implementation. It is a direction for change that allows many possible paths. There are a multitude of possibilities. We must make some of these possibilities real—and test them in real classrooms with students that represent the diversity of California's multicultural population.

This process has begun. In response to the NCTM *Curriculum and Evaluation Standards*, new materials—with integrated assessment and new instructional techniques—are being developed and tested in classrooms with diverse students across the country. Even so, the ideas in this Framework have not been implemented all together on a wide scale. Therefore, real change in schools is necessarily uncertain and expected to be uneven. As new courses evolve, they will become accessible to more students, supporting full development of all students' mathematical potential—the especially talented, the traditionally disenfranchised, and students that are both or neither. It will take time, resources, and problem solving to reinvent the curriculum to serve all students well.

The efficacy and acceptance of new programs will depend not only on the quality of the curriculum, but on a variety of other factors. Therefore, action needs to occur on many fronts. These elements are essential to a good start:

- knowledge and commitment at the local level;
- availability of appropriate instructional materials and supplies;
- external assessments consistent with instructional programs;
- cooperation among different parts of the educational system;
- teacher involvement in planning; and
- professional development for teachers.

Teachers and Change

Ultimately, it is teachers who will make new mathematics programs a reality in the classroom. As teachers, we have begun our part in thousands of classrooms across the state. Many of us use manipulatives and cooperative learning; we assign complex problems and maintain portfolios; we think about the mathematical power of all of our students; and we are changing the ways we and our students think about mathematics.

"...American teachers are overworked...The full realization of how little time American teachers have when they are not directly in charge of children became clear to us during a meeting in Beijing...Beijing teachers teach no more than three hours a day, unless the teacher is a homeroom teacher, in which case, the total is four hours...The situation is similar in Japan. According to our estimate, Japanese elementary school teachers are in charge of classes only 60 percent of the time they are at school."

—Stigler and Stevenson, "How Asian Teachers Polish Each Lesson to Perfection," p. 45

Any new program makes demands on teachers. This one asks us to look at mathematics in a new way and to redefine our role in the classroom. To make it work, we will need support; and one of the most important areas of support is in time:

- time to collaborate with peers: time to plan together, visit one another's classrooms, review student work, and make judgments about program strengths, weaknesses, and overall effectiveness;
- time to prepare for class and to plan program;
- time for continuing to learn mathematics;
- time to respond to student work;
- time to meet together with outside consultants who can raise important questions and guide the inquiry process;
- time for school planning and organizational meetings; and
- time to attend meetings and professional association conferences.

And the additional time provided for professional activities must be quality time. Time after school and unpaid Saturdays are not enough. Teachers will need at least ten days of extra professional time annually—preferably spread throughout the school year—to implement the programs described here, and to share our successes and disappointments. Emerging site leaders will need more.

But the needs go beyond time. Change of the scope presented here requires totally new instructional materials—products of the industry, imagination, and flexibility of materials developers, working in collaboration with practicing teachers. And students will need mathematical tools from blocks to computers available for doing their mathematical work.

New materials and equipment by themselves are not enough to address the long-term needs of students. Teachers are asking questions such as, "How do I develop a cohesive plan for what my students experience? How do I address the needs of all my students in a diverse classroom? How do I know that my students are developing mathematical power, and not just having fun?" No one can answer these questions alone; neither will mandating a workshop take care of the problems. We have to work together in an environment of continual, quality professional development.

Teachers may be expected to teach mathematics not yet invented when many of us were in school such as discrete mathematics or mathematics which we may not have studied such as statistics. Our solution to these difficulties will be a combination of upgrading adults' mathematical understanding and learning along with the students'. Part of a balanced program of staff development will include mathematics content, but we will also find that genuinely not knowing the answer—and modeling good questioning and learning behavior—gives students a clear message about process and about the value of thinking. The key is to recognize what we need to learn and to share our experiences with students.

Teachers also receive mixed messages. On the one hand, the Framework sets forth goals for mathematical power, while on the other, local testing mandates may continue to emphasize narrow skill attainment. We all know implicitly that what we test—in the eyes of Authority—is what is really important. Professional development may be directed toward implementing the Framework, but if teachers are held responsible for increasing test scores on low level skills, what will receive emphasis? Once teachers and administrators together agree on the goals of mathematical power—and clarify the differences between those goals and the traditional ones—we can work together to match external testing to the system's real goals for its students.

"Planning for authentic assessment can have a powerful influence on the education provided for students. Since 'what you test is what you get,' we must be sure our assessments set high standards."

—Stenmark, *Mathematics Assessment*, p.1

We send another mixed message when we ask teachers to be professional. On the one hand, we ask teachers to take responsibility for their own continuing education, and to take the time to do whatever is necessary to get the job done: to oversee the intellectual and social development of the next generation. On the other hand, we often isolate teachers in classrooms, give them little say in the organization of their daily lives, evaluate them on the basis of narrow, easily codified criteria, and subject them to salary scales that some say attract only the devoted and the desperate.

But the biggest challenge for us as teachers will be within ourselves. It will take courage for us to abandon our traditional roles as gatekeepers and sources of information and approval—and become the "chief questioners"—the facilitators and catalysts for the students. We reflect, experiment, and accept uncertainty as part of the new professional norms. It can be difficult to share doubts and confusions with colleagues. We may be tempted to lose patience or abandon hope. But this reform ultimately empowers teachers. Only through professional exploration and examination can we gain the experience and confidence necessary to implement the new programs and take the curriculum into our own hands.

Students and Change

Students are also members of the school community; they must change as well. Students, like their teachers, will learn to work in different ways and to play different roles. Like their teachers, they will need "staff" development in these new ways of working and studying. Enlisting students, their parents, and the community in the reform process can make the outcome—as well as the process—better for all.

In the programs called for in this Framework, we will ask students to do more work and to take more responsibility for organizing and revising their work outside of class. Although students will be working harder—and on tougher assignments—the assignments will be more accessible to students than those from traditional programs. Parents and community members can make a major contribution by supporting community understanding of what is happening in education and by finding ways of helping students, for example, by organizing places and times for students to work together outside of class.

Over the next decade, local, state, and national initiatives will likely impose higher and higher expectations on programs and students. Any new national assessment instruments will be based on the NCTM *Standards;* California efforts will be based on this Framework, which extends the national document. These new efforts will increasingly involve assessing student work on projects from regular instruction, portfolios, and open-ended responses rather than multiple-choice items and micro-tasks. To be ready, California students need to develop—and we all need to nurture—a mathematical work ethic that requires self-discipline and working to meet a high-quality standard.

Change Takes Time

While we might want immediate and rapid change, a uniform timeline would be counterproductive. As much as we want students now in school to benefit from the new programs, we should be careful not to move too fast and alienate critical supporters. In every school, we must all understand the need for change, adopt a carefully planned course of action, and let ourselves experiment and take risks in the classroom. Only then can positive change take root—to the benefit of California's children.

This Framework is not the last word; it is only the next word. It is time to leave the old ways behind, even though we cannot be certain what lies ahead.This Framework asks of all of us—teachers, parents, administrators, materials developers, and students—the courage to look in the mirror, and the courage to change what we see.

☐ "Saturday Scholars" pairs local science experts with talented teenagers

Talented juniors and seniors climb out of bed early on Saturdays and go back to school in Charleston, South Carolina. The Saturday Scholars program, headed by Karen M. Kendo, science supervisor of the Charleston County School District, brings lecturers from the medical college staff, other colleges, and the scientific community, and pairs them with high schoolers chosen by their teachers. In operation for four years now, the program also includes regular field trips to local facilities and institutions—a marine research vessel and a wildlife monitoring station, for instance—plus on-site demonstrations. The program, initiated in response to the national shortage of teenagers with advanced math and science backgrounds, is funded by the school district.

For more information, contact Karen M. Kendo, science supervisor, Charleston County School District, Division of Instruction and Curriculum, 3 Chisholm Street, Charleston, SC 29401; 803-722-8461. ☐

☐ The Secret Garden: It could be behind your school

Here's an idea, lifted from a popular program in Nashville. Have your students read the children's classic, *The Secret Garden*. Then contact your local botanical society or gardening club and plant a garden in the back of the school. This was the interdisciplinary approach used by 100 fourth graders in Nashville. The city's Cheekwood Botanical Gardens kicked off its "Secret Garden" project by donating copies of the book to area classrooms. While teachers read the book aloud to their classes, the botanical garden sent trained volunteers into the classrooms to help students plant mystery seeds and bulbs. During the following weeks, students worked in groups to observe emerging plants and work on daily journals. Teachers received materials suggesting how *The Secret Garden* could be used to meet curriculum requirements in a range of subjects.

For more information, write to Growing Ideas, National Gardening Association, 180 Flynn Ave., Burlington, VT 05401. ☐

☐ Use the want ads to teach the importance of math

Pupils in Chicago find jobs in the newspaper want ads and practice living on the advertised salary. The lesson is part of a program that teaches grade schoolers why numbers matter in real life. Here's how it works. The teacher asks the fifth-grade students to clip out ads listing jobs they would be interested in. Then they figure out how they'll live on the advertised salary. Problems crop up along the way. "If I'm making only $200 each week, then what kind of an apartment can I afford? What kind of insurance do I need to buy? Are benefits included in the job? If so, what are they worth?" During one classroom session, the teacher asks the pupils to try starting a business based on real data from the community. The program is called "Math at Work." It consists of 20 lessons developed by professors at Chicago's DePaul University.

For more information on the program, call Barbara Radner at DePaul's center for Urban Education, 312-362-8173. ☐

☐ Hands-on science education: "Science to Go" kits

Deciding they needed "a hands-on, activity-oriented approach to science education," St. Vrain Valley School District elementary school teachers spent many long hours developing "Science to Go" kits.

"The district decided that textbooks were not the way to go when teaching science to elementary school students," explains Karen Hunter, a teacher on special assignment in the Colorado district. They now have 76 different staff-developed kits, each constituting a complete two-week instruction unit. Each kit has all materials needed, teacher's guides, and students handouts in both English and Spanish. The focus of each unit is on observation, measurement, classification, and organizational and communications skills.

For more information, contact Hunter at St. Vrain Schools, 395 S. Pratt Parkway, Longmont, CO 80501; 303-776-6200, ext. 242. ☐

☐ Science test scores rise as school adopts new curriculum

A case study of one Chicago elementary school shows how student achievement and interest in science can dramatically improve. Four years ago, teachers at Healy Elementary were uncomfortable teaching science and so they drilled students on facts and terms rather than on concepts. Not surprisingly, science test scores were low. Then the school won a $43,000 state grant to improve science education. The principal used the money to set up teacher workshops in hands-on science, like how to get crickets to survive in severe heat, determining the density of various objects like stone and lead, and controlling temperatures on chicken eggs in an incubator. The supplies for each experiment (simple materials like petri dishes, graduated cylinders, and aquariums) were packaged together so teachers did not have to organize each lesson. In addition, the school hired a new science teacher to conduct special lessons in classrooms where home-room teachers needed extra help. Two years ago, the school added another feature to the science curriculum. Using Chapter 1 money, the school assembled science kits for kindergartners to take home to use with their parents help. Families studied the seasonal changes in leaves and the different pitches of a tuning fork. The students recorded the results of each experiment in lab books. Finally, the school required all students to participate in an annual science fair or risk getting an F for an entire marking period. With this encouragement, the science fair has dramatically improved. This year students conducted experiments in chromatography, growing mold, and explaining the solar system. The school reports that science test scores have improved dramatically as well.

For more information, contact Beverly Tunney, Principal, Healy Elementary School, 3010 S. Parnell, Chicago, IL 60616; 312-534-9190. ☐

☐ Math teacher shows students they can learn what they want to learn

When math students at Edward Bok Vocational-Technical School in Philadelphia complain that they cannot memorize the rules of algebra or the definitions in geometry, teacher Jerry Silverman has a class exercise ready to show them they can "learn what they want to learn." The first time he tried it, he asked how many students could tell him the latest plot twists in the soap opera "All My Children." Sure enough, nearly all of them, boys as well as girls, raised their hands. The student he called on recited all the intricate details. The same thing happened when Silverman called on other students to bring him up to date on other soaps. But the same students ran into trouble when asked to define terms like "multiplicative identity" or "trapezoid." Once students realized they knew more about television than math, the interest and level of their work "increased noticeably," says Silverman.

The teacher also hangs student art work on classroom walls to increase their pride in their class participation. Geometry students create artistic geometric designs at the beginning of the semester, and algebra students add imaginative posters that include the latest algebraic rule they have learned as the weeks pass.

For more information, contact Jerry Silverman at Edward Bok Vocational-Technical High School, 8th and Misslin Streets, Philadelphia, PA 19147; 215-952-6200. ☐

☐ Math class begins with elevated train ride

The purpose of the Algebra Project is "to address the crisis in mathematics education among inner-city kids," says Dr. Winifred French, principal of Reavis Elementary School in Chicago. A grant from the MacArthur Foundation allows Reavis to participate, with schools in Atlanta and Boston, in the program designed by Bob Moses, author of "The Algebra Project Transition Curriculum." Teachers get two-week and follow-up training in the concept of problem-solving and cooperative learning in math, says French.

"Breaking the myth" that math is too hard to understand is a basic part of the program, says Douglas Gills, a parent member of Reavis's Local School Council. Sixth-grade students begin the year with a ride on a Chicago elevated train. The "el" then figures in their math equations dealing with distance, speed, etc., bringing meaning to the concepts they must master. They also report their observations on topics of their choice, such as the downtown skyline from the el or the people waiting on the platforms. They learn to use scientific language and to illustrate with graphs. The program continues through eighth grade.

Parents are invited to attend the class. Last year, from six to ten came regularly, and Gills expects to see many more this year.

For more information, contact French at Reavis Elementary School, 834 W. 50th St., Chicago, IL 60609; 312-535-1060. Or contact Gills at Kenwood-Oakland Community Organization, 1238 E. 46th St., Chicago, IL 60653; 312-548-7500 or Bob Moses, Algebra Project, 22 Wheatland Ave., Boston, MA 02121; 617-287-1508. ☐

☐ Chicago Bulls help young fans learn math and science

About 170 city and suburban third- to eighth-grade classes subscribe to the Thursday *Chicago Sun-Times* as participants in "Around the NBA in Math and Science with the Chicago Bulls." Shooting percentages, points-per-game averages, and team statistics take on a new dimension as they learn how to calculate them for themselves. Weather, geometry, fractions, graphs, ecology and other areas of science and math are studied in the context of local climate, current events, and pro basketball.

Classes sign up for from four to 12 weeks and pay $21 per classroom for four weeks. Every Thursday, the class receives a copy of the *Sun-Times* and an activities packet for each student, materials needed, and teacher's curriculum guide and lesson plan. The 25 activities are coordinated with the Bulls' games.

Sun-Times School Services Manager Ken Scott, a teacher himself for nine years before coming to the paper in 1988,. thought up the program. He says he chose Thursdays because the Bulls usually play on Wednesdays, so their box scores appear in the Thursday paper. Also, the weekly food section, central to the nutrition-related lessons, comes out on Thursdays. Scott also started the "White Sox Grand Slam Geography Game" program for spring semester, and a White Sox summer math and reading program along the same liens. Both programs are scheduled to be offered again this year.

For more information, contact Scott at the *Chicago Sun-Times*, 401 N. Wabash Ave., Chicago, IL 60611; 312-321-3161. ☐

☐ Teachers create materials for primary science, reading

Frustrated in their search for what works best for their students, more and more teachers have been creating their own texts and instructional materials rather than waiting for the publishing industry to do it for them. Here are two recent ventures that the teachers offer to share with others.

Unable to find "comprehensive science materials suitable for use" by her kindergarten and first grade classes, teacher Cynthia Hinojosa wrote twenty booklets, each with a 20- to 30-minute science lesson; hands-on experiments using inexpensive, readily available materials; and a bibliography of stories related to the lesson. Among the 20 topics are astronomy, ecosystems, energy, evolution, genetics, and geology; each booklet is available for $5.

Teacher Maryellen Riley found that traditional fables and fairy tales were the literature most likely to catch the interest of her students, but "in their original form, they can be hard to understand." So Riley has rewritten many of the classic stories, along with a guide for follow-up activities including pages which can be reproduced, and compiled them into a book available for $6.

For a complete list of the K-1 Science Booklets, send a self-addressed, stamped envelope to Hinojosa at 7272 Elk Circle #1, Huntington Beach, CA 92647. For more information, contact Riley at PSC 634, APO Miami, FL 34005. ☐

☐ Hands-on science education: Learning without books

Hands-on science education has replaced science-by-the-(text)book this fall for students of the Trotwood-Madison (Ohio) elementary schools. Everything from plants to ant farms and from experiments to lectures given by Novel Prize-winning scientists will be used to replace those old teaching stand-bys.

The hands-on curriculum, developed at Wright State University with a $400,000 grant from the National Science Foundation, aims to get students to "live" science, not just think about it during class, says Wright State's Randy Moore. According to Moore, the program goal is to redesign science education in kindergarten through sixth grade, providing hands-on workshops for teachers, substitutes from Wright State for the teachers attending the workshops, scientific field trips and classroom contact with renowned scientists for the students, and weekend activities to get parents involved with the program.

Tabulating results of their first year, Moore notes that students' grades and enthusiasm for science improved significantly. Now more than eighty percent want to take more science courses, whereas less than half wanted to do so last year. Teachers also said they preferred the new method.

For more information, contact Randy Moore, Chairman, Biological Sciences Dept., Wright State University, Dayton, OH 45435; 513-873-2655. ☐

☐ Professional actors help teach problem-solving

Heritage Middle School, in Westerville City, Ohio, hired a troupe of professional actors for Detect-a-Mystery, a unique project to develop students' skills in reading, gathering information, and solving problems.

The actors and school staff spent a week acting out the murder mystery and coaching students to solve it. First, the students were introduced to the "suspects" at an assembly. Students questioned the suspects and "witnesses" at an assembly. Students questioned the suspects and "witnesses" in the week that followed. They dusted for fingerprints in science lab, decoded a letter in language arts, and calculated a timetable of the crime in math class. New evidence was posted every day for all to see. In an assembly at the end of the week, students competed to solve the whodunit. The first to do so correctly won the prize.

For more information, contact Robert Schultz, Principal, Heritage Middle School, 390 N. Spring Rd., Westerville, OH; 614-895-5928. ☐

☐ Hands-on science education: Waterworks

Fourteen Brown County, Ohio, middle school science teachers are now equipped with water-testing kits and a thorough, up-to-date understanding of the relationship of clean water to the quality of life after participating in a two-day workshop developed by the county's Office of Education and the Brown County Extension Office.

An Ohio State University professor lectured, and Brown County Extension Office agents led the teachers in a hands-on workshop in water testing. They provided each teacher with water-testing kits of their own so they could pass on the hands-on instruction to their pupils. Teachers also toured the county's laboratory, pumping station, chlorination plant, and well field.

A grant from the Brown County Rural Water Association paid for the training session. Total cost of the project, including substitute teachers and materials, added up to more than $5,000.

For more information, contact Dr. Karen Mancl, Water Quality Dept., Ohio State University, North High Street, Columbus, OH; 614-292-6446. ☐

Instructional Resources

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Tom Fiore
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Research Triangle Institute
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Connie Muther
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257 East Center Street
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Association for Supervision and Curriculum Development
1250 Pitt Street
Alexandria, VA 22314
(703) 549-9110

Technical Education Research Center (TERC)
(K-12 math and science learning)
2067 Massachusetts Avenue
Cambridge, MA 02140
(617) 547-0430

ERIC Clearinghouse for Science, Mathematics, and Environmental Education
David Haury, Director
Room 310
Ohio State University
1200 Chambers Road
Columbus, OH 43212-1792

Educational Development Center
(Hands-on elementary science curriculum)
55 Chapel Street
Newton, MA 02160
1 (800) 225-4276 ext. 430

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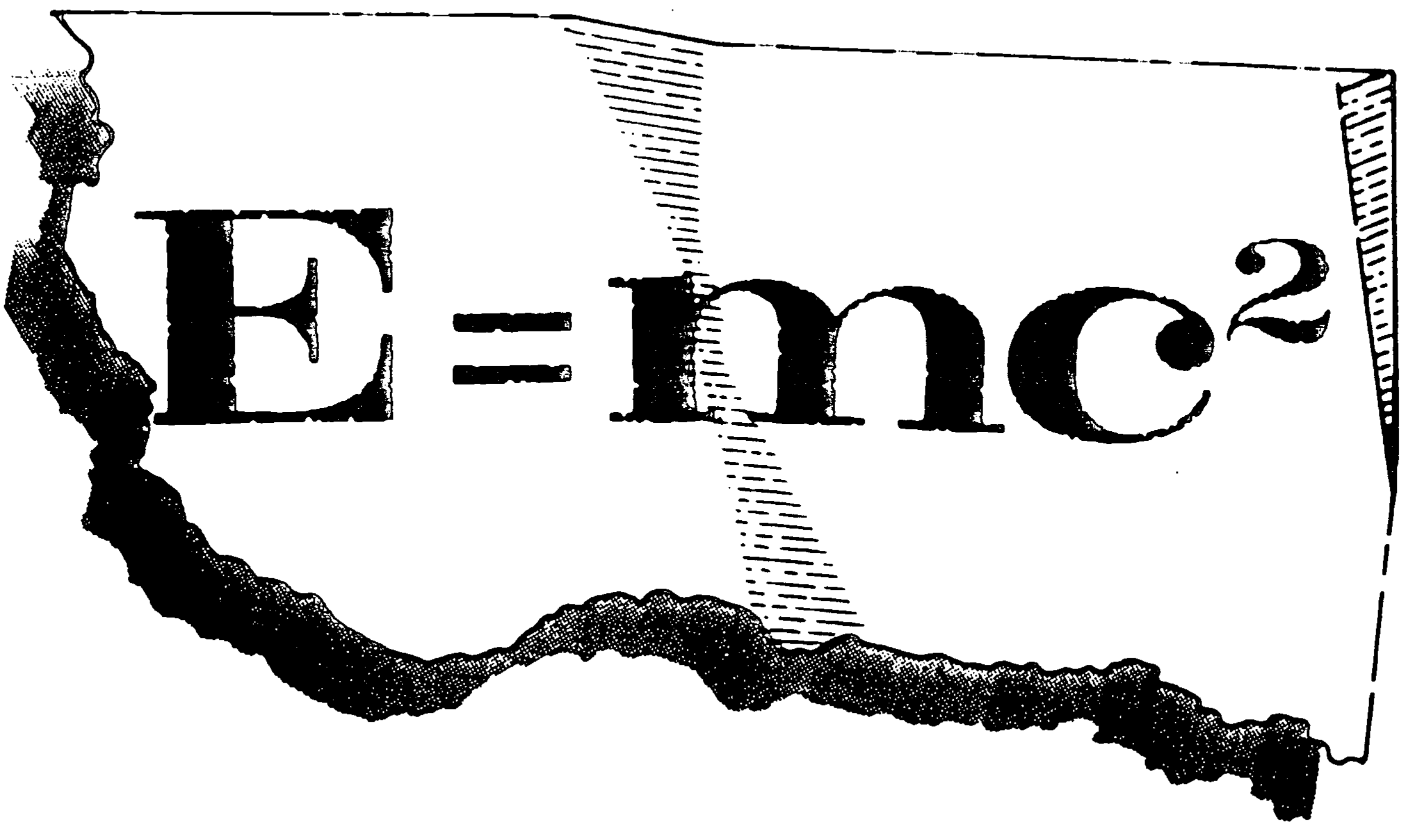
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Council of Chief State School Officers
State Education Assessment Center

Science and Mathematics Indicators Project
January 1992

HAS SCIENCE AND MATHEMATICS EDUCATION IMPROVED SINCE A NATION AT RISK?

Trends in Course Enrollments, Qualified Teachers, and Student Achievement

Rolf K. Blank and Pamela Engler

Improving student learning in mathematics and science is a high priority for our elementary and secondary schools. The national educational goals of the President and governors, set in 1990, state that science and mathematics achievement of American high school graduates will be first in the world by the year 2000. In September 1991, the National Education Goals Panel recommended measures to be used in tracking progress toward the goal and reported baseline data on several measures. The Panel set high expectations for improving the quality of science and mathematics. As policymakers and educators plan initiatives for working toward Goal 4 on science and mathematics achievement, it may be helpful to assess the progress that has been made over the past decade in response to the calls for education reform in the early 1980's.

National Commissions and State Policy Reforms

In the early 1980's many national and state reports made recommendations for reform of our education system (National Commission on Excellence in Education, 1983; National Science Board Commission on Precollege Mathematics, Science, and Technology Education, 1983; Task Force on Education for Economic Growth, 1983; Twentieth Century Fund, 1983). The report of the National Commission on Excellence in Education, A Nation at Risk: The Imperative for Education Reform, received the most attention and response. The Excellence Commission deplored a "rising tide of mediocrity" in our education system and identified specific problems in the areas of science and mathematics. The report noted the poor performance of American students on international assessments in science and mathematics, declining average scores on national achievement tests, and the relatively small amount of science and mathematics instruction received by the average American student. The Excellence Commission recommended that three mathematics and three science courses be required for high school graduation and that science be made a "new basic" in elementary school.

National commission reports also highlighted the problem of underqualified teachers in science and mathematics and impending teacher shortages (National Science Board, 1983; Carnegie Forum on Education and the Economy, 1986). In the early 1980's national experts saw a major problem in insufficient preparation of teachers in science and mathematics, particularly at the elementary and middle school levels (Johnston and Aldridge, 1984). Other data showed that many well-qualified science and mathematics teachers were leaving teaching, few new graduates in science and mathematics were going into teaching, and many science and mathematics teachers would be retiring in the 1990's (Aldrich, 1983; Darling-Hammond, 1984).

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States took the lead in responding to A Nation at Risk and other national commission reports (National Governors Association, 1986). States increased course credit requirements for graduation (particularly in mathematics and science), raised standards for teacher preparation, mandated teacher tests for certification, set higher levels for teacher pay, developed state curriculum guidelines and frameworks, and established new statewide student assessments (Blank and Espenshade, 1988; Goertz, 1988; CCSSO, 1989).

Studies of State Reforms. Debate has arisen concerning the effects of the state policy initiatives on education reform at the district, school, and classroom levels. One argument is that the state policy changes do not have substantial or lasting effects on how schools are organized, on the curriculum that is actually taught in classrooms, or on how teachers teach (Fuhrman et al, 1988; Firestone, et al. 1989; Smith and O'Day, 1991; David, et al, 1990). Another position is that state policy reforms did increase the amount of time spent on core academic subjects and improved student learning of basic skills, but that teaching and learning of higher order thinking skills were not advanced (Clune et al. 1989; ETS Policy Information Center, 1990). Some state policymakers argue that, while there is evidence that state reforms have produced improvements in science and mathematics education, more needs to be done (Connecticut Department of Education, 1989; Honig, 1990; California Department of Education, 1991).

Much of the debate about effects of state policies is based on analyses of education reforms in one state or a small number of states. National and state-by-state data are now available for assessing state policy reforms. This paper summarizes some of the evidence concerning key indicators of change in science and mathematics education.

Three questions are addressed:

(1) Are students receiving more instruction in science and mathematics now than 10 years ago?
(2) Has the supply of qualified teachers in science and mathematics improved?
(3) Are students learning more science and mathematics?

Data and findings from four sources are used to address these questions: National transcript studies of high school graduates conducted by the National Center for Education Statistics (NCES), the National Assessment of Educational Progress (NAEP) assessments in science and mathematics, the Council of Chief State School Officers' State Indicators of Science and Mathematics Education, and the NCES Schools and Staffing Survey.

1. Are Students Receiving More Instruction in Science and Mathematics?

One of the common responses from state legislatures and state boards of education to calls for state education reforms was to raise course credit requirements in science and mathematics. From 1980 to 1987, 43 states increased mathematics course requirements for graduation and 40 states increased science requirements (Education Commission of the States, 1984; Blank and Espenshade, 1988). The number of states mandating or recommending a specific amount of time for science and mathematics instruction in elementary grades increased to 26 states by 1987 (Blank and Espenshade, 1988). One way of measuring the effect of this policy approach for improving science and mathematics is to determine the extent of change in student course taking in science and mathematics.

Rates of course enrollments by course level indicate the proportion of students advancing through the secondary science and mathematics curriculum. The rate of course taking in science and mathematics is also an important indicator because of the relationship between course-taking and student learning in these subjects. Research with large national surveys and international surveys (e.g., National Assessment of Education Progress, National Longitudinal Study, High School and Beyond, Second IEA Mathematics Assessment) demonstrates that there is a direct, positive relationship between the amount of elementary instructional time and secondary course taking in science and mathematics and the rate of student learning in these subjects (Jones, et al., 1986; Dossey, et al., 1988; Mullis, et al., 1988; Rock, et al., 1985; McKnight, et al., 1987; National Center for Education Statistics, 1991b). Walberg conducted a quantitative synthesis of 3,000 studies and identified instructional time as one of the nine "productive factors" in learning in schools (1984). Sebring found a positive relationship between science and mathematics course taking and College Board achievement test scores for students in California and New York (1987).

State-by-state course taking data were collected in 1989-90 and reported by the Council of Chief State School Officers (CCSSO) through a system of state indicators

(Blank and Dalkilic, 1990)[1]. National trends in high school course enrollments can be assessed by comparing the 1990 data with data from transcripts of nationally representative samples of high school seniors in 1982 (High School and Beyond Study) and 1987 (National Transcript Study) (Kolstad and Thorne, 1989).

o **Enrollments increased in science and mathematics "gatekeeper" courses from 1982 to 1990.** The percentage of students taking algebra 1 by the time they graduate increased from 65 percent in 1982 to 81 percent in 1990, the percentage taking algebra 2 went from 35 percent to 49 percent, and calculus enrollments increased from 5 percent to 9 percent. The percentage of students taking first year biology by the time they graduate increased from 75 percent in 1982 to 95 percent in 1990, the percentage taking chemistry went from 31 percent to 45 percent, and physics enrollments increased from 14 percent to 20 percent. Enrollments increased at all levels of high school science and mathematics during the 1980's. Rates increased more in lower level courses, such as algebra 1 and biology, than in upper level courses.

Trends in Course Taking in Science and Mathematics

	% Students Enrolled 1982	% Students Enrolled 1990
Algebra 1	65%	81%
Algebra 2	35	49
Calculus	5	9
Biology, 1st Year	75	95
Chemistry	31	45
Physics	14	20

High School and Beyond data for 1982, Kolstad and Thorne, 1989; State data for 1990, Blank and Dalkilic, 1990

o **Enrollments in science and mathematics vary widely by state.** An example of state-to-state differences in course taking is the variation in the proportion of students taking algebra 2. In Montana, 65 percent of students take algebra 2 while in Hawaii only 33 percent take mathematics at this level. As of 1989-90, 20 of 38 states reported more than 50 percent of students take algebra 2. The proportion of students taking chemistry by the time they graduate varies from 62 percent in Connecticut to 26 percent in Idaho. As of 1989-90, 11 of 38 states reported more than 50 percent of students taking chemistry (Blank and Dalkilic, 1990). Tables 1 and 2 (attached) provide state-by-state data on course enrollments for three levels of high school science and mathematics.

o **Gender differences in course taking are at advanced levels.** Sixteen states reported science and mathematics course enrollments by student gender in 1989-90. The data from these states show that rates of course taking are equivalent for male and female students from junior high courses up through trigonometry (in mathematics) and chemistry (in science). Differences occur in the advanced courses. On average, boys comprise 55 percent of enrollees in calculus and 60 percent of enrollees in physics; girls comprise 55 percent of enrollees in advanced/second year biology (Blank and Dalkilic, 1990). A comparison of the state figures to national statistics from 1982 (Kolstad and Thorne, 1989) shows that the rate at which girls take advanced mathematics and physics increased about three percent during the 1980's.

o **Participation in science and mathematics differs widely by student race/ethnicity.** Data from the national transcript study in 1987 show that science and mathematics enrollments are highest for Asian students and lowest for African-American and Hispanic students. For example, the percentage of students taking algebra 2 were: Asian--67 percent, white 52 percent, African-American--32 percent, and Hispanic--30 percent. The percentage of students taking chemistry were: Asian--70 percent, white--48 percent, African-American--30 percent, and Hispanic--29 percent (Kolstad and Thorne, 1989).

o **Science and mathematics enrollments as of 1990 are below recommendations of Excellence Commission.** Enrollments in science and mathematics increased in the 1980's but the rate did not reach the level recommended by the National Commission on Excellence in Education. The 49 percent rate for algebra 2 in 1990 indicates the proportion of graduates that take three years of high

1 In the 1989-90 school year, 38 states collected and reported data on enrollments in science and mathematics of public school students in grades 9-12. States reported the data to CCSSO using common reporting categories which provide the basis for valid state-to-state comparisons. CCSSO researchers used statistical analyses to calculate national estimates from the state data. The science and mathematics indicators were developed through support of the National Science Foundation, Office of Studies, Evaluation, and Dissemination.

school mathematics, since algebra 2 is typically the third course in the high school mathematics curriculum. The 45 percent rate for chemistry in 1990 indicates the proportion of students who take three years of high school science. Thus, by 1990 not quite half of American graduates met the standard for high school science and mathematics recommended by the Excellence Commission.[2]

o **Large high school enrollments in lower level mathematics courses.** In the fall of 1989, 84 percent of all students in grades 9-12 were taking a course in mathematics. Over one-fourth of the students (27%) were taking a course at a level prior to algebra 1, i.e., general mathematics, vocational/business mathematics, or pre-algebra (Blank and Dalkilic, 1990). Thus, to meet state graduation requirements, many students are taking mathematics courses which are generally not in the high school mathematics curriculum.

o **States with higher requirements have more overall course taking in science and mathematics and slightly more upper level course taking.** The data on course taking confirm that the amount of science and mathematics instruction did increase in the time period after states set higher graduation requirements. Were increases the result of changing state requirements? The 1990 CCSSO data show that states requiring 2.5 to 3 credits (13 states in mathematics, 6 states in science) had an average of 10 percent higher enrollments overall in mathematics and science than states requiring two credits (34 states mathematics, 38 states science). The high-requirement states have two to four percent more students taking upper level science and mathematics courses (e.g., chemistry, physics, geometry, algebra 2, trigonometry) (Blank and Dalkilic, 1990). Thus, the cross-sectional data from 1989-90 show that students take more courses in states with higher requirements. However, they do not necessarily take higher level courses. Data show there is a weak relationship between state requirements and enrollments in upper level science and mathematics courses. This issue will be studied further as state trend data are available through CCSSO.

In sum, course taking data indicate that American high school students are now taking more science and mathematics courses in high school at all levels, and the data suggest that state policies are related to the increased enrollments. However, the rates of increased course taking are smaller for more advanced courses such as chemistry, physics, trigonometry, and calculus.

2 The average number of credits earned in mathematics increased from 2.4 in 1982 to 2.98 in 1987 (these statistics included lower level courses such as general mathematics and pre-algebra), and the average number of credits in science increased from 2.19 in 1982 to 2.63 in 1987, which is an increase of half a credit in each subject (Kolstad and Thorne, 1989).

2. Has the Supply of Qualified Teachers in Science and Mathematics Improved?

Central to policy reforms in the 1980's many states began initiatives aimed at improving the supply and quality of teachers. State policies increased incentives for entering and staying in teaching. For example, many states raised the minimum pay scale for teachers, and about half established alternative certification policies (CCSSO, 1989). States also developed loan and scholarship programs in critical teaching fields. At the same time, states raised standards for becoming a teacher. For example, by 1987 all states had specific state requirements for the amount of subject area preparation for certification of science and mathematics teachers (Blank and Espenshade, 1988). In addition, 36 states mandated written tests of teacher knowledge for certification (ETS Policy Information Center, 1990).

These policy initiatives responded to predictions that supply of qualified teachers was declining and existing teachers were insufficiently prepared, particularly in science and mathematics. Now, as we enter the 1990's, it is important to assess whether the condition of the teaching force in science and mathematics has improved and whether predictions of severe shortages in the 1990's are still likely. One of the major objectives under Goal 4 on science and mathematics is to "increase by 50% the number of teachers with a substantive background in science and mathematics" (National Governors Association, 1990). Two national panels have recently outlined the need for improved data on teacher supply, demand, and quality (National Research Council, 1990; NEGP, 1991). At present, some data are available from the NCES Schools and Staffing Survey and the CCSSO Science and Mathematics Indicators to assess key indicators of supply and shortages of qualified science and mathematics teachers.

Current Teacher Supply in Science and Mathematics

In 1989-90, there were approximately 111 thousand teachers of mathematics and 102 thousand teachers of science in public high schools in the 50 states and the District of Columbia (Blank and Dalkilic, 1990). This compares with 10.8 million students in grades 9-12 enrolled in public schools, (NCES, 1990), or an average of 107 students per mathematics teacher and 116 students per science teacher.[3]

Considering these overall numbers of students and teachers, what data are available to tell us if the supply of teachers for our schools has improved or declined? A first level of analysis is whether school districts are able to hire teachers to put in science and mathematics classrooms, i.e., the availability of new or continuing teachers, without considering teacher quality.

o **Low attrition rate of teachers.** The supply of teachers did not decline during the 1980's due to high attrition. The attrition rate of teachers is now relatively low--about 5 percent per year for science and mathematics teachers as well as for all public school teachers (Bobbitt, 1991). However, attrition rates are higher for teachers in the physical sciences, due to more professional opportunities outside of teaching that offer significantly higher pay (Murnane, et al, 1988).

o **Teachers reaching retirement age varies by state; rate of retirement will increase in mid 1990's.** Data on the ages of current teachers allow projections of potential shortages due to retirements. In 1989-90, state data showed that 19 percent of high school mathematics teachers and approximately 22 percent of science teachers were over age 50, while 21 percent of all high school teachers were over age 50. Thus, as a national average, science and mathematics teachers will not be retiring more rapidly than other teachers. However, the proportion of science and mathematics teachers over age 50 varies by state from 10 percent to over 30 percent. A shortage of science and mathematics teachers can be anticipated in a few states that have much higher percentages of their teaching force over 50 than other states. These states include Minnesota, Delaware, California, Michigan, and Illinois (Blank and Dalkilic, 1990). Projections by NCES show that attrition rates will rise to almost 10 percent after 1995 due to increasing retirement (NCES, 1989).

Percentage of Teachers Over Age 50

	Math	Biology	Chemistry	Physics
National Average	19%	20%	22%	23%
California	26%	21%	23%	22%
Connecticut	20	24	27	29
Delaware	28	23	41	29
Illinois	23	28	30	32
Michigan	24	26	33	29
Minnesota	29	30	45	43
Wisconsin	21	27	28	30

Blank and Dalkilic, 1990

o **More new hires from reserve pool and more college graduates in science and math education.** In 1987-88, about seven percent of all teachers were new hires (NCES, 1991a). This rate was constant during the 1980's (Kirby, et al, 1991). However, in the 1980's school districts depended less on new college graduates for new hires than in the past. NCES found that in 1988, only 26 percent of new hires were first-year teachers (Rollefson, 1991). In some districts, over half of new hires were from the "reserve pool" of teachers who left teaching and returned (NRC, 1990; Kirby, et al, 1991). Hiring from the reserve pool went up sharply in the 1980's. At the same time, efforts in the 1980's to encourage more science and mathematics teachers appear to have worked because the number of new certified college graduates in science and mathematics teaching increased (Lauritzen, 1990). The number of 1988 college graduates with majors in mathematics education was more than twice the number in 1982 (2,250 vs. 1,000), and the number of graduates with part-time majors in science education doubled in the same period (2,200 in 1988 vs. 950 in 1982) (NCES, 1985, 1990).

3 Students per teacher averages adjusted by the number of part-time teachers of science and mathematics.

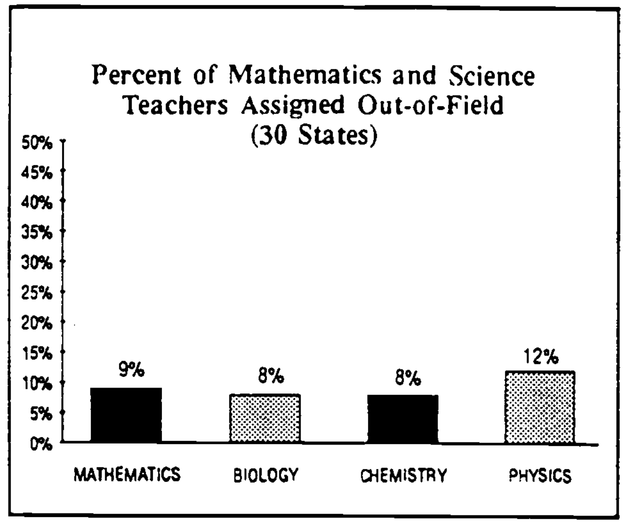
o **Shortage of chemistry and physics teachers.** National data for the 1987-88 school year show that only one percent of all teaching positions were unfilled (NCES, 1991a). However, school principals report that physics and chemistry teachers are harder to hire than teachers in any other field (Weiss, 1987). According to state data in 11 states, there are more high schools than the total number of assigned chemistry teachers, and in 28 states there are more high schools than the total number of assigned physics teachers. The number of assigned physics teachers is less than one-half the number of high schools in Illinois, Michigan, Mississippi, New Hampshire, Oklahoma, and Utah (Blank and Dalkilic, 1990).

Supply of Qualified Science and Mathematics Teachers

To address the question of whether there is an adequate teacher supply also requires application of a criterion of a "qualified" teacher in science and mathematics. For example, the criterion used by the National Education Goals Panel is the proportion of science and mathematics teachers in each state with a college major in their assigned field of teaching (NEGP, 1991). Another definition of qualified has been based on the standards established by the professional science and mathematics teacher associations (Weiss, 1989; National Science Board, 1989). A definition often used by states is whether a teacher is state-certified in the assigned teaching field (Blank and Dalkilic, 1990). Data are available to examine the supply of qualified teachers using several different indicators.

o **1 of 11 science and mathematics teachers not certified in assigned field (assigned out-of-field).** CCSSO data from states show that nine percent of high school mathematics teachers are not certified in mathematics, and eight percent of biology teachers, eight percent of chemistry teachers, and 12 percent of physics teachers are not certified in these fields.[4] State-by-state analyses of teacher certification show that some states have 20 to 30 percent of mathematics and science teachers assigned "out-of-field" while a few states have no teachers assigned out-of-field. The state data show that states with more out-of-field teachers have many small, rural districts (e.g. South Dakota, Illinois, Mississippi) or states experiencing rapid population growth (e.g. California).

4 These figures include teachers with a primary, secondary, or one period assignment.



Out-of-Field = Not state certified in assigned field
Blank and Dalkilic, 1990

o **One-half of science and mathematics teachers majored in their teaching field.** The NCES Schools and Staffing Survey provided data on the proportion of teachers in science and mathematics with a college major in their assigned teaching field. The data show that 42 percent of all high school teachers of mathematics have a mathematics major, and 54 percent of all teachers of science majored in a science field. The percent of teachers with majors in mathematics varies by state from 20 percent (Louisiana) to 62 percent (Kentucky), and in science from 31 percent (Louisiana) to 73 percent (Minnesota, Missouri) (Blank and Dalkilic, 1990; National Education Goals Panel, 1991). Table 3 (attached) provides state-by-state percentages of teachers that majored in mathematics, mathematics education, science, and science education.

Equity in the Teaching Force

Another consideration in analyzing the supply of science and mathematics teachers is equity, i.e., the extent to which gender and race/ethnicity of teachers matches the characteristics of students. Oakes (1990b) found that the rate of participation of female and minority students in science and mathematics courses is related to the presence of female and minority teachers.

o **The proportion of female teachers in science and mathematics varies widely by state.** The majority of high school science and mathematics teachers are male, but the gender distribution varies by field and by state. For example, 45 percent of mathematics teachers are female, while 22 percent of physics teachers are female. The percent of female teachers in mathematics varies by state from 21 percent (Minnesota) to 69 percent (South Carolina), and the percent of female teachers in physics varies by state from 10 percent (Michigan, Minnesota, Utah) to 49 percent (Alabama) (Blank and Dalkilic, 1990).

Gender of Mathematics and Science Teachers

	Percent Female	Percent Male
Mathematics	45%	55%
Biology	37	63
Chemistry	34	66
Physics	22	78
All Public High School Teachers	50	50

Blank and Dalkilic, 1990

o **Shortage of minority teachers in all science and mathematics fields.** State data on the race/ethnicity of high school science and mathematics teachers show that there is a wide disparity between the supply of minority science and mathematics teachers and the number of minority students in virtually all states. The proportion of minority teachers are: mathematics--11 percent, biology--10 percent, chemistry--7 percent, and physics--5 percent, while 11 percent of all high school teachers are from minority groups (Blank and Dalkilic, 1990). The student population in our public schools is 32 percent minority. Table 4 (attached) summarizes the state-by-state data on minority teachers and minority students. From 1982 to 1987 the percent of all public school teachers that are from minority groups increased two percent (from 8 to 10 percent), and the proportion of teachers who are African-American declined by one percent (NCES, 1990).

Minority and White Teachers in Mathematics and Science

	Percent Minority	Percent White
Mathematics	11%	89%
Biology	10	90
Chemistry	7	93
Physics	5	95
All Public High Schools	11	89

Blank and Dalkilic, 1990

o **Fewer qualified teachers in schools with high percent of disadvantaged and minority students.** Oakes (1990a) analyzed the qualifications of science and mathematics teachers by student and school characteristics and found that inner-city schools and schools with more disadvantaged and minority students have a significantly lower proportion of well-qualified teachers than other schools.

Other Factors in Analyzing Teachers. The data presented here on supply and shortages of science and mathematics teachers provide some indicators of the condition of science and mathematics teaching in our schools. To obtain a complete analysis, several other factors should be considered. For example, a key variable is the effects of increased demand in the future, such as from higher enrollments in high school and mathematics. The data have addressed teacher supply and shortages in high school science and mathematics, but shortages of qualified teachers may be more acute at the middle school/junior high level. Also, recent research has found that the average elementary classroom teacher has poor preparation in science and limited preparation in mathematics (Weiss, 1989). Finally, the indicators of "qualified teachers" do not measure actual teaching skills or practices, rather they measure the teacher's preparation for teaching in their subject. The National Education Goals Panel has recommended the collection and reporting of more detailed information on teaching skills and practices.

In sum, the current data on science and mathematics teachers lead to three general findings: first, some indicators of teacher shortages have improved since the early 1980's; second, teacher shortages vary by specialty within science and mathematics and by state; and, third, the criterion of a "qualified teacher" needs to be specified to determine shortages of science and mathematics teachers. We also know that shortages are greater in certain types of school districts and schools.

3. Are Students Learning More Science and Mathematics?

The National Assessment of Educational Progress (NAEP) has been monitoring the knowledge and skills of American students in science and mathematics since 1970. Nationally-representative samples of students at ages 9, 13, and 17 have been assessed every two to four years in science and mathematics. The use of common test items over time in NAEP provides a basis for measuring achievement trends. The recent NCES report Trends in Academic Progress provides details on the extent of improvement in science and mathematics learning of students since 1982 when state reforms began (NCES, 1991c).[5]

o **Average achievement in science and mathematics increased slightly from 1982 to 1990.** NAEP proficiency scores declined from 1973 to 1982 in both science and mathematics. From 1982 to 1990, NAEP scores showed significant improvement in science at ages 9 and 17 (from 221 to 229, 283 to 290) and in mathematics at ages 9 and 17 (219 to 230, 299 to 305). During the same period, NAEP scores showed less improvement in science and mathematics at age 13. Levels of achievement in science and mathematics are about the same as they were 20 years ago, and leading educators agree that much improvement is needed. However, the NAEP trends do show that progress has been made during the 1980's in increasing science and math learning.

Achievement Trends in NAEP

Average NAEP Proficiency Scores from 1982 to 1990					
Science	1982	1990	Mathematics	1982	1990
Age 17	283	290	Age 17	299	305
Age 13	250	255	Age 13	269	270
Age 9	221	229	Age 9	219	230

NCES, 1991 Trends in Academic Progress

Mathematics and science educators have pointed out that the NAEP achievement trends are based on information from multiple choice questions. Even though the trend results are valuable, multiple choice items largely assess students' factual knowledge rather than student learning and skills in problem solving and application. Some changes are being made in the NAEP design. Beginning with the 1990 mathematics assessment and the 1994 science assessment, the subsequent NAEP trend results will incorporate new open-ended items and other alternate methods of assessment.

o **Increased achievement of African-Americans in science and mathematics.**[6] Although the achievement levels of African-American students continue to average below the level of white students, the gap in achievement between African-Americans and whites has been reduced in both science and mathematics since 1982. As shown on page 9, the scores of African-Americans in science improved significantly at ages 9, 13, and 17 in the 1980s, with the largest gain at age 17 of 18 points. African-American students' scores in mathematics also increased significantly at all ages, with a 17 point increase at age 17 (NCES, 1991c). Smith and O'Day use the NAEP trend data to show that there has been considerable progress toward the goal of equality of educational outcomes since 1966, even though there is still much more progress needed (1991).

5 NAEP scores are reported on a proficiency scale that ranges from 0 to 500.

6 The NAEP trend data are also reported for Hispanic students. This population also showed improved achievement, although with a pattern by age, subject, and level that is somewhat different from African-American students.

Achievement Trends in NAEP for African-American Students

Average NAEP Proficiency Scores from 1982 to 1990					
Science	1982	1990	Mathematics	1982	1990
Age 17	235	253	Age 17	272	289
Age 13	217	226	Age 13	240	249
Age 9	187	196	Age 9	195	208

NCES, 1991 Trends in Academic Progress

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o **Student proficiency in mathematics improving, but still low.** The National Education Goals Panel reported the 1990 NAEP mathematics scores in its first report in September 1991, and concluded that at grades 4, 8, and 12, less than 20 percent of students demonstrated "competency" in mathematics for their grade level (1991). NAEP trend data are reported by proficiency levels, and 1990 results indicate that the majority of students are proficient at a level of mathematics that is below what could be expected for their age and grade.[7] However, the trend data also show that mathematics proficiency has improved at all grade levels, with the most improvement at age 9. The trends by age and proficiency level are shown on page 10.

o Among 17 year olds, only 7 percent scored at or above the mathematics level indicating proficiency with algebra and geometry and multi-step problem solving (i.e., prepared for advanced mathematics beyond high school). From 1982 to 1990 the percentage of students at this level increased only one percent. The percent of 17 year olds at or above the next lowest level--proficiency in fractions, decimals, percents and simple algebra and geometry--increased from 49 percent to 56 percent.

o At age 9 (about 4th grade), 28 percent of students scored at or above the proficiency level of numerical operations with multiplication and division and beginning problem solving, which was a 9 percent increase since 1982. At the next lowest level--proficiency in additive numerical operations and problem solving with whole numbers--82 percent of the nine year olds were proficient, which was an 11 percent increase from 1982 (NCES, 1991c).

o At age 13 (about 8th grade), 17 percent of students scored at or above the proficiency level of fractions,decimals, percents, and simple algebra and geometry, and this represented no change over 1982. In 1990, 75 percent of 13-year olds were proficient at the next lowest level--numerical operations with multiplication and division and beginning problem solving, and this percentage increased by 4 percent in the 1980's.

o **State-by-state mathematics results show wide variation in learning.** In 1990, NAEP conducted a Trial State Assessment of public school students in mathematics at grade 8. The results provide the first state-by-state comparisons on mathematics proficiency of U.S. eighth graders (NCES, 1991b).

The 1990 results showed wide variation in mathematics knowledge and skills within and between states. The percentages of students scoring at the proficiency level of reasoning and problem solving with fractions, decimals, percents, and simple algebra and geometry (300 scale level), varied by state from 24 percent of students in North Dakota to 2 percent of students in the District of Columbia. At the proficiency level of multiplication and division and two-step problem solving (250 scale level), state percentages varied from 88 percent of eighth graders in North Dakota and Montana to 43 percent in Louisiana (NCES, 1991b). As compared to previous NAEP assessments, the 1990 mathematics assessment had a substantially greater emphasis on problem solving in each mathematics content area and the 1990 assessment required use of calculators.[8]

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7 Panels of teachers and mathematics educators reviewed and rated the mathematics content of NAEP questions that clearly differentiated student performance at each proficiency level (NCES, 1991b).

8 The assessment objectives for the 1990 mathematics assessment were developed through a new consensus process that was headed by the Council of Chief State School Officers (CCSSO, 1988). The process involved representatives from mathematics, mathematics education, administrators, policymakers, and the participating states. The assessment objectives relied heavily on the new Curriculum and Evaluation Standards for School Mathematics (1989) produced by the National Council of Teachers of Mathematics. The NAEP proficiency scores by state reflect student performance on the new questions for 1990 combined with performance on the questions used to report trends over time.

NAEP Trends in Mathematics by Proficiency Level

Percentages of Students at Four Levels from 1982 to 1990			
Proficiency Level	Age	1982 % of Students	1990 % of Students
Algebra, geometry, multistep problem solving (350)	17	6%	7%
Fractions, decimals, percents, simple algebra & geometry (300)	17 13	49 17	56 17
Multiplication, division, basic problem solving (250)	13 9	71 19	75 28
Additive numerical operations (200)	9	71	82

NCES, 1991 Trends in Academic Progress

o **NAEP mathematics scores are related to course taking in mathematics.** The 8th and 12th grade students taking the 1990 NAEP mathematics assessment reported on their current and previous mathematics course taking. The data show that 39 percent of 12th grade students took four years of high school mathematics. The average achievement score for these students was 36 points higher than students who had taken less than three years of high school mathematics, or almost the equivalent of one level on the proficiency scale (NCES, 1991b). The 1990 results demonstrated a strong positive relationship between level of course taking in mathematics and mathematics achievement at both 8th and 12th grades.

Summary of Findings

States undertook many policy initiatives in the 1980's with the goal of stimulating improvements in the quality of education. Recently educators, scholars, and policymakers have questioned the effects of the state reforms on changing education in schools and classrooms. Students are taking more science and mathematics courses in high school at all levels, and the data suggest that state policies are related to the increased enrollments. However, the rates of increased course taking are smaller for more advanced courses such as chemistry, physics, trigonometry, and calculus. The data indicate that some states have made significantly more progress than others in encouraging more students to pursue study in science and mathematics. State graduation requirements have had limited success in increasing study of higher level science and mathematics, indicating that other reforms at state, district, or school levels are needed to accomplish this objective.

Trend analyses of NAEP assessments in science and mathematics show that proficiency scores have increased somewhat since 1982. The average achievement of 17-year-olds increased significantly in science and mathematics, and the achievement of 9-year-olds increased significantly in mathematics. The rate of improvement in NAEP proficiency scores has been greater for African-American students than for white students in science and mathematics, and the gap in achievement has been reduced. The NAEP achievement results showed a strong, positive relationship to the amount of coursework in science and mathematics.

Although some progress was made in the 1980's, NAEP results in mathematics indicate that much improvement still needs to be made. A majority of students' mathematics knowledge and skills in mathematics are lower than what mathematics educators expect for students at grades 4, 8, and 12. Much of the improvement in NAEP mathematics scores in the 1980's was at the proficiency levels involving numeral operations and beginning problem solving. As we move into the 1990's, mathematics educators are emphasizing that all students need to learn mathematics reasoning, higher level problem solving, and applications (NCTM, 1989). Mathematics educators and science educators are recommending that NAEP assessments move away from reliance on multiple choice items toward testing methods that give better information about students skills in problem solving and application of knowledge, such as open-ended items, hands-on exercises, and portfolios.

Many of the state policy initiatives were aimed at improving the supply and quality of teachers. Nationally, there are shortages of science and mathematics teachers but predictions of severe shortages have not materialized as of 1990. There are several reasons: the attrition rate of science and mathematics teachers is low and it has not increased during the 1980's; many experienced teachers have returned to the classroom; and, the number of new graduates in science and mathematics teaching has gone up.

There are shortages of qualified high school science and mathematics teachers, as measured by the number of teachers assigned out of their field of certification and by the proportion of teachers with majors in their assigned fields. Shortages of qualified teachers vary widely from state to state, and shortages are much higher in districts with more poor and minority students. Some states with more older teachers are likely to experience shortages of science and mathematics teachers in the 1990's. In addition, a number of states currently have shortages of qualified chemistry and physics teachers. State or local efforts to increase study of upper level science and mathematics could produce further shortages. However, the capacity of school districts to hire new teachers and offer new courses may be restrained by the present budgetary problems in many states.

Table 1
ESTIMATED PROPORTION OF PUBLIC SCHOOL STUDENTS TAKING SELECTED MATHEMATICS COURSES BY GRADUATION

STATE	ALGEBRA 1 (Formal Math Level 1)	ALGEBRA 2 (Formal Math Level 3)	CALCULUS (Formal Math Level 5)
ALABAMA	70%	46%	6%
ALASKA	—	—	—
ARIZONA	—	—	—
ARKANSAS	88	48	5
CALIFORNIA	92	44	9
COLORADO	—	—	—
CONNECTICUT	74	61	14
DELAWARE	73	43	17
DC	65	39	3
FLORIDA	78	42	9
GEORGIA	—	—	—
HAWAII	52	33	4
IDAHO	95+	64	6
ILLINOIS	77	39	9
INDIANA	60	45	8
IOWA	92	50	9
KANSAS	66	47	9
KENTUCKY	81	54	6
LOUISIANA	95+	64	4
MAINE	84	64	—
MARYLAND	94	51	13
MASSACHUSETTS	—	—	—
MICHIGAN	—	—	—
MINNESOTA	90	55	12
MISSISSIPPI	85	58	3
MISSOURI	95	58	8
MONTANA	94	65	6
NEBRASKA	75	54	6
NEVADA	90	32	5
NEW HAMPSHIRE	—	—	—
NEW JERSEY	—	—	—
NEW MEXICO	95+	47	8
NEW YORK	69	46	12
NORTH CAROLINA	67	51	8
NORTH DAKOTA	95	64	3
OHIO	80	47	8
OKLAHOMA	95+	60	8
OREGON	—	—	—
PENNSYLVANIA	88	57	16
RHODE ISLAND	—	—	—
SOUTH CAROLINA	69	55	7
SOUTH DAKOTA	—	—	—
TENNESSEE	79	54	4
TEXAS	82	54	5
UTAH	82	63	13
VERMONT	—	—	—
VIRGINIA	81	55	11
WASHINGTON	—	—	—
WEST VIRGINIA	73	42	2
WISCONSIN	79	36	9
WYOMING	73	29	8
U.S. TOTAL	81%	49%	9%

Note: Each state proportion is a statistical estimate of course taking of high school students by the time they graduate based on the total course enrollment in grades 9-12 in Fall 1989 (See Appendix Table A-5) divided by the estimated number of students in a grade cohort during four years of high school. The statistical estimating method is imprecise above 95 percent course taking rate. (see Appendix C for further explanation)

Algebra 1 percentages include grade 8.

—Data not available

U.S. Total=Proportion of all high school students estimated to take each course, including imputation for non-reporting states.

Source: State Departments of Education, Data on Public Schools, Fall 1989; N. Carolina and Wisconsin, Fall 1988

Council of Chief State School Officers, State Education Assessment Center, Washington, DC, 1990

Table 2

ESTIMATED PROPORTION OF PUBLIC HIGH SCHOOL STUDENTS TAKING SELECTED SCIENCE COURSES BY GRADUATION

STATE	BIOLOGY 1st Year	CHEMISTRY 1st Year	PHYSICS 1st Year
ALABAMA	95+%	38%	21%
ALASKA	—	—	—
ARIZONA	—	—	—
ARKANSAS	95+	33	13
CALIFORNIA	91	33	16
COLORADO	—	—	—
CONNECTICUT	95+	62	36
DELAWARE	95+	48	19
DC	75	46	13
FLORIDA	95+	44	19
GEORGIA	—	—	—
HAWAII	88	40	21
IDAHO	80	26	15
ILLINOIS	78	40	20
INDIANA	95+	42	19
IOWA	95+	57	27
KANSAS	95+	45	17
KENTUCKY	95+	45	14
LOUISIANA	90	50	21
MAINE	94	58	—
MARYLAND	95+	61	27
MASSACHUSETTS	—	—	—
MICHIGAN	—	—	—
MINNESOTA	95+	44	23
MISSISSIPPI	95+	55	17
MISSOURI	86	41	16
MONTANA	95+	48	24
NEBRASKA	95+	46	21
NEVADA	65	33	13
NEW HAMPSHIRE	—	—	—
NEW JERSEY	—	—	—
NEW MEXICO	95+	33	15
NEW YORK	95+	56	28
NORTH CAROLINA	95+	47	15
NORTH DAKOTA	95+	54	24
OHIO	95+	49	20
OKLAHOMA	93	37	10
OREGON	—	—	—
PENNSYLVANIA	95+	56	29
RHODE ISLAND	—	—	—
SOUTH CAROLINA	95+	51	16
SOUTH DAKOTA	—	—	—
TENNESSEE	88	42	11
TEXAS	95+	40	12
UTAH	80	37	20
VERMONT	—	—	—
VIRGINIA	95+	57	23
WASHINGTON	—	—	—
WEST VIRGINIA	95+	40	11
WISCONSIN	95+	51	25
WYOMING	86	36	16
U.S. TOTAL	95+%	45%	20%

Note: Each state proportion is a statistical estimate of course taking of high school students by the time they graduate based on the total course enrollment in grades 9–12 in Fall 1989 (See Appendix Table A-6) divided by the estimated number of students in a grade cohort during four years of high school. The statistical estimating method is imprecise above 95 percent course taking rate. (see Appendix C for further explanation)

—Data not available

U.S. Total=Proportion of all high school students estimated to take each course, including imputation for non-reporting states.

Source: State Departments of Education, Data on Public Schools, Fall 1989; N. Carolina and Wisconsin, Fall 1988

Council of Chief State School Officers, State Education Assessment Center, Washington, DC, 1990

Table 3
PERCENTAGE OF MATHEMATICS AND SCIENCE TEACHERS WITH COLLEGE MAJOR IN FIELD

	Teachers of Math % with Math Major	Teachers of Science % with Science Major	Teachers of Math % with Major in Math or Math Education	Teachers of Science % with Major in Science or Science Education
ALABAMA	39 %	52 %	69 %	63 %
ALASKA	25	48	32	55
ARIZONA	–	43	–	51
ARKANSAS	37	41	63	54
CALIFORNIA	33	52	37	54
COLORADO	30	66	55	75
CONNECTICUT	43	65	57	67
DELAWARE	–	–	–	–
DIST OF COLUMBIA	–	–	–	–
FLORIDA	26	56	60	67
GEORGIA	54	54	76	62
HAWAII	–	–	–	–
IDAHO	33	47	60	52
ILLINOIS	51	56	67	63
INDIANA	37	50	59	65
IOWA	45	55	64	68
KANSAS	44	41	74	44
KENTUCKY	62	57	73	67
LOUISIANA	20	31	55	44
MAINE	22	48	49	57
MARYLAND	58	–	90	–
MASSACHUSETTS	51	59	61	62
MICHIGAN	47	56	71	68
MINNESOTA	54	73	75	82
MISSISSIPPI	49	46	77	72
MISSOURI	40	73	71	76
MONTANA	–	54	62	68
NEBRASKA	32	47	67	55
NEVADA	–	–	–	–
NEW HAMPSHIRE	–	–	–	–
NEW JERSEY	53	71	73	82
NEW MEXICO	54	47	57	54
NEW YORK	49	58	67	69
NORTH CAROLINA	26	49	60	64
NORTH DAKOTA	28	61	65	74
OHIO	44	61	68	71
OKLAHOMA	24	41	52	56
OREGON	31	58	42	66
PENNSYLVANIA	41	55	83	81
RHODE ISLAND	–	–	–	–
SOUTH CAROLINA	47	58	68	78
SOUTH DAKOTA	40	38	65	44
TENNESSEE	46	33	57	44
TEXAS	42	51	60	57
UTAH	24	32	40	37
VERMONT	–	–	–	–
VIRGINIA	57	74	71	77
WASHINGTON	27	36	43	43
WEST VIRGINIA	44	47	74	58
WISCONSIN	49	66	76	77
WYOMING	31	39	55	49
U.S. TOTAL	42 %	54 %	63 %	64 %

– Too few cases for a reliable estimate.
Source: Schools and Staffing Survey, Public School Teachers, National Center for Education Statistics, Spring 1988
Council of Chief State School Officers, State Education Assessment Center, Washington, DC, 1990

Table 4 MINORITY TEACHERS IN MATHEMATICS AND SCIENCE BY MINORITY STUDENTS IN STATE					
		Percent Minority Teachers (9-12)			
STATE	Percent Minority Students (K-12)	Math	Biology	Chemistry	All High Schools
MAINE	2 %	.2 %	0 %	0 %	.3 %
IOWA	6	.4	0	1	1
IDAHO	7 *	2	1	0	2
MONTANA	7 *	1	1	0	2
UTAH	7	2	2	1	3
NORTH DAKOTA	8	.2	1	1	2
KENTUCKY	10	2	3	1	4
INDIANA	14	3	3	2	4
KANSAS	15	3	2	3	4
RHODE ISLAND	16	2	2	5	6
WISCONSIN	14	2	2	1	2
OHIO	16	3	5	2	6
PENNSYLVANIA	17	3	3	1	3
MICHIGAN	22	7	3	1	8
NEVADA	24	9	7	3	10
COLORADO	24	5	6	–	7
CONNECTICUT	24	3	3	2	5
ARKANSAS	25	10	10	6	10
OKLAHOMA	25	5	5	4	6
VIRGINIA	27 *	13	14	10	15
DELAWARE	31	8	4	0	11
NORTH CAROLINA	33	14	16	11	16
NEW JERSEY	34	10	7	5	10
ARIZONA	36	6	5	–	10
ILLINOIS	34	11	12	7	12
ALABAMA	37	18	19	17	21
MARYLAND	38	17	16	–	–
SOUTH CAROLINA	42	22	21	17	20
TEXAS	50	18	17	11	19
MISSISSIPPI	51	26	30	27	31
CALIFORNIA	53	18	16	12	18
NEW MEXICO	58	20	19	19	25
HAWAII	77	71	61	67	78
U.S. TOTAL	32 %	11 %	10 %	7 %	11 %

Percent minority teachers = sum of four non-white categories of public school teachers.
Minority teachers reported under Biology for Colorado, Arizona, Maryland = All science fields.
Sources: (teachers) State Departments of Education, Fall 1989; (students) NCES Common Core of Data, Public School Universe, Fall 1989; (*) USDE Office for Civil Rights, State Summaries of Projected Data. 1986.
Council of Chief State School Officers, State Education Assessment Center, Washington, DC, 1990

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REINVENTING MATH

Active learning promises radical changes, as teachers say the rote approach doesn't add up

By DAVID STIPP

THERE ARE 26 SHEEP and 10 goats on a ship. How old is the captain?

When researchers asked 41 second-graders this question on a math test a few years ago, about 90% of the children gave the same answer: 36. The children, from suburban schools near Birmingham, Ala., had recently scored well above average on the math part of a statewide, standardized achievement test. With perfect fidelity, they followed a rule that had yielded the right answer on similar-sounding problems before: add the given numbers.

The responses vividly illustrate what's wrong with U.S. math education, argues Constance Kamii, a University of Alabama education researcher who posed the question to the students in a study. Traditional math teaching—in which children memorize rules, then do routine exercises largely geared to prepare them for state-required achievement tests—at best imparts "lower-order" skills that make students into "machinelike" number manipulators, she says.

Given this abstract, rote approach to teaching math, "it's surprising anyone stays with it" beyond required minimums, adds Iris Weiss, president of Horizon Research Inc., Chapel Hill, N.C., a consultant on math- and science-education issues.

Beyond New Math

While such views aren't new, the number of math teachers and school administrators embracing them has probably reached an all-time high during the past few years. As a result, math education is undergoing change that promises to be far more pervasive and persistent than past reform movements such as the fizzled new-math movement of two decades ago (remember trying to multiply in base 3?).

The *new* new math springs from the same educational philosophy that has inspired "active learning" in other disciplines. While some teachers believe that active learning is best suited for "softer" disciplines, such as English or social studies, an increasing number of math scholars disagree. Using the term "constructivism," they argue that children learn math best when they construct their own knowledge by wrestling with personally engaging problems.

"The model of learning as transmission of information from teacher to student is bankrupt," declares Brian Drayton, at the Technical Education Research Center, a Cambridge, Mass., nonprofit concern developing new math and science curricula based on active-learning principles.

The case for improving math education has been stated so often by handwringers in high places that it now sounds like a mathematical proof: If children don't know math, they won't be able to acquire technical skills. If they don't have those skills, U.S. economic competitiveness will decline in the increasingly technological marketplace. Therefore, children had better know math. As signs multiply that America is losing economic ground, this argument adds up with unprecedented force.

Concern about math education also is rising as an inverse function of low math scores on the federally sponsored National Assessment of Education Progress. In the latest NAEP math report, from 1990, only 5% of high-school seniors showed an understanding of geometry and algebra. Fewer than half of the seniors showed a thorough grasp of decimals, percents and fractions.

Such students haven't a clue about algebra, which "has become the filter for going on to higher education and getting good jobs," says John Dossey, an Illinois State University math professor and past president of the National Council of Teachers of Mathematics. Even plumbers, he adds, must know more math than most high-school seniors do in order to pass today's licensing exams—for instance, to figure the right slope for a drain pipe, given its diameter and flow-handling requirements.

Three years ago, Dr. Dossey helped forge a remarkable consensus at the 70,000-member NCTM on new standards for teaching math—a blueprint aimed at dramatically changing math pedagogy in America. While general enough to accommodate different teaching styles, the standards plainly take a 90-degree turn away from traditional teaching's emphasis on what reformers call "drill and kill."

Among other things, the standards urge teachers to ask students to work in groups, think out loud in class as they grapple with problems, use calculators and spend time trying different approaches to problems rather than just seeking the right answer. Problems should be better geared to students' interests. An example from Dr. Dossey: Records set by world-class women swimmers have been getting closer to men's times in some events. Ask students to use graphs and equations to figure out if and when women will surpass men.

At Education Development Center Inc., a Newton, Mass., concern generating new math and science curricula, staffers proudly display a seven-foot-long cardboard pencil that students made in a class based on one of the center's new math offerings. It is a scale-model replica of a pencil from Brobdingnag, the land of the giants in "Gulliver's Travels." The children had read a story, developed at the center, based on Swift's classic. It challenged them to calculate the exact dimensions of various objects in Brobdingnag, given the size of, say, a paper clip there.

The NCTM standards also advise that "many students are intrigued by number tricks," such as: "Think of a number. Add 5 to it. Multiply the result by 2. Subtract 4. Divide by 2. Subtract the number you first thought of. I bet I can read your mind: Your answer is 3."

Some 41 states have adopted or are in the process of adopting the NCTM standards, while four more are using them as a basis for crafting their own similar standards, according to the NCTM. But less than one-third of elementary-school teachers and only about one-half of high-school teachers surveyed recently by Horizon Research said they were "well aware" of the new standards.

Teachers' hesitation is understandable, given constructivists' assertion that those who have spent years developing lucid lectures have been doing the wrong thing. Rather, teachers should mostly just ask questions, biting their tongues when necessary so that students have a chance to work things out for themselves.

Start From Scratch

Alabama's Dr. Kamii, an ardent constructivist, goes a step further by arguing that children should learn by "reinventing arithmetic." After second-graders have been introduced to addition and counting by 10s, for example, their teacher might then ask them to suggest and debate ways to subtract 18 from 36. One group, she says, invented this method: "Take 10 from 30, and that's 20. Take 8 from 6, and that's 2 in the hole. So now take 2 from the 20, and the answer is 18." The students not only found a handy way to subtract but also discovered a conceptual basis for negative numbers, she says.

At a constructivist summer math program for female high-school students at Mount Holyoke College, South Hadley, Mass., teachers strive to foster independent thinking by refusing to tell students whether their answers are right or wrong. Students typically work in pairs in class to solve problems and are asked to explain their reasoning to partners. Meanwhile, teachers move among the buzzing groups like benevolent but teasing Zen masters, steering their charges toward enlightenment by asking questions that focus attention on mistakes or unnoticed ways through the math maze.

Among other things, the approach builds confidence by making students "more aware of the knowledge base they've already developed and their ability to use it," says Charlene Morrow, the program's co-director.

Bothered and Bewildered

Of course, it doesn't always work: When teacher Hannia Gonzalez asked her student pairs to explain why dividing by a fraction is the same as inverting and multiplying by it, most were still stumped after a half-hour of frustrated bewilderment. Finally one young woman snapped, "I'm perfectly content with the explanation that multiplication and division are opposites." When Ms. Gonzalez gently probed for deeper reasons, the student sighed heavily and wrote, "I'm tired and bored" on her notebook; she then pouted, head in hands.

But most students—including ones both gifted and slow in math—praise the program, even while describing it with words like "torture." "I get really excited when I figure out something here," says Frances Watson, a high-school junior from Concord, N.C. "I've done it for myself. It hasn't been handed to me."

Just as in other disciplines testing active learning, skeptics question whether math students will get all the basics they need. Moreover, students who learn math the traditional way don't just memorize without understanding—they "figure out concepts" while doing drills, maintains David C. Geary, a University of Missouri psychologist. Dr. Geary recently co-directed a study comparing the addition skills of constructivist-taught first-graders from Columbia, Mo., with students in Hangzhou, China, who learned math through drills. The Chinese could do sums much faster. The researchers also found that the American students often laboriously counted to get answers, while their Chinese counterparts frequently used more sophisticated methods, such as "decomposing" hard sums into combinations of easier ones.

"Constructivists take the view that anything kids don't like is negative," Dr. Geary says. "But if you're going to be good at something, you sometimes have to do things that aren't fun," such as memorization and drills. For Dr. Geary, the "optimal" teaching approach would involve both traditional drills and constructivist methods.

But how do students from constructivist classes do on those crucial achievement tests?

In a recent study led by Paul Cobb and other researchers at Purdue University, second-graders in 10 experimental constructivist math classes in Indiana public schools were compared with peers in eight traditional math classes. At the end of the school year, the two groups got comparable scores on a statewide achievement test, but the constructivist learners showed a better grasp of numerical concepts on a different test with nonstandard questions like, "What number do two 1s and four 10s make?"

Math-education reformers believe that many teachers won't embrace the new NCTM standards until "the tail that wags the dog" in education—achievement tests—puts more emphasis on understanding and less on computational skills. That's beginning to happen: In New York, for example, statewide math exams given to high-school students include open-ended questions, such as proving sides of certain triangles are equal in length.

But constructivists, who often sound like unreconstructed 1960s crusaders, argue that important benefits of their approach won't necessarily show up in test scores. Fostering "autonomy" should be the main aim of education, maintains Alabama's Dr. Kamii. "Kids should be able to judge for themselves whether something is true."

Constructivism can't guarantee independent thinking, but it appears to help. When asked the nonsense question about the ship captain's age, more than a fourth of second-graders from constructivist math classes dismissed it as senseless, reports Dr. Kamii. No student from traditional math classes did. ▦

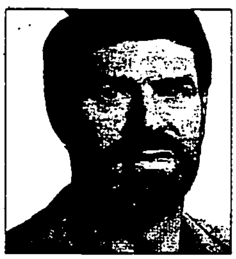
MR. STIPP IS A STAFF REPORTER IN THE WALL STREET JOURNAL'S BOSTON BUREAU.

Why My Kids Hate Science

BY ROBERT M. HAZEN

Last year my sixth-grade daughter, Elizabeth, was subjected to science. Her education, week after week, consisted of mindless memorization of big words like "batholith" and "saprophyte"—words that an average Ph.D. scientist wouldn't know. She recited the accomplishments of famous scientists who did things like "improved nuclear fusion"—never mind that she hasn't the vaguest notion of what nuclear fusion means. Elizabeth did very well (she's good at memorizing things). And now she hates science. My eighth-grade son, Ben, was also abused by science education. Week after week he had to perform canned laboratory experiments—projects with preordained right and wrong answers. Ben figured out how to guess the right answers, so he got good grades. Now he hates science, too.

Science can provide an exhilarating outlet for every child's curiosity. Science education should teach ways to ask questions, and create a framework for seeking answers. In elementary school, because of jargon and mathematical abstraction, my children got the mistaken impression that science is difficult, boring and irrelevant to their everyday interests. Year by year, class by class across America, the number of students who persevere with science education shrinks.



Who is to blame for this turnoff? Scientists themselves are at fault.

As a professional geologist who has tried to convey some of the wonder and excitement of science to nonscientists, I am saddened and angered to see "the great science turnoff." I know that science is profoundly important in our lives. Informed decisions can't be made about where we live, what we eat and how we treat our environment without basic knowledge about our physical world, the knowledge that constitutes scientific literacy. Yet studies and surveys prove that our educational system is turning out millions of scientifically illiterate graduates. What's gone wrong? Who is to blame?

Some people say the problem is too much TV, or lack of parental supervision, or the sometimes poor media image of scientists. Perhaps the fault lies in declining national standards of education, poorly trained teachers or inadequate resources. Maybe students are just too dumb. But I can't escape the truth. Blame for the scientific literacy crisis in America lies squarely at the feet of working scientists. Too often we have sacrificed general education for our own specialized interests. Why haven't children been taught the basics in science? Because most university scientists at the top of the educational hierarchy couldn't care less about teaching anyone but future scientists. To them, science education is a long process of elimination that weeds out and casts aside the unworthy. It's not surprising that scientists have guided science education in this way. All the good things in academic life—tenure, promotion, salary, prestige—hinge on one's reputation in specialized research. Educators focus on teaching advanced courses to students who are willing to run the laboratory. Time devoted to teaching, or even reading, general science is time wasted.

One amazing consequence of this emphasis is that working scientists are often as scientifically illiterate as nonscientists. I'm a good example. The last time I took a course in biology was in ninth grade, long before genetics had made it into the textbooks. In college I studied lots of earth science, even more in graduate school. But from that distant day in 1962 when I dissected a frog, to quite recently when as a teacher I was forced to learn about the revolution in our understanding of life, I was as illiterate in modern genetics as it was possible to be. The average Ph.D. scientist doesn't know enough to teach general science at any level.

Working physicists or geologists or biologists know a great deal about their specialties. That's why Americans win so many Nobel Prizes. But all that specialization comes at a price. National science leaders, who usually are the ones who have done the best playing the research game, have fostered an education policy more concerned with producing the next generation of specialized scientists than educating the average citizen. This policy has backfired by turning off students in unprecedented numbers.

The picture may seem bleak, but the solution is not all that difficult. First, we need to recognize that science can be shared without jargon and complex mathematics. You don't have to be a scientist to appreciate the overarching scientific principles that influence every action of our lives. The central ideas of science are simple and elegant—together they form a seamless web of knowledge that ties together every aspect of our physical experience.

Then we need teachers who are able to convey this unified vision with confidence and enthusiasm. Teachers can't give students a vision if no one has ever given it to them, so every college and university needs to institute general science courses. These courses should be required of all future teachers. Administrators at institutions of higher learning should be as quick to reward the gifted teachers of general science with raises and tenure as they have been to reward the gifted science researcher.

The science classroom, at least through junior high school, should be a hands-on exploration of the universe. Textbooks that are daunting and boring should be burned. Standardized tests that bully teachers into creating rigid curricula should be outlawed. Our children should be given the chance to explore backward in time, look outward through space and discover unity in the workings of the cosmos. Armed with that knowledge they will someday combat disease, create new materials and shape our environment in marvelous ways. Science will also give them the means to predict the consequences of their actions and perhaps, with wisdom, to save us from ourselves.

Hazen, a scientist at Carnegie Institution of Washington and Robinson Professor at George Mason University, is coauthor with James Trefil of "Science Matters: Achieving Scientific Literacy," published by Doubleday.

The Regional Laboratory Math and Science Initiative

Regional Educational Laboratories help to apply the best available knowledge from research and development and from experience to the improvement of schools and education policy. Their first priority in the present contract period (1990-95) is to serve the needs of at-risk students. The Laboratories conduct a variety of technical assistance and applied R&D activities, often collaborating with others. Some activities are targeted at individual local schools and districts, with the intent of finding generalizable solutions to pressing educational problems. Others focus at the state level and may result in significant improvements in state policies and programs.

Laboratories disseminate information widely, both regionally and nationally. They do this through such means as newsletters, research syntheses, conferences, and participation in regional meetings and forums. The Laboratories also increasingly use electronic forms of dissemination, including teleconferences and online information retrieval and exchange systems.

The Math and Science Initiative

In fiscal year 1992, the 10 Laboratories began a new, program-wide initiative to improve mathematics and science education. The $35 million appropriation for the year included $4.16 million for this initiative. Under the initiative, the Laboratories are to:

- Collect, synthesize, and analyze information about **curriculum frameworks** in mathematics and science. The information will be disseminated to local and state education agencies to help them with curriculum-related reform needs.

- Review and synthesize existing **performance assessment methods**; develop criteria and methods for selecting and using performance assessments; and develop training materials for teachers and school staff in using such assessments.

- Identify, select, verify, document, and disseminate information about **successful programs and practices** in mathematics and science education.

- Assess the training needs of mathematics and science teachers; infuse **case study methods** into existing professional development programs; and develop a cadre of teacher educators and others who are capable of leading case discussions in such programs.

- Design, pilot, and field-test new **school development resource centers**. These centers, to be focused initially on mathematics and science education, will provide protected space within a school building for resource materials for teachers, parents, and others, and access point for requesting and receiving research and related materials, a place for professional development activities, and access to electronic bulletin boards and other forms of telecommunications.

Appropriations for FY 93 are pending.

Mathematics and Science Resources

The **American Association for the Advancement of Science (AAAS)** is one of the world's leading scientific societies. The AAAS engages in a variety of activities to advance science and human progress. To help meet these goals, the AAAS has a diversified agenda of programs bearing on science and technology policy; the responsibilities and human rights of scientists; intergovernmental relations in science; the public's understanding of science; science education; and opportunities in science and engineering for women, minorities, and disabled individuals. AAAS' **Project 2061**, which will span over a decade, includes a three-phase plan of action that will contribute to the reform of education in science, mathematics, and technology. 1333 H Street, NW, Washington, DC 20005, (202) 326-6446.

The Education Division of the **American Chemical Society (ACS)** created Chemistry in the Community (CHEMCom), a year-long chemistry course designed for college-bound high schools students who do not plan to pursue careers in science. The eight-unit course emphasizes the impact of chemistry on society by addressing chemistry-related technology issues relevant to the community in which students live. ACS also funds minigrants to assist teachers in developing and implementing innovative curriculum. The program funds projects that focus on the relationship among science, technology, and society issues. Teachers receive up to $1,000 in materials development funds. 1155 16th Street, NW, Washington, DC 20036 (202) 872-6179.

The **Educational Testing Service** administers the National Assessment of Educational Progress (NAEP) as well as related projects, such as state assessments and the International Assessment of Educational Progress. Rosedale Road, Princeton, NJ 08541, (800) 223-0267.

The **ERIC Clearinghouse for Science, Mathematics, and Environmental Education**, funded by the U.S. Department of Education, is located at The Ohio State University. Its primary function is to retrieve and disseminate print information related to science, mathematics, and environmental education. These materials are announced in Resources in Education and Current Index to Journals in Education, two monthly publications. For more information, contact David Hauryat, The Ohio State University, 1200 Chambers Road, Room 310, Columbus, Ohio 43212, (614) 292-6717.

The **Mathematical Association of America (MAA)** is a membership organization for mathematics teachers, students, scientists mathematicians, and mathematics enthusiasts. The MAA provides professional contacts through national meetings and hands-on training through minicourses conducted at four regional meetings each year. 1529 18th Street, NW, Washington, DC 20036, (202) 387-5200.

The **Mathematical Sciences Education Board (MSEB)** was established in 1985 to provide a continuing national overview and assessment capability for mathematics education and is concerned with excellence in mathematical sciences education for all students at all levels. 818 Connecticut Avenue, NW, Suite 500, Washington, DC 20006.

Note: This list was extracted from (and updates) a larger one originally prepared by the National Center for Improving Science Education.

The **National Center for Improving Science Education** (NCISE) aims to promote changes in state and local policies and practices in three areas: the science curriculum, science teaching, and the assessment of student learning in science. The Center recommends a hands-on, inquiry-based, constructivist approach to science. NCISE is a division of the NETWORK, Inc., 300 Brickstone Square, Suite 900, Andover, MA 01810, (508) 470-1080.

The **National Council of Teachers of Mathematics** (NCTM) is dedicated to the improvement of mathematics instruction at all levels. Through its publications, conferences, and other services, this professional organization provides a forum for discussing new developments, sharing innovative classroom experiences, and evaluating trends in the teaching of mathematics. 1906 Association Drive, Reston, VA 22091, (703) 620-9840.

Groups Affiliated with NCTM National Level

International Study Group on Ethnomathematics
Luis Ortiz-Franco
NCTM Representative
2333 East Van Owen Avenue
Orange, CA 92667
(714) 997-6595

National Council of Supervisors of Mathematics
Benjamin Dudley
21 Paddock Lane
Willingboro, NJ 08046
(609) 877-6248

United Federation of Teachers Mathematics Teachers Committee
Nadine Simmons
1730 Mulford Avenue #2N
Bronx, NY 10461

Women and Mathematics Education
Judy Olson
Department of Mathematics
Western Illinois University
Macomb, IL 61455

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing service to the government, the public, and the scientific community. 2001 Wisconsin Avenue NW, Washington, DC 20007, (202) 334-2000.

The **National Science Foundation** (NSF) provides grants for research in the sciences and engineering and for exemplary projects in science, mathematics and engineering education. One education program of interest to states is the **Statewide Systemic Initiatives Program** (SSI), which supports states that develop initiatives promising integrated, systemic changes in their education systems. NSF increasingly supports projects that tie together and sequence effectively the development of new curricula and the special activities necessary to prepare teachers to use the new instructional materials imaginatively. 1800 G Street NW, Washington, DC 20550 (202) 357-5000 (357-7073 for SSI).

The **National Science Resources Center** (NSRC) is jointly sponsored by the Smithsonian Institution and the National Academy of Sciences. The NSRC is working to improve the teaching of science and mathematics in the nation's schools by disseminating information about effective science and mathematics teaching resources, developing curriculum materials, and sponsoring outreach and leadership-development activities. The NSRC has established as its first priority the improvement of science and teaching in elementary schools, and has initiated a number of programs in this area.(202) 357-3313.

The **National Science Teachers Association** (NSTA) sponsors the **Project on Scope, Sequence, and Coordination of Secondary School Science**, a major reform of science at the secondary level. The project recommends that all students study science every year for six years, and advocates carefully sequenced, well-coordinated instruction of all the sciences. As opposed to the traditional "layer cake" curriculum in which science is taught in year-long, discrete, and compressed disciplines, the NSTA project provides for spacing the study of each of the sciences spread out over several years. 1742 Connecticut Avenue, NW, Washington, D.C. 20009, (202) 328-5800.

Science Service, Inc. sponsors an annual directory containing over 700 lists of science training programs for students, including summer and academic year courses and research. Science Service also administeres the **Westinghouse Talent Search**, a competition that focuses on independent research projects and offers scholarships to high school seniors with exceptional talent in science, mathematics, or engineering. 1719 N Street, NW, Washington, DC 20036, (202) 785-2255.

Technical Education Research Centers (TERC) develops computer-based laboratory materials and sponsors programs for teachers in the use of computers to teach science. The Henderson Carriage Building, 2067 Massachusetts Avenue, Cambridge, MA 02140, (617) 547-0430.

The **Triangle Coalition for Science and Technology Education** is a consortium of over 90 national organizations with representation from business, industry, and labor; scientific and engineering societies; and education associations. These organizations are joined together to increase the effectiveness and efficiency of their efforts to reform science and technology education. 5112 Berwyn Road (3rd Floor), College Park, MD 20740, (301) 220-0871.

Other Mathematics and Science Resources

American Association of Physics Teachers
Dr. Bernard Khoury,
Deputy Executive Officer
5112 Berwyn Road
College Park, MD 20740
(301) 345-4200

American Astronomical Society
Mary Kay Hemenway,
Education Officer
Box 3818, University Station
Charlottesville, VA 22903
(804) 924-7955

American Geological Institute
Marilyn Suiter,
Director of Education
National Center for Earth Science
Education
4220 King Street
Alexandria, VA 22302
(703) 379-2480

American Institute of Physics
Donald Kirwan
Education Division Chairman
335 East 45th Street
New York, NY 10017
(212) 661-9404

American Physical Society
Brian Schwartz,
Program Officer
335 East 45th Street
New York, NY 10017
(212) 682-7341

American Society for Engineering Education
Dr. Frank L. Huband,
Executive Director
#200, 11 Dupont Circle, NW
Washington, D.C. 20036
(202) 293-7080

Association of Science-Technology Centers
Bonnie VanDorn, Executive Director
Suite 500, 1025 Vermont Avenue, NW,
Washington, DC 20005
(202) 783-7200

Association of State Supervisors of Mathematics
Charles Watson, President
Arkansas Department of Education
4 State Capitol Mall
Little Rock, AR 72201
(501) 682-4474

Biological Sciences Curriculum Study
Joseph McInerney, Director
830 N. Tejon Street, Suite 405
Colorado Springs, CO 80903
(719) 578-1136

City College Workshop Center
Hubert Dyasi, Director
136th and Convent Avenue
Room 4-220, North Academic Complex
City College School of Education
New York, NY 10031
(212) 690-4162

Council of State Science Supervisors
Bill Spooner, President
Department of Public Instruction
116 West Edenton Street
Raleigh, NC 27603-1712
(919) 733-3694

Education Development Center
Patricia Sacco
55 Chapel Street
Newton, MA 02160
(617) 969-7100

Educational Products Information Exchange
Kenneth Komoski,
Executive Director
EPIE Institute
P.O. Box 839
Water Mill, NY 11976
(516) 728-9100

International Association for the Advancement of Science Teaching
David Lockard
University of Maryland
Benjamin Building
College Park , MD 20742
(301) 405-3165

International Chemistry Olympiad
Martha Turckes
American Chemical Society
1156 16th Street
Washington, DC 20036
(202) 872-4600

International Mathematical Olympiad
Walter Mientka, Chair
MAA Committee on American Mathematics Competitions
Mathematics Department
University of Nebraska
Lincoln, NE 68588
(402) 472-7211

International Technology Education Association
Kendall Starkweather,
Executive Director
1914 Association Drive
Reston, VA 22091
(703) 860-2100

Lawrence Hall of Science
Barbara Ando
University of California
Berkeley, CA 94720
(510) 642-2858

National Association of Biology Teachers
Patricia J. McWethy,
Executive Director
11250 Roger Bacon Drive #19
Reston, VA 22090
(703) 471-1134

National Association of Elementary School Principals
Samuel G. Sava,
Executive Director
Mary Hahn,
Program Coordinator
1615 Duke Street
Alexandria, VA 22314
(703) 684-3345

National Association of Research in Science Teaching
John Stover,
219 Bluemont Hall
Kansas State University
Manhattan, KS 66506
(913) 532-6294

National Association for Science, Technology, and Society
Dr. Carl Mitcham, Director
The Pennsylvania State University
128 Willard Building
University Park, PA 16802
(814) 865-9951

National Center for Earth Science Education
Marilyn J. Suiter, Jr.
American Geological Institute
4220 King Street
Alexandria, VA 22302
(703) 379-2480

National Center for Science Education, Inc.
Eugenie C. Scott, Executive Director
2107 Dwight Way, #105
Berkeley, CA 94704
(510) 528-2521

National Earth Science Teachers Association
Wendell Mohling, President
1742 Connecticut Avenue, NW
Washington, DC 20009
(202) 328-5800

National Science Supervisors Association
Emma Walton, President
Anchorage School District
4600 DeBarr Avenue
P.O. Box 196614
Anchorage, AK 99519
(907) 333-9561

North American Association for Environmental Education
Edward McCrea
Executive Vice President
P.O. Box 400
Troy, OH 45373
(513) 698-6493

School Science and Mathematics Association
Darrel W. Fyffe
Executive Secretary
Bowling Green State University
126 Life Science Building
Bowling Green, OH 43403
(419) 372-7393

Federal Agencies

The **U.S. Department of Commerce's Office of Metric Programs** supports a variety of activities in industry and schools related to metric education. Room 4845H, Washington, DC 20230, (202) 377-3036.

The **U.S. Department of Education** administers the **Eisenhower Mathematics and Science Education Program,** which includes a State Program and a National Program. The State Program provides formula grants to State and local educational agencies (SEAS and LEAs) and competitive grants to institutions of higher education to improve the skills of teachers and the quality of instruction in mathematics and science. SEAs and LEAs must use these funds to address the teacher training needs that they identified in statutorily required State and local needs assessment reports. The National Program funds grants and cooperative agreements for projects of national significance in mathematics and science education. The Department also oversees the **National Diffusion Network (NDN),** which disseminates education programs that have undergone rigorous evaluation and have been proven effective. For the Eisenhower Program, contact Kathy Fuller, FIRST Office, Office of Educational Research and Improvement, Department of Education, 555 New Jersey Ave., NW, Washington, DC 20208, (202) 219-1496. For NDN programs, contact Carolyn S. Lee, same address, (202) 219-2157.

The **U.S. Department of Energy (DOE)** administers the **Teacher Research Associates Program,** which provides selected science and mathematics teachers with 8-week, summer research assignments at 21 DOE National Laboratories. DOE also has formed **Laboratory Partnerships with Rural and Urban Schools.** Through these partnerships, the laboratories provide a range of technical assistance to the school systems, including summer research appointments for teachers and students; mentoring of students by DOE scientists; assistance in the development of classroom and out-of-classroom science experiments; equipment loans; and short courses and institutes for teachers on energy-related topics. For the Teacher Research Associates Program, contact John Ortman, Office of University and Science Education Programs, 1000 Independence Ave. SW, 20585, (202) 586-8949. For the Laboratory Partnerships, contact Kassie Andrews Weller at the same address and phone number.

The **Environmental Protection Agency (EPA),** through its **Environmental Education Urban Initiative,** supports and participates in the development and implementation of programs for urban, inner city youth and teachers. The initiative encourages environmental careers and enhances awareness of science through experiential, environmentally oriented projects and programs. EETP-PP, Office of Environmental Education, Environmental Protection Agency, 401 M St., SW, Washington, DC 20460, (202) 382-4484.

The **Federal Coordinating Council for Science, Engineering, and Technology,** established by the President, has reviewed all departments and agencies of the federal government to comprehensively identify programs affecting science and mathematics education. These programs are listed and described in the document, By the Year 2000: First in the World, which can be ordered through CBIS System, 7420 Fullerton Road, Suite 110, Springfield, VA 22153, (800) 443-3742, Document Number EA022727.

The U.S. **Department of Interior** sponsors **Student Programs**, which support students from high school through graduate school as laboratory assistants, technicians, or beginning scientists working with U.S. Geological Survey professional staff. The **Joint Education Initiative (JEDI)** is an effort by the U.S. Geological Survey in association with the Jet Propulsion Laboratory, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the Smithsonian Institution, and other organizations to enhance and promote precollege earth sciences by developing educational materials that incorporate actual databases and software used by professional earth scientists. Student Programs, 103 National Center, Reston, VA 22092, (703) 343-3888; Joint Education Initiative Program, 912 National Center, Reston, VA 22092, (703) 648-6631.

The **National Aeronautics and Space Administration (NASA)** sponsors **Teacher Resource Centers** at nine major NASA installations. These centers provide easy access to a variety of materials for classes at all levels. NASA has also established **Regional Teacher Resource Rooms** at 15 locations throughout the country to provide materials and classroom activities for teachers. Elementary & Secondary Programs, NASA Headquarters, Washington, DC 20546, (202) 453-8396.

The U.S. **Department of the Navy's Office of Naval Research** (ONR) offers **High School Apprenticeship Awards** to encourage high school students to consider careers as scientists or engineers. ONR funds special classroom activities and supports students working on research projects under the guidance of ONR principal investigators at universities. ONR also runs the **Naval Science Awards Program** to stimulate scientific achievement among high school students. The Navy and Marine Corps participate in some 330 regional and state science and engineering fairs which exhibit projects by high school students. The International Science and Engineering Fair is held in May each year. Code 11SP, 800 North Quincy Street, Arlington, VA 22217, (202) 696-4108.

Improving Equity

Equals develops teacher training programs and curricular materials designed to promote student participation in mathematics courses and careers. Lawrence Hall of Science, University of California, Berkeley, CA 94720, (415) 642-1823.

The **Mathematics, Engineering, Science Achievement (MESA) Program** serves the populations that are underrepresented in colleges, especially in science/mathematics curricula, by virtue of ethnicity, socio-economic level or sex. The program provides an opportunity for such students to explore the academic disciplines in a challenging and supportive environment. The program runs outside of school hours and requires collaboration of the students, their parents, and the MESA faculty. Has served students from 4th through 12th grades. Lawrence Hall of Science, University of California, Berkeley, CA 94720.

The **Mathematics and Science Education Network (MSEN)** Pre-College Program of North Carolina is an incentive program modeled on the MESA program in California (described above). Will also accept nonminority girls. Serves students from grades 6 through 12. In addition to the rigorous Saturday academies and summer scholars programs, students may participate in academic enrichment classes daily as a school elective. University of North Carolina, 201 Peabody Hall, CB #3345, Chapel Hill, NC 27599-3345.

The **Women's Educational Equity Act Publishing Center** has several resources that promote the participation and achievement of girls in mathematics and science. Educational Development Center, 55 Chapel Street, Newton, MA 02160, (800) 225-3088 or (617) 969-7100.

Federal Agencies

The U.S. Department of Agriculture's Agricultural Research Service (ARS) administers the **Research Apprentice Program**. ARS scientists are encouraged to act as mentors to high-potential students interested in agricultural, biological, or physical sciences. ARS also has a **Program in Agriculture and Life Sciences for Minority Students (PALMS)**. The 6-day program at the Beltsville, Maryland, Agricultural Research Center includes lectures, hands-on experiences, and job seminars. Room 339A, 14th Street and Independence Avenue, SW, Washington, DC 20250, (202) 447-6161.

The U.S. Department of Commerce has established the **Metropolitan Consortium for Minorities in Engineering and Science Career Orientation Program**. This is a summer experience for high school juniors and seniors from the metropolitan Washington, D.C. area. National Sea Grant College Program, Silver Spring Metro Building 1, 1335 East West Highway, Silver Spring, MD 20910, (301) 427-2431.

The U.S. Environmental Protection Agency (EPA), through its **Office of Environmental Education**, sponsors a **Minority Student Fellowship Program**. It supports seniors and graduate students majoring in agriculture, science, or engineering at historically black colleges. 401 M Street, SW, Washington, DC 20460, (202) 382-7445.

The U.S. Department of Interior has established the **Minority Participation in the Earth Sciences (MPES) Program**. In it, minorities and women are encouraged to pursue undergraduate and graduate training in earth sciences and related fields. The program provides on-the-job opportunities for participants to work with professionals and increases students' knowledge of earth sciences. High school, undergraduate, and graduate students, and teachers participate in MPES activities. U.S. Geological Survey, 103 National Center, Reston, VA 22092, (703) 343-3888.

Other Equity Resources

Association for Women in Science
Catherine Didion
1522 K Street, NW #820
Washington, DC 20005
(202) 408-0742

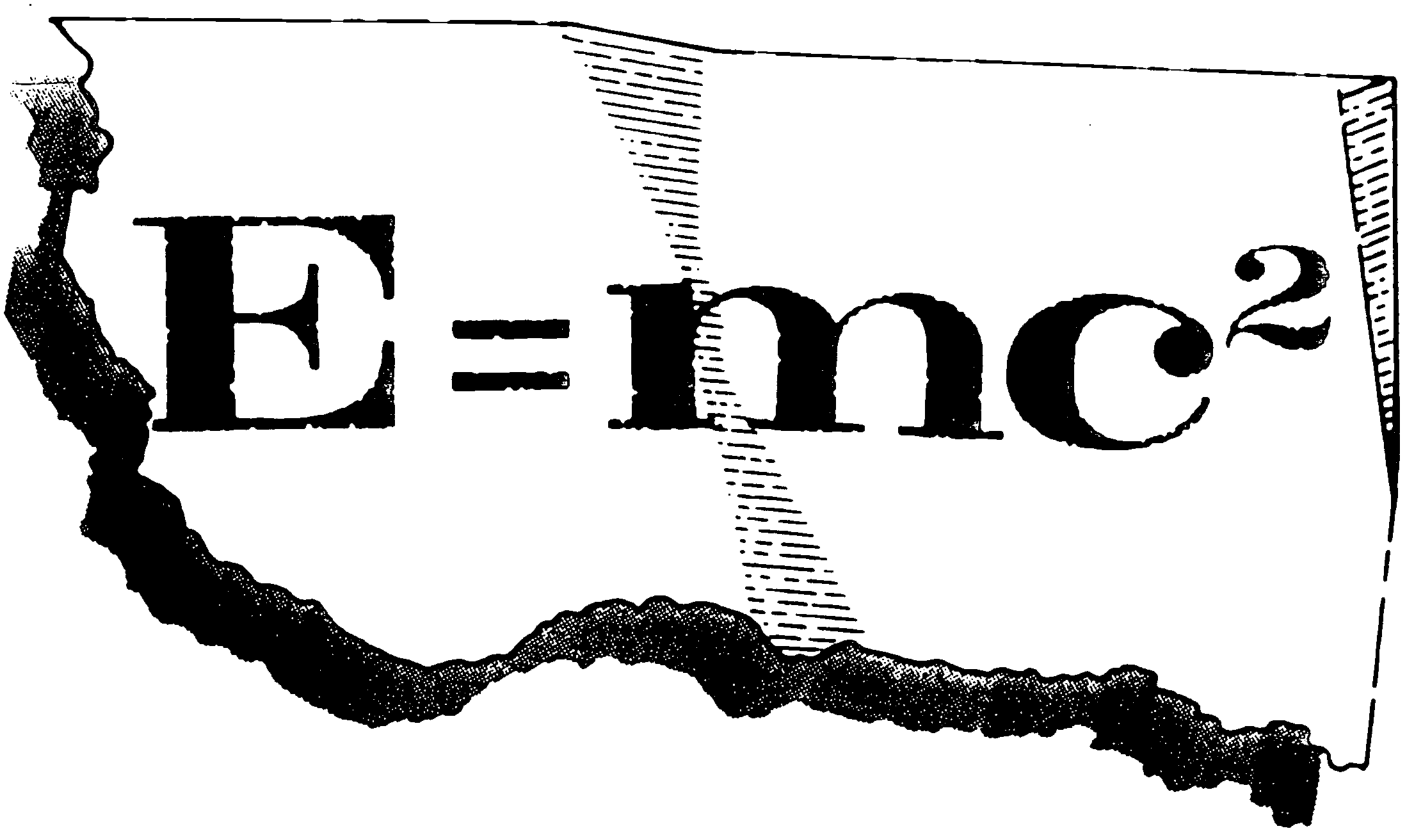
Girls, Inc.
Operation SMART
Margaret Gates,
Executive Director
Ellen Wahl
Director of Program Services
Libby Palmer,
Director, Operation SMART
30 East 33rd Street
New York, NY 10016
(212) 689-3700

Title IV Desegregation Assistance Centers

Funded under Title IV, Civil Rights Act of 1964, these 10 desegregation assistance centers provide technical assistance and training services to school districts in their regions. They focus specifically on helping educators promote equal opportunity on the basis of race, national origin, and sex. Although specific services vary from center to center, most will have resources--training, consultations, materials, and model programs--to address equity in mathematics and science for young women and minorities.

New England Center for Equity Assistance (NECEA) **The NETWORK** Ray Rose 290 South Main Street Andover, MA 01810 (508) 470-1080	Region I:	Connecticut, New Hampshire, Vermont, Maine, Rhode Island, Massachusetts
Metro Center LaMar Miller New York University Room 72, 32 Washington Place New York, NY 10003 (212) 998-5110	Region II:	New Jersey, New York, Puerto Rico, Virgin Islands
Mid-Atlantic Equity Center Sheryl Denbo The American University 5454 Wisconsin Avenue, NW Suite 1500 Chevy Chase, MD 20815 (301) 885-8517	Region III:	Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, West Virginia
Southern Education Foundation Gordon Foster 135 Auburn Avenue Atlanta, Georgia 30303 (404) 523-0001	Region IV:	Alabama, Florida, Georgia, Kentucky, Mississippi, South Carolina, North Carolina, Tennessee
The University of Michigan School of Education Percy Bates PED -- Room 1005 Ann Arbor, Michigan 48109 (313) 763-9910	Region V:	Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin

Intercultural Development Research Association Jose A. Gardenas Suite 350, 5835 Callaghan San Antonio, TX 78228 (512) 884-8140	Region VI:	Arkansas, Louisiana, New Mexico, Oklahoma, Texas
Kansas State University School of Education Charles Rankin Bluemont Hall Manhattan, Kansas 66606 (913) 532-6408	Region VII:	Iowa, Kansas, Missouri, Nebraska
Mid-Continent Regional Educational Laboratory Shirley McCune Equity Division Suite 500, 2550 South Parker Road Aurora, CO 80014 (303) 337-0990	Region VIII:	Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming
Southwest Regional Laboratory for Educational Research and Development Harriet Doss-Willis 4665 Lampson Avenue Los Alamitos, CA 90720 (310) 598-7661	Region IX:	Arizona, California, Nevada
INTERFACE Esther Puentes Suite 202, 4800 SW Griffith Drive Beaverton, OR 87006 (503) 644-5741	Region X:	Alaska, Hawaii, Idaho, Oregon, Washington, American Samoa, Guam, Northern Mariana Islands, Trust Territory of the Pacific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University of Southern California • Harvard University
Michigan State University • Stanford University
University of Wisconsin-Madison
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The Governance of Teacher Education and Systemic Reform

Hendrick D. Gideonse

The governance of teacher education embraces the structures of government agencies and teacher preparation institutions responsible for addressing such policy matters, the processes employed by those structures in arriving at policy (e.g., sources of initiative, advisory input, opportunities for review, accountability schemes), and the functions of teacher education policy (e.g., establishing entrance qualifications, levels of preparation, nature of the preparation program, and exit standards). In the United States, the structures for governing teacher education are diverse. In most states, formal authority over teacher education policy has been vested in lay hands through state boards of education. In a few, it rests with professional standards and practices boards. State legislatures, national accreditation and certification bodies, and state and national commissions also play a role in policy development. Within this governance structure, colleges and universities exercise considerable latitude in designing and implementing teacher preparation programs.

Policymakers face many obstacles as they work to bring the governance of teacher education into productive alignment with the press for systemic reform. These include: (1) overcoming the "12-year observational apprenticeship," where students bring to teacher education programs the understandings about and attitudes toward teaching that they developed during their years in elementary and secondary school; (2) shared responsibility but diffused authority for the education of prospective teachers between schools, colleges and departments of education (SCDEs) and schools of liberal arts and education; (3) the relative poverty of resources in teacher education programs; (4) the absence of a research and development substructure for education; (5) the lack of a consensus within the teacher education, teaching and policy communities on what we mean by teaching, teacher preparation or advancing the profession; (6) a lack of identification with the profession and with teacher education as a function; (7) institutional diversity in teacher education; (8) jaded views of past state regulatory effort; (9) limited incentives for entering teaching; and (10) the impact of emergency certification and alternative routes to certification on the ability of institutions to upgrade teacher preparation programs and on the willingness of local school districts to recruit the most qualified teachers through salary and improved working conditions.

In addition, policymakers face two other issues. First, which "system" do we have in mind when we talk of systemic reform: the entire educational system, including higher education, political structures, local/state/federal jurisdictions, and corporate elements; the accountability system (that enterprise responsible for defining goals, measuring progress and establishing corrective action); or the system defined as the interface of teachers and students in the interest of student learning? Each of these conceptions of system is different and each has different implications for policy. Second, what goal(s) do we seek through and for reform? Systemic reform must address the processes of goal definition, legitimation, assessment and reformulation, as well as the content of learning outcomes.

The challenge to the policy community is to transform teacher preparation and certification policies in a way that will support the push for reform of the classroom. "The governance of teacher education for purposes of achieving systemic reform will need to establish a policy context that lends SCDE's the same freedom to explore, the same opportunity to learn from error, the same opportunity to make the meanings of learning real to them that a constructivist learning environment would provide for children."

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Teachers' Professional Development in a Climate of Educational Reform

Judith Warren Little

There are five current streams of reform which present challenges, possibilities and constraints for teachers' professional development. The first stream of reform involves reforms in subject matter teaching — standards, curriculum and pedagogy. These reforms aspire to "more ambitious student outcomes." These pose a challenge to teachers both because they may represent a substantial departure from teacher's prior experience, established beliefs, and present practice, and because in the course of establishing these reforms, teachers may be pressed to move on many fronts at once. The second strand of reforms centers on the problems of equity and the increasing diversity of the student population. These reforms focus on the factors which contribute to the persistent achievement disparities among students from differing family backgrounds. The third wave of reforms involves the nature, extent and uses of student assessment. Reform proposals argue for more widespread and rigorous use of authentic assessment. The fourth wave of reform focuses on the social organization of schooling. These reforms call for schoolwide restructuring, for systemic reform rather than the restructuring of specific programs or practices. The final wave of school reform focuses on the professionalization of teaching. These reforms center on teacher's demonstrated knowledge base, conditions surrounding teacher licensure, and on the structure of career opportunities in teaching.

A major difficulty in professional development is the absence of "fit" between the nature of the task of reform and the prevailing models of professional development — in particular, the dominance of a training paradigm built on "knowledge consumption," and the lesser support for an inquiry and problem-solving paradigm built around "knowledge production." Six principles for professional development which would stand up to the complexity of present reforms are: (1) meaningful intellectual, social, and emotional engagement with ideas, with materials, and with colleagues both in and out of teaching; (2) an explicit historical and contextual sensitivity: a means of locating new ideas in relation to individual and institutional histories, practices, and circumstances; (3) support for principled and informed dissent; (4) a "big picture" perspective on the purposes and practices of schooling, as a means of seeing and acting upon the connections among teachers' classroom practice, schoolwide structures and cultures, and students' experiences; (5) support for teachers (and students, parents) in learning and using the techniques and perspectives of inquiry; and (6) a mechanism to produce bureaucratic restraint and to achieve balance between the interests of individuals and the interests of institutions.

Four alternatives for professional development which make some deliberate attempt to embody these principles are: teacher collaboratives and other networks, subject matter associations, school university collaborations targeted at school reform, and special institutes and centers. District-sponsored staff development and union-initiated projects are more problematic alternatives, but are so central to teachers' lives and employment as to command policy attention.

In addition to the lack of "fit" between the reform task and traditional models of development, issues in the design of professional development also center around: the sheer complexity of the reform tasks being proposed, and the relative absence of tested principles, policies, and practices together with the contradictions across policies and the propensity to seize upon early stage experiments as "models"; and the relative inattention to teachers' "opportunity to learn" with in the salaried work day and work year — an issue in the social organization of teachers' work in schools and their participation in a wider professional community.

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Professional Development and Systemic Reform

Jane L. David and Jennifer A. O'Day

Systemic reform is driven by the goal of more ambitious learning for *all* students, guided and supported by an integrated set of policies that send reinforcing signals about what students—and educators—are expected to know and be able to do. In contrast to the current array of conflicting signals and patchwork policies, systemic reform aims to align curriculum, materials, assessments, certification and licensing, as well as professional preparation and development, around a set of demanding learning outcomes for students.

This conception of reform has profound implications for teaching and for the organization of schools and of the larger education system. It will require the removal of current political and organizational barriers to policy coordination. It will also require fundamental changes in educational governance to support school site authority and flexibility. Teachers and administrators will have to play very different roles which in turn demand a very different set of skills and knowledge.

Challenging standards, curriculum frameworks, and new forms of assessment have commanded considerable attention in recent months. Far less attention is being paid to the gap between what teachers are taught to do and the far greater repertoire of knowledge and skills they will need to create learning opportunities that will lead to ambitious outcomes for students. Such learning environments are far more complicated and difficult to create than typical teacher talk, worksheets, and multiple-choice tests. Analogously, the role of principals—and district administrators—becomes a far more complex act of inspiring teachers, affirming new values and beliefs, seeking information and resources, and removing barriers.

The insights about learning that have resulted in ambitious goals for students apply to adults as well. Yet neither professional preparation or development for educators nor requirements for licensing and certification reflect these insights. The challenge is daunting. Nevertheless, there are a growing number of examples of dramatically different approaches to teacher and administrator preparation and development, and their credentialing, that offer bridges to the future—bridges which can be supported by consistent signals about what we want students and educators to know and be able to do.

Brief to policymakers

When School Restructuring Meets Systemic Curriculum Reform

Fred M. Newmann and William H. Clune

Policymakers face a throng of proposals to improve education: chartered schools, school choice, new systems of testing, year round schools to name a few. While the merits of each initiative should be considered, policymakers must also assess how one reform relates to another. Examining the connections helps to minimize inefficiencies when separate interventions contradict one another or operate in isolation. Education policy should be crafted to support a set of mutually beneficial reforms.

We examine here the relationship between two initiatives: school restructuring and systemic curriculum reform. School restructuring tends to focus primarily upon process–the roles and rules that govern how educators and students function in schools. Systemic curriculum reform concentrates more directly on content and curriculum across a range of schools.[1] We describe the main features of each initiative, and consider both the promise and limitations systemic curriculum reform holds for school restructuring.

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School Restructuring

School restructuring can include any number of departures from conventional practice that fundamentally change the roles of teachers, administrators, students, and parents working with schools.[2] Some notable innovations include school-based management; team teaching across grades or disciplines; longer class periods meeting fewer times per week; replacing ability grouping with heterogeneous classes; replacing Carnegie units with outcomes-based assessment.

School restructuring differs from prior reforms in several appealing ways. It invites fundamental redesign of teaching and learning to address the underlying causes, rather than the symptoms, of low quality education. It recognizes the importance of building school-wide vision and capacity to identify and solve problems, rather than adopting one project after another to placate separate interests within the school. It understands that for reforms to work, school staff must be committed and that commitment arises largely through a participatory and collegial school organization, not a top-down hierarchy.

In its search for new approaches, however, school restructuring itself raises new problems. Teaching responsibilities broaden, calling for a host of commitments and competencies in such new roles as instructional coach, curriculum team member, entrepreneur to build new programs, student advisor/confidant, and participant in organizational decision-making. Few teachers have been formally prepared to perform well in these diverse roles.

Second, the attention to governance, collaborative professional interaction, and student need for social support can easily divert staff energy away from critical issues in curriculum and instruction. By involving teachers in numerous activities other than teaching a common curriculum, school restructuring can diminish attention from important curricular issues.

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Finally, when teachers do focus on improving curriculum and instruction, they often confront three problems that school restructuring alone cannot solve: (a) disagreement within the school on how and what to teach; (b) lack of curriculum materials that offer challenging academic content engaging for culturally diverse and at-risk students; and, (c) district or state policies in curriculum, assessment, teacher preparation, or staff development that hinder the school's efforts to improve curriculum and instruction.

Systemic reform promises to provide the new "beef" or substantive content to replace superficial curriculum coverage and tedious instruction in basic skills.

Whether school restructuring will contribute improved, high quality curriculum seems to be an open question. How can systemic curriculum reform help restructured schools to resolve these problems?

Systemic Curriculum Reform

According to advocates of systemic reform, the institutions that most influence curriculum and instruction in schools are colleges and universities that prepare teachers; state agencies that license teachers; regional agencies that issue regulations on curriculum, testing, and staff development; producers of tests and instructional materials; and staff development organizations.[3] Yet these organizations are not coordinated to support high quality, challenging curriculum. Suppose that a state developed high quality guidelines for curriculum content K-12. Publishers' texts, geared to a national market of different expectations, offer few resources to teach the intended material. The state's own university prepares novice teachers not to teach the state curriculum, but instead to pass courses in the academic disciplines and education that might even contradict the curriculum. The new state curriculum would likewise be ignored, or its aims undermined by producers of national tests. The systemic solution is to find a way of aligning the products and services of these organizations.

Reform of this sort needs to be developed through a state or broad regional framework, not school by school. Not only do schools lack authority and influence over the institutions which shape curriculum, but individual schools lack the technical capacity to develop comprehensive programs. It is the states' constitutional responsibility to provide all students equal access to high quality education.[4]

Systemic curriculum reform relies on resources and standards beyond the school, but proponents also recognize the dangers of centralized, top-down regulation. They insist that individual schools retain broad discretion over instruction. Systemic reform would provide substantive content through curriculum standards, instructional materials, assessments and staff development, bu' would refrain from prescribing details of classroom practice and school organization. Instead, it would present guidelines and resources for assessment, curriculum and staff development that individual schools could adapt. Teacher preparation institutions would align their instruction to the system's guidelines and resources.

The Promise of Systemic Curriculum Reform

Teachers in restructured schools often consider curriculum guides, published instructional materials, and tests woefully inadequate. They crave ideas for teaching academic subjects in ways that motivate culturally diverse students who they often feel have not been adequately prepared for the current grade level or course. Although individual teachers may work hard to develop new curriculum and tests, there is usually not enough time to reach solid consensus about the best curriculum, or to produce materials of sufficient quality to be validated by authorities beyond the school. And they worry that the knowledge and skills they teach will wither away for lack of reinforcement in subsequent curriculum.

Ideally, systemic curriculum reform would solve these problems by offering curriculum guides, instructional materials, and assessment tools impressive enough to stimulate greater staff consensus within schools. A longitudinal curriculum framework would permit teachers to assume certain student competence at entry and count on reasonable continuity in subsequent studies. Continuous access to staff development aligned with these resources would help teachers to use and adapt the curriculum to suit the special circumstances of their student body.

By providing such a framework, teachers would be free to think more productively about critical details of pedagogy which now receive almost no attention. In this sense, systemic reform promises to provide the new "beef" or substantive content to replace superficial curriculum coverage and tedious instruction in basic skills. The school restructuring process could then focus on delivering the content most effectively.

Limits of Systemic Curriculum Reform

Other nations such as Japan or Germany have already achieved alignment of curriculum, testing, and teacher preparation. These countrie have an ambitious common curriculum for all students in primary school; almost no standardized testing; and a high degree of teacher commitment ›d cooperation in preparing lessons to teach the .rriculum. School restructuring in the United States, however, raises at least four issues that systemic reform proposals have yet to resolve: (a) reaching broad consensus on curriculum goals; (b) overcoming economic and political obstacles to institutional alignment; (c) retaining sufficient autonomy for schools and teachers to cultivate professional commitment to systemic curriculum; and (d) offering staff development broad enough to improve the existing skills of teachers and address legitimate concerns beyond curriculum.

Systemic policy in other nations is supported by strong cultural and institutional consensus over curriculum content. But in the United States, longstanding disagreement over curriculum goals will probably continue. Reaching agreement will be complicated by persisting conflict between traditional and progressive visions of education.[5] For example, traditionalists emphasize the need for exposure to broad surveys of knowledge and basic skills, while progressives stress in-depth understanding and critical thinking of a smaller set of topics.

The second problem is how actually to achieve 'ignment at a state, regional, or national level. ne producers of curriculum guidelines, instructional materials, tests, teacher education, and staff development include a variety of public and private organizations operating under different authority structures and incentive systems. Theoretically, a central state organization could conceptualize, produce, and deliver all the required goods and services. Or the state could conceivably create powerful economic incentives for existing organizations to align their work more closely to a state framework. One problem of depending upon the state for alignment is that democratic, interest-group politics often produce trade-offs, compromises, and incoherent policy. Coordinating the work of diverse, traditionally autonomous organizations, will ultimately depend on building sustained, serious commitment to a more challenging curriculum for all children. Alignment thus depends upon broad consensus.

How to arrive at consensus on and alignment toward appropriate, *high quality* curriculum standards is another matter. Potential dangers of inadequate or even harmful systemic standards raise the dilemma of centralized, top-down, versus decentralized, bottom-up reform. How will states :ve specific guidance but at the same time permit ‚cal schools and individual teachers enough discretion and autonomy to respond to their unique circumstances? The challenge is to strike a balance between two extremes. A highly specific and prescribed curriculum dampens local ownership, but a very general one with broad-ranging options, offers no definitive guidance.

Systemic curriculum reform concentrates appropriately on *curriculum*, but it must also recognize the existing skills and concerns of teachers. Most teachers are not prepared for the new content or pedagogy contemplated by systemic reform. For example, "teaching for understanding" in mathematics requires both a new way of thinking about math and a new, more participatory kind of teaching.[6] At the same time, teachers raise lots of questions related to curriculum implementation. How can the curriculum be taught to a heterogeneous group? How can I get students to talk constructively with one another about the curriculum? How can I keep all students up to date when at least 20% are absent each day? How can we get all members of our teaching team to buy in to the plan? How do I respond to parents who think the curriculum is either too regimented or too permissive? Where will I find time to respond thoughtfully to each student's writing? To implement high quality curriculum teachers need help with these and other issues arising out of the new roles they assume in restructured schools. Systemic reform thus confronts a twin challenge in staff development: providing training commensurate with the difficulty of the new material and simultaneously translating it to the broader needs of teachers in specific contexts.

Policymakers must develop consensus around an inspiring vision of educational content and deliver the resources necessary for substantial change.

Conclusion

Systemic curriculum reform has the potential to offer restructured schools a high quality curriculum, while school restructuring offers a process for building the teaching/learning environments capable of supporting such a curriculum in diverse school communities. To reach this potential, policymakers must develop consensus around an inspiring vision of educational content and deliver the resources necessary for substantial change. School restructurers must focus on curriculum and confront problems with implementing a new, challenging vision of teaching and learning. Equity is an important common concern for both policy and practice because of the promise and perils of high standards for an increasingly diverse population of students.

Endnotes

1. See Clune, W. H. (1990). Educational governance and student achievement. In W. H. Clune & J. F. Witte (Eds.), *Choice and control in American education: Vol. 2. The practice of choice, decentralization and school restructuring* (pp. 391-423). Philadelphia: Falmer Press.

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Improving Equity

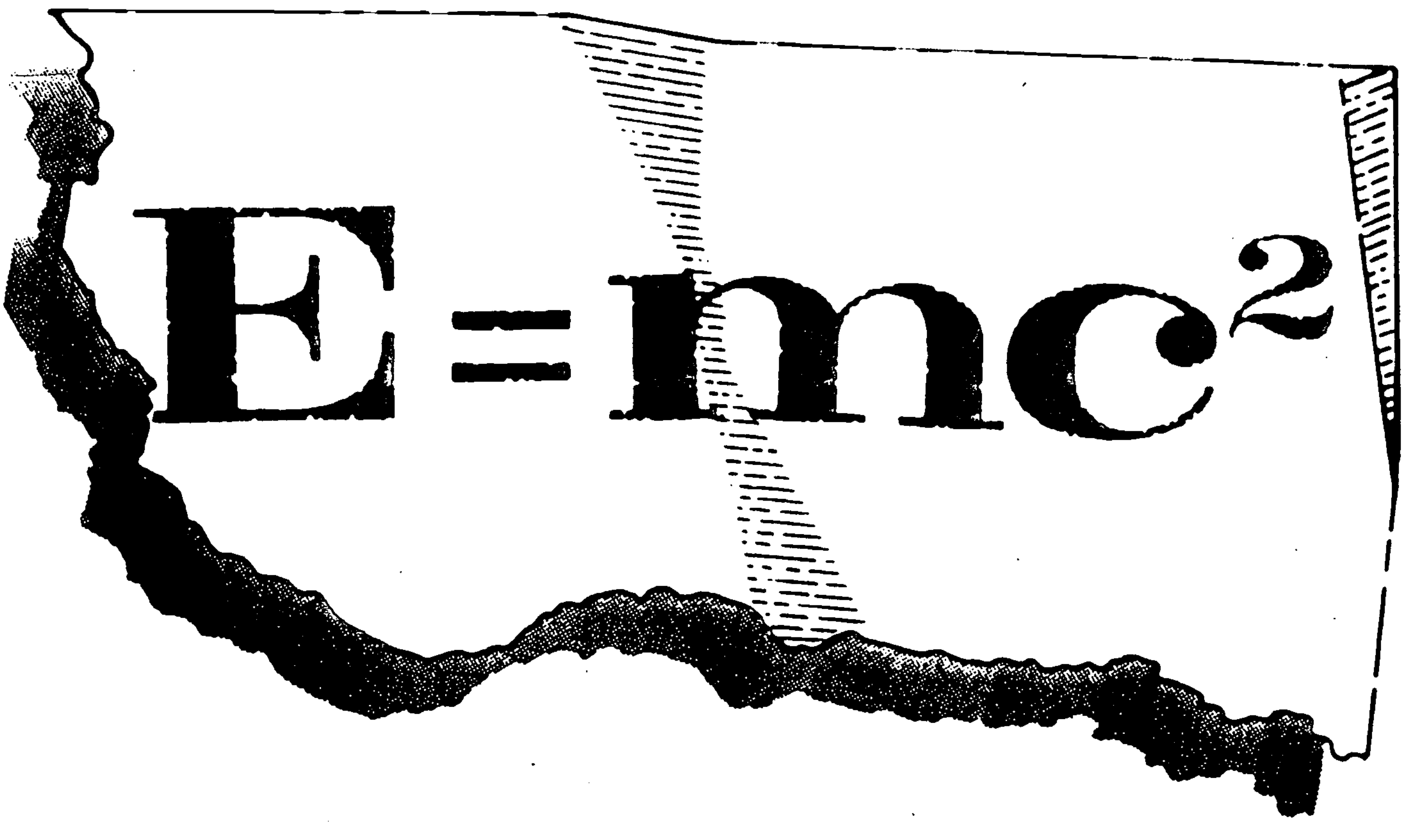
The **Children's Defense Fund (CDF)** is a research and advocacy organization for children's issues. CDF's goal is to educate the nation about the needs of children and encourage preventive investment in children before they become sick, drop out of school, or get into trouble. 122 C Street NW, Washington, DC 20001, (202) 628-8787.

The **Quality Education for Minorities Network** runs the **Quality Education for Minorities Project.** Although the project is directed at upgrading the quality of education to minorities, it benefits all students. Policymakers determine the goals in education and turn over the responsibility and authority for achieving those goals to the community--the students, teachers, principals, parents, and child development professionals. Efforts are made to address the students' needs, be they physical or emotional, both at school and at home. Children are graded not by age but by skill mastery--especially in the early grades. 1818 N Street, NW, Washington, DC 20036, (202) 659-1818.

Federal Agencies

The **U.S. Department of Health and Human Services (HHS)** administers the **Minority High School Student Research Apprentice Program,** the single largest program in the HHS precollege initiative. The program awards grants to eligible institutions so that they may bring minority students into their research projects as research apprentices. In FY 1991, the program began a high school science teacher initiative. This new effort will allow teachers who are members of a minority group, or who teach a significant number of minority students, to participate in a summer research project to update their knowledge and skills in modern research tools and techniques.

The **National Institutes of Health** administer the **Minority High School Student Research Apprentice Program,** which supports students who work individually on projects with NIH researchers. Room 10A11, Westwood Building, 5333 Westbard Avenue, Bethesda, MD 20892.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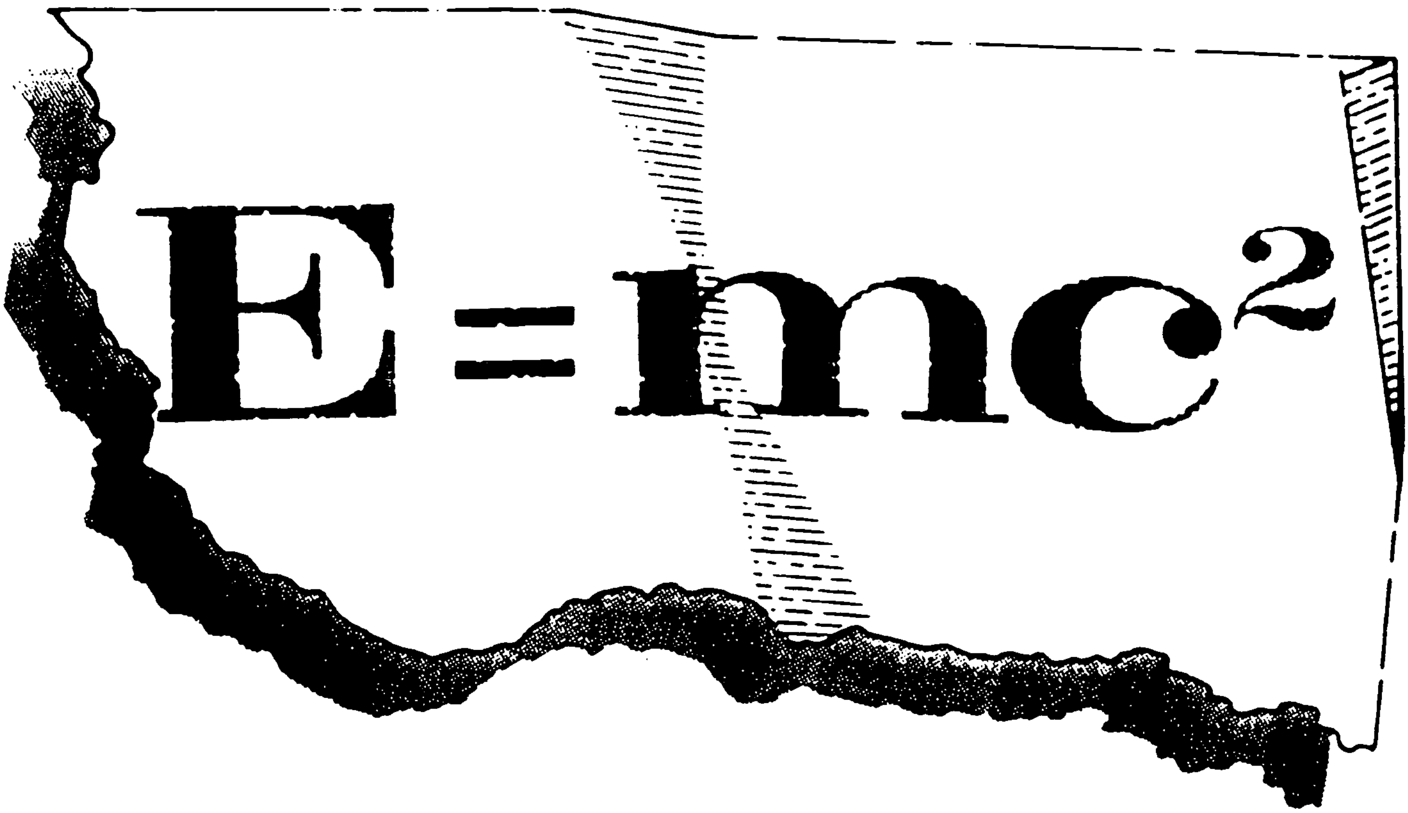
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Demonstrations

and

Exhibits

Exhibits

During the conference there will be exhibits of exemplary science and mathematics instructional materials and professional development materials at various locations in the hotel and in the Office of Educational Research and Improvement.

Listed below are the names and locations of the exhibits. Additional information about the exhibitors is on the following pages.

American Association for the Advancement of Science
Executive Foyer (Lower Level)

Mathematical Sciences Education Board
Jersey Ave Sandwich Shop (Mezzanine Level)

National Council of Teachers of Mathematics (NCTM)
Executive Foyer (Lower Level)

Triangle Coalition for Science and Technology Education
Lower Level Lobby

U. S. Department of Education; Dwight D. Eisenhower Mathematics and Science Education Programs
Lower Level Lobby

U.S. Department of Education; Office of Educational Research and Improvement
Main Lobby

U. S. Department of Energy
Jersey Ave Sandwich Shop (Mezzanine Level)

General Information
Lower Level Lobby

American Association for the Advancement of Science (AAAS)

PROJECT 2061 is a reform initiative in science literacy from the AAAS. Student centered and teacher driven, its goal is to improve the quality, increase the relevance, and broaden the availability of the natural and social sciences, mathematics, and technology for all students K-12.

The Project's 1989 report, Science for All Americans (SFAA), outlined what all high school graduates should know and be able to do in all of the sciences, mathematics, and technology. Teams of educators at six demographically distinct sites are translating Science for All Americans' learning goals into benchmarks for science literacy at grades 2, 5, 8, and 12. These cross-grade/cross-discipline teams are also designing instructional blocks for alternative approaches to an integrated curriculum framework. A computerized design and resources system will assist school districts in developing their curricula locally.

Contact:
Gary Hammond
AAAS
1333 H St. NW
Washington, DC 20005

Mathematical Sciences Education Board

The Mathematical Sciences Education Board works to inform and enhance public understanding and to provide national leadership for policy and strategy towards the improvement of mathematics education.

Contact:
Ann Kahn
Director of Organizational Relations
2101 Constitution Avenue, NW, HA476
Washington, DC 20418

National Council of Teachers of Mathematics (NCTM)

NCTM is the nation's largest organization concerned with the improvement of mathematics education in elementary, secondary and senior high schools as well as two-year and teacher-education colleges. Through its many publications and information services, this professional organization of more than 92,000 members and 245 affiliated groups in the United States and Canada serves as a forum for discussing new developments in mathematics education and sharing innovative classroom techniques. General information on NCTM will be available at the exhibit booth.

Contact:
NCTM
James M. Clayton and L. Eileen Erickson
1906 Association Drive
Reston, VA 22091

Triangle Coalition for Science and Technology Education

The Triangle Coalition is a national organization of over 100 members which brings together three major sectors in the interest of education reform: business/industry/labor, science/engineering and education. Member organizations are involved as equal partners in science and technology education reform by linking their resources to a national network of alliances and other members. The Triangle Coalition focuses its efforts on: resource mobilization, communication and advocacy.

Contact:
Lauren Williams
5112 Berwyn Road
College Park, MD 20740

U.S. Department of Education, Dwight D. Eisenhower Mathematics and Science Education Program

The Eisenhower program focuses on professional development in math and science education K-12; provides financial assistance to states through activities implemented by state and local educational agencies and institutions of higher education; and focuses on instructional and career opportunities for underrepresented and underserved populations in scientific and technical fields. The Triangle Coalition's Eisenhower math and science technical assistance and leadership development project will be featured. Program information and publications, as well as information on the upcoming 1992 Eisenhower Mathematics and Science National Conference will be available.

Contact:
Vera Faulkner
Triangle Coalition
5112 Berwyn Road, 3rd Floor
College Park, MD 20740

U.S. Department of Education, Office of Educational Research and Improvement (OERI)

OERI is the primary research agency of the Department of Education. The office funds research and demonstration and school improvement programs; collects and analyzes statistics; reports on the condition of education; and disseminates information about education programs. The exhibit will highlight OERI programs and products aimed at improving the achievement of American students in mathematics and science.

Contact:
Kay McKinney
OERI
555 New Jersey Avenue, NW
Washington, DC 20208

U.S. Department of Energy

"Faces of the Future" describes pre-college through post-graduate education programs sponsored by the U.S. Department of Energy. Teacher Research Associate Program (TRAC) applications will be available at the booth. TRAC offers 8 week research appointments for science and mathematics teachers in grades 7-10.

Contact:
John Ortman
U.S. Department of Energy
AT-50
Washington, DC 20585

General Information

Various organizations and individuals attending the conference have provided material for this general exhibit. This exhibit will provide material on professional development activities and information on science and mathematics related projects and program.

DEMONSTRATION GROUP 1: **Promoting Hands-On Education Through a Regional Student Weather Network**

PRESENTER:

Donald P. LaSalle
President
Talcott Mountain Science Center
Montevideo Road
Avon, CT 06001
(203) 677-8571
(203) 676-0421 (Fax)

PROJECT FOCUS:

Teaching Math
Teaching Science
Instructional Resources
Professional Development

PROJECT DESCRIPTION:

The National Student Weather Network uses state-of-the-art telecommunications technology to enable students and teachers in over 150 schools throughout the country to have a variety of hands-on experiences investigating the weather. Using computer modems and specialized software (Accu-Weather Forecaster), students have direct access to the same up-to-the-minute weather data used by professional meteorologists. Students are also provided with a set of weather instruments to do local weather observations, which are shared electronically among all the schools in the Network. For supportive training, Talcott Mountain produces a series of live, interactive video teleconferences (broadcast by satellite and cable TV), featuring a meteorologist who uses the day's weather data to explain basic concepts of meteorology. Through these exciting hands-on experiences, students learn about the weather and telecommunications technology, and develop critical scientific thinking skills.

The workshop will include a demonstration of the project in action, with live weather reports on the day of the Conference, hands-on weather instruments, and an explanation of how other schools can participate. The Weather Network is a national demonstration project funded by the U.S. Department of Education Fund for Innovation in Education.

DEMONSTRATION GROUP 2: Learning Through Hands-On Science

PRESENTER:

Roberta Jaffe
1156 High Street
Santa Cruz, CA 95064
(408) 459-2001
Fax: (408) 459-3483

PROJECT FOCUS:

Teaching Science
Instructional Resources
Professional Development

PROJECT DESCRIPTION:

The **Life Lab Science Program** strives to ensure students' future interests and success in science by improving student attitudes toward the study of science, and increasing students' level of knowledge and skill acquisition in science. The instructional approach is a combination of indoor and outdoor hands-on science activities with the key component being the garden lab. Students and teachers collaborate to transform their school grounds, classrooms or both into thriving garden laboratories for the application of scientific processes. Imagine planting a garden and exploring science and nutrition as you investigate soils, climate, light, plants, and animals--all in the context of learning how to grow your garden. Through the National Diffusion Network, over 500 schools (from Alaska to Florida) are actively participating in Life Lab. Life Lab challenges students to ask questions about their environment, make observations, research topics, and set up experiments in search of answers. Children find opportunities to probe important science concepts, confront their misunderstandings, and build new ideas, while developing strong science, communication, and cooperation skills.

The **Life Lab Science Program** offers garden-based introductory workshops, ongoing technical assistance, and advanced workshops to educators nationwide based on our two curricula: The Growing Classroom (Addison-Wesley, 1990) and **Life Lab Science** (Videodiscovery, 1992). The National Diffusion Network project, The **Growing Classroom**, is an activity guide for grades 2-6 that provides classroom and garden-based activities for students to pose and investigate questions, make keen observations, and research high interest topics. **Life Lab Science** was developed through funding from the National Science Foundation and offers a comprehensive science package that integrates life, earth, and physical science through investigating the garden system.

In this workshop experience, the new **Life Lab Science** curriculum uses laser disc technology to expand hands-on activities. If you change the shape of a seed, will that affect its lifelong journey? You will experience how students develop their conceptual understanding of structure and function as you work with others to explore your own ideas.

DEMONSTRATION GROUP 3: When Elementary Students Do What Scientists Do

PRESENTER: Sally Crissman
The National Center for Improving Science Education
2000 L Street, NW Suite 603
Washington, DC 20036
(202) 467-0652
Fax: (202) 467-0659

PROJECT FOCUS: Teaching Science
Instructional Resources

PROJECT DESCRIPTION:

The National Center for Improving Science Education is a division of The Network Inc., a nonprofit organization dedicated to education reform. Our science center's mission is to promote change in state and local policies and practices in science curriculum, teaching, and assessment. Our core work includes providing practical guidance for educational policymakers, curriculum developers, and practitioners who are responsible for the decisions that shape diverse learning environments for science and technology education. We help by synthesizing the findings, recommendations, and perspectives embodied in policy studies, research reports, and exemplary practice and then transforming this information into practical resources.

One area of emphasis for our synthesis work is science education in the elementary school, in the middle grades, and in high school. This presentation highlights and explicates one recommendation from our synthesis: that science classrooms reflect an understanding of how scientific knowledge is acquired. It will look at how curriculum and instruction can be (must be) designed to enable students, all students, to engage in scientific inquiry in a content-rich, interesting, active manner. Learning and teaching in these settings is both substantial and memorable. Students come to know science as it is actually practiced and see ways they can use scientific understanding and knowledge in their own lives.

DEMONSTRATION GROUP 4: Problem-Based Learning Theory and Practice

PRESENTER:

William Stepien, Director
Center for Problem-Based Learning, Illinois Mathematics and Science Academy
1500 West Sullivan Road
Aurora, IL 60506-1000
(708) 801-6956
Fax: (708) 801-6976

PROJECT FOCUS:

Teaching Science
Instructional Resources

PROJECT DESCRIPTION:

The Center provides curriculum development help and teacher training for K-12 schools interested in developing the problem-solving ability of their students. Affiliated with the Illinois Mathematics and Science Academy, the Center works directly with faculty at the Academy in developing problem-based "post hole" units for traditional classes and entirely problem-driven courses such as Science, Society and the Future, an interdisciplinary elective that investigates real-world problems containing important science issues. Observations of Science, Society and the Future can be arranged through the Illinois Mathematics and Science Academy.

Besides its affiliation with the Academy, the Center is maintaining long-term relationships with a number of schools and projects to promote research and development activities involving learners across all ability and grade levels.

DEMONSTRATION GROUP 5: Marsville: The Cosmic Village

PRESENTER: Dick Methia, Vice President
Educational Programs
Challenger Center Space Science Education
1055 North Fairfax Street, Suite 100
Alexandria, VA 22314
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Fax: (703) 683-7546

PROJECT FOCUS: Teaching Math
Teaching Science
Instructional Resources
Professional Development

PROJECT DESCRIPTION:

Challenger Center believes that children can be brought to a "paradigm shift" which reverses their established negative attitudes toward science. For that purpose, Challenger Center creates for youth positive experiences with science. Challenger Center's programs are experiences which place children in totally new imaginative environments where team work, problem solving and hands-on science, technology and communication activities are the norm.

"Marsville," developed in partnership with Educational Information Resources Center (EIRC) of Sewell, New Jersey, is an inter-disciplinary, middle school space simulation which begins in the classrooms of many schools that interact through telecommunications. It culminates in an out-of-school event called a Link-Up. Every Link-Up involves several hundred students and their teachers from participating schools in the creation of a human settlement on Mars. Each phase of the project entails science/technology content, computation and communication skills, problem solving, cooperative learning and responsible decision making, the key elements of Challenger Center's instructional model.

DEMONSTRATION GROUP 6: **The Second Voyage of the Mimi**

PRESENTERS: Stephanie Maddox and Pamela Holmes, Teachers
Wakefield Forest Elementary School
Fairfax County, Virginia

CONTACT PERSON: Lisa Paul
Wings for Learning
1600 Green Hills Road
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PROJECT FOCUS: Teaching Science
Teaching Math

PROJECT DESCRIPTION:

The Second Voyage of the Mimi was created by Bank Street College of Education with funding from the U.S. Department of Education and National Science Foundation. This mathematics/science multimedia program covers the ancient Maya civilization that created large and magnificent cities in the jungles of Central America between 200 AD and 900 AD.

A sample lesson utilizing video tape, the Maya Math Student Guide and related computer software will be used during the demonstration. The Maya number system (Base 20) will be the central focus of the lesson. This approach has the students explore numbers in the way that archaeologists do when they are trying to understand the meaning of the writings they discover.

DEMONSTRATION GROUP 7: **The Pit and the Pendulum**

PRESENTERS:

Diane Resek, Professor
Department of Mathematics
San Francisco State University
1640 Holloway Avenue
San Francisco, CA 84132
(415) 338-2071
(510) 643-5757 (Fax)

Theresa Hernandez-Heinz
Mathematic Coordinator, 9-12
San Francisco Unified School District
San Francisco, CA

PROJECT FOCUS: **Teaching Math**
Instructional Resources

PROJECT DESCRIPTION:

In 1989, the National Council of Teachers of Mathematics (NCTM) published Curriculum and Evaluation Standards for School Mathematics, which called for major reforms in mathematics education.

Over the past three years, the Interactive Mathematics Project (IMP) has developed a new, three-year high school mathematics curriculum, which is the first in the country to embody the vision of NCTM's Standards. This material is being taught in 28 schools with diverse populations in seven states.

The National Science Foundation has awarded the project $9 million dollars, effective September 1992, for five years in order to promote the reform advocated in the Standards and other national reports. IMP is particularly interested in how such changes can be evaluated and how they can be disseminated on a wider scale.

The Interactive Mathematics Project will:

- formally evaluate the effectiveness of the curriculum for students;
- implement the curriculum in schools throughout the country, connected to four regional centers (the California regional center already exists);
- assess the needs for teach in-serve in large scale implementation;
- write a fourth-year curriculum; and
- synthesize, revise, and publish the complete curriculum.

DEMONSTRATION GROUP 8: **Used Numbers: Real Data in the Classroom**

PRESENTER:

Susan Jo Russell
Math Center Coordinator
TERC
2067 Massachusetts Avenue
Cambridge, MA 02140
(617) 547-0430

PROJECT FOCUS:

Teaching Math
Professional Development

PROJECT DESCRIPTION:

Used Numbers: Real Data in the Classroom developed materials for students and teachers in grades K-6 focused on collecting, organizing, representing, describing, and interpreting data. In an information-rich society such as ours, statistics are an increasingly important aspect of daily life and work. We are constantly bombarded with information about everything around us. This wealth of data can be mystifying or it can help us make choices about our actions. Educators and mathematicians now stress the importance of incorporating data analysis and statistics into the elementary mathematics curriculum to prepare students for living and working in a world filled with information based on data. The **Curriculum and Evaluation Standards** of the National Council of Teachers of Mathematics highlight statistics as one of the key content strands for all grade levels.

The **Used Numbers** materials consist of six curriculum units (three for primary grades, three for upper grades): each unit provides a 3- to 4-week course of study. Through collecting and analyzing real data, students develop and use ideas and tools from key areas of mathematics--counting, measuring, sorting and classification, estimating, graphing, computing in context, and statistics--and they are introduced to appropriate uses of computers and calculators for data analysis. The units are also a tool for teacher development. While the units provide a series of investigations for students, they are addressed directly to teachers; included in each unit are notes to the teacher about the mathematical content, pedagogical approaches, and illustrations of how children learn these mathematical ideas. The materials were tested extensively in classrooms with diverse populations. We are able to draw on these classroom experiences to inform teachers about the issues that are likely to be raised during student discussion and ways in which they can guide and support their students in their mathematical thinking. Also available are two videotapes for teachers (one for primary grades, one for upper elementary grades). The materials are published by Dale Seymor Publications, P. O. Box 10888, Palo Alto, CA 94303.

DEMONSTRATION GROUP 9: Geometer's Sketchpad

PRESENTER:

Steven Rasmussen
President
Key Curriculum Press
P.O. Box 2304
Berkeley, CA 94702
(510) 548-2304
(510) 548-0755 (Fax)

PROJECT FOCUS:

Teaching Math
Instructional Resources
Professional Development

PROJECT DESCRIPTION:

The Geometer's Sketchpad is a dynamic geometry construction and exploration tool which recently won the Software Publisher's Association award as the Best Educational Software of the Year. With the Geometer's Sketchpad, students create figures with freehand drawing and construction tools. They then dynamically manipulate the figures in their quest to discover geometric relationships and create visual proofs. The open-endedness of the Sketchpad environment allows students unlimited potential for exploration. Simple textbook diagrams, working models of the Pythagorean Theorem, perspective drawings, Escher-like tessellations, fractals and animations of the sine wave are but a few of the possibilities. Dynamic dragging of the "givens" of a construction leads students to mathematical conjectures and generalizations about geometric relationships that remain constant and others that change.

Initial development of the Geometer's Sketchpad at Swathmore College was funded by the National Science Foundation. Currently, under an SBIR grant from NSF, Key Curriculum Press, as Sketchpad's publisher, is engaged in research to determine how the software is being used in classrooms, how it can be better used for teaching mathematics and assessing student learning, and how the program can be further improved to encompass more mathematics and reach a wider audience. Special emphasis in this research is being placed on special populations of students.

DEMONSTRATION GROUP 10: Video Environments That Promote Active Learning

PRESENTERS:

Susan R. Goldman
John D. Bransford
Learning Technology Center
Box 45 Peabody College
Vanderbilt University
Nashville, TN 37203
(615) 322-8070
Fax: (615) 343-7556

PROJECT FOCUS:

Teaching Math
Instructional Resources
Professional Development

PROJECT DESCRIPTION:

This Jasper Woodbury Problem Solving Series consists of six narratives on videodisc that contain problems designed to teach argumentation, problem formulation and problem solving to 5th and 6th grade mathematics students. The series is consistent with recent guidelines from the NCTM recommending that students be provided with increased opportunities to engage in collaborative learning, sustained problem solving on complex problems, and meaningful discussions of mathematical concepts. The Jasper stories are designed according to a specific set of principles. The stories follow a typical narrative structure, except that at the end of each story the main character is confronted with a complex problem to solve. Students are motivated to solve the problem in order to find out how the story ends.

The six stories in the Jasper series were designed so that pairs of videos have similar problem schemas. For example, one pair of videos involves trip planning and mathematical concepts such as rate, distance, and time. To solve the problems in another pair, students use concepts from elementary statistics to construct business plans. In the third pair of videos, students apply geometric principles and map skills to problems involving way-finding.

A broad scale implementation of the Jasper series was undertaken during the 1990-91 school year. Sixteen sites in nine states implemented the program in 5th and 6th grade classes. Results indicate significant gains in performance on tests of mathematical planning and problem solving and on attitudes toward mathematics.

DEMONSTRATION GROUP 11: Linking Educational Reform with the Effective Use of Technology

PRESENTERS:

Deb Nicholls
Digital Equipment Corporation
Worldwide Education Business Manager
4 Results Way
Marlborough, MA 01752
(508) 467-5107

Kenneth DiPietro
Director of Technology
Rhode Island Department of Education
Providence, Rhode Island

John Gillipo
Director
Center for Educational
and Learning Technology
Marlborough, MA

PROJECT FOCUS:

Teaching Mathematics
Teaching Science
Instructional Resources
Professional Development

PROJECT DESCRIPTION:

This presentation will provide an overview of how a comprehensive, multi-vendor information technology networking system can be used to implement 21st century educational reforms. Several statewide and local school district case study models will be presented. The presenters will provide implementation strategies for improving teaching, learning and management in mathematics and science education using a fully integrated and cost-effective technology solution.

DEMONSTRATION GROUP 12: Science and Technology for Children Program

PRESENTER:

Sally Shuler
Deputy Director

Douglas Lapp
Executive Director
National Science Resources Center
National Academy of Sciences
Smithsonian Institution
Washington, DC
(202) 357-3313

PROJECT FOCUS:

Teaching Science
Institutional Resources

PROJECT DESCRIPTION:

This session will demonstrate lessons and provide information about the Science and Technology for Children (STC) Program, a unique elementary science curriculum development project of the National Science Resources Center (NSRC). The STC program consists of a series of inquiry-centered hands-on investigations of scientific phenomena. The units are thoroughly tested to ensure that the hands-on curriculum units produced are scientifically accurate and pedagogically appropriate for children and teachers.

The lessons incorporate the "Focus-Explore-Reflect-Apply" learning cycle, using a constructivist approach to learning. The units include ideas on ways to incorporate the use of science trade books, suggestions to help teachers anticipate many classroom situations, ways to make use of cooperative learning experience to teach students how to work in groups, ways to link the teaching of science with the development of skills in mathematics, language arts, and social studies; and embedded ways to assess students acquisition of specific science concepts and skills before, during, and following the teaching of the units.

The STC curriculum units for grades one through six can be used as a complete elementary science program or individually, as a supplement to an existing program.

DEMONSTRATION GROUP 13: **Learning To Use Manipulatives in Teaching Mathematics**

PRESENTERS:

Mary M. Hatfield
Gary Bitter
College of Education EDB 225
Arizona State University
Tempe, AZ 85887
(602) 965-6067
Fax: (602) 965-8887

PROJECT FOCUS: **Teaching Mathematics**

PROJECT DESCRIPTION:

This project addresses the professional development of preservice and inservice teachers by providing them with opportunities via interactive multimedia to observe and analyze hands-on instructional approaches to mathematics teaching and learning with diverse students. As educational reform directs changes in current teaching practices, mathematics teachers need to examine their assumptions about the nature of mathematics and how it should be taught. Teachers should observe, analyze, and evaluate exemplary mathematics teaching as they consider and explore new ways to teach.

Teaching Mathematics Methods Using Interacvtive Videodisc (TMMUIV) uses interactive multimedia technology as a powerful tool for the professional development of teachers to guide them on the use of manipulatives in teaching elementary mathematics. TTMUIV, funded by the National Science Foundation, combines full-motion video, text, sound and animation for a view of real-life episodes of exemplary mathematics teaching in grades 1, 3, and 5. The system offers multiple perspectives on the implementation of methods for teaching mathematics that take into consideration teachers' prior conceptions of learning, teaching subject matter, and mathematics. Each of the two databases, geoboard and base-10 blocks, is organized into fields on content, types of learning, manipulatives, teaching methods, and the NCTM teaching standards that call for teachers to analyze multiple episodes of classroom teaching. The analysis of important instructional events helps develop cognitive frameworks for thinking about teaching and learning mathematics.

University-level professional development programs seek ways to bring the reality of the elementary classroom to the university setting along with enhancing the teachers' awareness of the teaching-learning process. Interactive multimedia serves this instructional need by allowing users to analyze teaching, pose alternative teaching strategies, and gain confidence in learning about different teaching situations. Ideas about learning have shifted away from the teacher as disseminator of information to the learners as the center of active learning. Being able to observe these teaching skills and concepts in action can greatly enhance the acquisition of basic instructonal skills by novice teachers as well as perfect the teaching practices of experienced teachers.

DEMONSTRATION GROUP 14: **Using Technology to Prepare Mathematics and Science Teachers**

PRESENTER: **Elizabeth Goldman**
Box 330, Peabody College
Vanderbilt University
Nashville, TN 37203
(615) 332-8100
Fax: (615) 322-8999

PROJECT FOCUS: **Teaching Math**
Teaching Science
Professional Development

PROJECT DESCRIPTION:

New societal goals for education, recommendations from current educational research findings, and theories from cognitive and social psychology challenge a number of traditional beliefs about mathematics and science learning. These beliefs involve how students learn, who should learn (or is capable of learning), and what is important to learn. Current recommendations for restructuring the teaching/learning process are based upon a theory of learning that has been labeled constructivist or student-centered. In this theory, learning is seen not as a transmission of information from teacher to student, but as an active, problem-solving process in which the learner builds upon prior understandings to construct new knowledge.

Teachers in student-centered classrooms must "read" children's reactions and comments and make appropriate teaching decisions based upon them. This process of analyzing children's thinking and orchestrating classroom activity and dialogue is difficult for beginning teachers to understand and learn how to do. In school, observations are not especially helpful, because in the complex and fast-moving environment of the classroom, novice teacher observers often miss critical features of the learning process. In this presentation, we will demonstrate how videodisc and integrated media technology are being used in university teacher education programs to help prospective elementary school teachers learn how to interpret children's understanding of mathematics and science concepts.

DEMONSTRATION GROUP 15: Changing Practice: Teaching Mathematics for Understanding

CONTACT PERSON: Steve Kirsner
National Center for Research on Teacher Learning
College of Education
116 Erickson Hall
Michigan State University
East Lansing, MI 48824
(517) 355-9302

PROJECT FOCUS: Teaching Mathematics
Professional Development

PROJECT DESCRIPTION:

This session will show examples of real classrooms where dedicated mathematics teacher are making serious efforts to teach mathematics for understanding. The National Center for Research on Teacher Learning (NCRTL) at Michigan State University has produced a video entitled "Changing Practice: Teaching Mathematics for Understanding." The video includes segments of elementary, middle, and high school mathematics classrooms that reflect the kinds of changes in teaching and learning described in the National Council of Teachers of Mathematics (NCTM) standards and similar reform documents.

The session will begin with a short classroom segment from the video, which will form the basis for a discussion about (1) why the NCTM believes teachers should change their practices, (2) how teachers can learn to teach mathematics for understanding and (3) how policymakers at all levels can provide support for teachers as they continue to learn and improve teaching for understanding.

This video can be purchased from the NCRTL as part of an inservice package. The package includes a set of inservice materials and is intended for a variety of audiences, including teachers, parents, policymakers, and teacher educators.

DEMONSTRATION GROUP 16: Teaching for **Number Sense Now!**

PRESENTER:

Francis (Skip) Fennell
Project Director
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PROJECT FOCUS:

Teaching Math
Instructional Resources
Professional Development

PROJECT DESCRIPTION:

Is 17 closer to 10 or 20? How many pennies can fit in your hand?
If the restaurant bill was $48.35, how much of a tip should we leave?
When we multiply 6.2 times 3.5 is the answer 21.7, 28.70. 18.3 or 217?
If a ten year old is 5 ft. tall, how tall will he be at age 20?

All of the questions above deal with the elusive notion of number sense. Number sense is an intuitive understanding of number meaning, magnitude and operation sense. But, more than anything else, number sense is a way of teaching. The **Number Sense Now!** project is designed to help teachers prepare for an elementary mathematics curriculum which has a number sense focus. The project (funded through the national Eisenhower Program) involves elementary classroom teachers and mathematics supervisors from Washington, D.C.; and Baltimore, Carroll and Howard counties in Maryland.

The **Number Sense Now!** project has produced a set of three inservice/professional development videotapes and accompanying print support materials. These materials demonstrate and promote number sense utilizing instructional approaches consistent with and supporting the NCTM standards. The project materials are designed for elementary classroom teachers and present videotaped vignettes of classroom lessons in which pupils are actively engaged in number sense related learning tasks. A chief objective of the project is to show how number sense can be an integral part of the elementary mathematics curriculum. The project's video and print materials are currently being piloted by approximately 40 school districts throughout the country. Each state supervisor of mathematics receives a copy (gratis) of all three project videotapes and supporting print materials. Additional materials will be made available through NCTM in 1993.

DEMONSTRATION GROUP 17: Initiating Systemic Change Through Science Instruction

PRESENTER: Kathy Daiker
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PROJECT FOCUS: Teaching Science
Professional Development
Instructional Resources

PROJECT DESCRIPTION:

This workshop focuses on one possibility for change in elementary schools--one way to ignite the enthusiasm needed by everyone involved for making significant change in American education. We're suggesting that you start with hands-on science. Science has been found to be an effective vehicle for bringing about change, and in light of technological advances currently taking place world-wide, scientific literacy is ever more important.

Several projects currently funded through the National Science Foundation and developed at the Lawrence Hall of Science at the University of California, Berkeley, focus on how change can successfully be brought about in elementary schools. One project is a hands-on science curriculum called the Full Option Science System (FOSS). When combined with Science Essentials, a multimedia component developed by Encyclopaedia Britannica Educational Corporation, the two parts form the Britannica Science System (BSS). BSS is written expressly for the large number of teachers who are doing a fine job in the classroom, but who may have been turned off to science, or feel they do not have the background to teach it successfully.

As part of the development, we investigated the needs of teachers and their students when instructional methods undergo a change from textbooks to hands-on science and technology. We have found that by using a vehicle such as BSS, teachers are not only teaching more science, but their overall teaching skill has improved as well.

When you experience a sample activity from the Britannica Science System, you'll see how this program teaches for understanding. Specifically, you'll learn an earth science concept using topography materials (topographic maps, simulated models) enriched through multimedia applications.

DEMONSTRATION GROUP 18: The Mechanical Universe: A Conceptual Approach to Physics

PRESENTER:

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PROJECT FOCUS:

Teaching Science
Instructional Resources
Professional Development

PROJECT DESCRIPTION:

The Mechanical Universe assists teachers in helping their students make conceptual changes that lead toward enhanced understanding of the physical world. The program combines content in the fundamental concepts of physics integrated with a teaching methodology based on a learning cycle of exploration, concept development, and application. Teachers gain specific ideas and methods on countering and correcting students' preconceptions and misconceptions about fundamental physical phenomena, as well as insights into applications of physics in everyday situations. Teachers also receive practical hands-on experience setting up and doing demonstrations and teaching interactively with the use of broadcast-quality video tapes developed by the project. The tapes illustrate key concepts and the historical development of physics with the aid of computer graphics and historical re-creations.

DEMONSTRATION GROUP 19: **Teaching Math and Science for Understanding**

PRESENTER:

Sally Shuler
Deputy Director

Douglas Lapp
Executive Director
National Science Resource Center
National Academy of Sciences
Smithsonian Institution
Washington, DC

PROJECT FOCUS: **Teaching Science**
Professional Development

PROJECT DESCRIPTION:

The implementation of effective, district-wide, hands-on elementary science programs requires informed leadership. To help develop this leadership, the NSRC conducts annual Elementary Science Leadership Institutes. The Elementary Science Leadership Institutes are a component of the NSRC's National Elementary Science Leadership Initiative, a four-year project that is engaging educators and scientists in a concerted effort to improve science education in the nation's elementary schools.

Each institute prepares teams of administrators, curriculum specialists, teachers, and scientists to design and implement effective hands-on science programs for their school districts. At each institute, participants enhance their leadership skills by engaging in workshops and discussions on hands-on science curriculum units, inservice education programs, support systems for supplying hands-on science materials to teachers, assessment methods for evaluating student performance, interdisciplinary approaches for integrating science with other curricula, and strategies for building administrative and community support for a hands-on elementary science program.

This session will provide information about this innovative professional development model for teachers, school administrators, and scientists that is designed to improve the teaching of science in local school districts throughout the country.

DEMONSTRATION GROUP 20: **SMART--Science and Mathematics Academies for Rural Teachers**

PRESENTER:

Rob Larson
Coordinator
Science and Mathematics Initiatives
Northwest Regional Educational Laboratory
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PROJECT FOCUS: **Professional Development**

PROJECT DESCRIPTION:

Imagine the exciting atmosphere of an engaging and stimulating secondary science or mathematics classroom. Combine this vision with teachers and students from very rural settings. Science and Mathematics Academies for Rural Teachers (SMART), National Eisenhower Project has helped these teachers live their dream. In this session, participants will explore strategies to champion rural secondary science and mathematics teaching in small, rural schools. Policy and curriculum implications discussed will (1) encourage preservice involvement and teaching in rural schools, (2) promote alliances in rural settings, and (3) enhance classroom teaching in secondary science and mathematics in rural areas.

DEMONSTRATION GROUP 21: **Problem Centered Mathematics Project**

PRESENTER: **Paul Cobb**
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PROJECT FOCUS: **Teaching Math**

PROJECT DESCRIPTION:

This NSF-funded project, which is currently in its seventh year, has developed instructional materials and strategies for 2nd and 3rd grade mathematics. In general, mathematics is viewed as a creative problem-solving activity. The instructional approach used for all topics, including mathematical computation, involves small-group problem solving followed by whole-class discussions of students' interpretations and solutions. Complete sets of instructional activities have been developed for 2nd and 3rd grade students drawing on current research on children's mathematical learning. The materials usually start with realistic problems and encourage students to construct increasingly sophisticated concepts by abstracting from application operations. Quantitative comparisons of project and nonproject classes indicate that project students are one grade level ahead of nonproject students in terms of arithmetical computation, have significantly more advanced mathematical concepts and problem-solving skills, place greater value on developing personally meaningful solutions, and are less inclined to avoid doing mathematics in school.

The challenge for the future is to achieve similar results in far less time than traditional instruction while continuing to give the highest priority to the development of mathematical understanding. Planning research and development work that focuses on these issues will be conducted in cooperation with the Freudenthal Institute at the State University of Utrecht in the Netherlands.

DEMONSTRATION GROUP 22: Image Processing for Teaching: Exploration and Discovery in Science and Mathematics

PRESENTERS: Larry Kendall
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Lunar and Planetary Laboratory
University of Arizona
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PROJECT FOCUS: Teaching Math
Teaching Science
Instructional Resources
Professional Development

PROJECT DESCRIPTION:

The "Image Processing for Teaching" (IPT) project, sponsored by NSF, Apple Computers, and the University of Arizona, provides a powerful medium to excite students about science and mathematics, especially children from minority groups and others whose needs have not been met by traditional "coded" ways of teaching these subjects. Using professional quality software on microcomputers, students explore a variety of scientific data sets, including biomedical imaging, Earth remote sensing and meteorology data, and planetary exploration images. They also learn about the many mathematical concepts that underlie image processing, such as coordinate systems, slope and intercept, pixels, binary arithmetic, along with many others. We have developed curriculum materials in all areas of mathematics and science for the upper elementary and secondary levels, allowing this tool to be used across a variety of grade levels and student interests.

Preliminary indications show image processing to be an effective and fun way to study how science and mathematics apply to the "real world" as represented by digital imagery. Image processing is also an innovation method with which to engage students in inquiry and discovery learning.

In our presentation, we will describe our program and demonstrate image processing. We have now developed an on site teacher education program for districts with the appropriate hardware. We have also developed a broad range of curricular materials built around image processing for a variety of science and mathematics content areas. We will discuss our dissemination efforts and show how you can get involved in this exciting program.

DEMONSTRATION GROUP 23: Plugged In to Hands-On Science

PRESENTERS:

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Math/Science Development
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PROJECT FOCUS:

Teaching Math
Teaching Science
Professional Development

PROJECT DESCRIPTION:

Computer technology offers students and teachers of mathematics a wide range of exciting new opportunities. From manipulatives on screen (coins, rulers, pattern blocks, etc.) to real time data collection, computers provide new experiences that enhance the learning process and challenge both students and teachers to new heights.

This session demonstrates some of the opportunities, joys and challenges of working with microbased labs which provide real time data collection. Join in the experiences and experiments of being "Plugged In to Hands-On Science."

DEMONSTRATION GROUP 24: The Optimal Learning Environment: Science and the Interactive Classroom

PRESENTER: D. Joseph Clark
Videodiscovery, Inc.
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PROJECT FOCUS: Teaching Science Instructional Resources
Professional Development

PROJECT DESCRIPTION:

The teaching of science, K-12, is in an exciting--and confounding--time of transition. New technologies abound, but what is their optimal use in the classroom? Hands-on science, inquiry-based learning, conceptual rather than factual approaches to science subjects--the new methods may be grounded in good theory, but how can administrators realistically put new theory into practice? Teachers are now asked to be "technologically literate classroom managers." But is the psychological profile of the teaching professional truly compatible with the change? Educational leaders who deal with these questions first will make the most effective decisions in this time of transition.

In this session on **The Optimal Learning Environment**, Professor D. Joseph Clark will discuss the most recent trends in science and technology adoptions and show examples of "bridging technology" for the science classroom, with interactive videodiscs, barcoded teachers' guides, and programs designed to turn passive students into active "Science Sleuths." The teacher still leads, but does not lecture; and students participate in their own education and assessment. Finally, Dr. Clark discusses the psychology of teaching in the optimal learning environment, and how staff development and technology development must go hand in hand to improve the science classroom.

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