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ABSTRACT

The outgrowth of a conference on how science education can best meet the needs and expectations of society, this volume is designed to provide a source of information and ideas about the future of the school science curriculum. It contains 15 papers, including: "Critical Questions and Tentative Answers for the School Science Curriculum" (Audrey B. Champagne and Leslie E. Hornig); "The School Science Curriculum: Principles for a Framework" (P. J. Black); "A Match or Not a Match: A Study of Intermediate Science Teaching Materials" (Rosalie A. Cohen); "Project 2061: Education for a Changing Future" (F. James Rutherford, Andrew Ahlgren, Patricia Warren, and Janice Merz); "Data Resources to Describe U.S. Precollege Science and Mathematics Curricula" (Dorothy M. Gilford); "The Science Report Card: A Description of the 1985-86 NAEP Science Assessment and the Higher Order Skills Assessment Pilot Study" (Ina V. A. Mullis); "The Second International Mathematics Study: Major Findings and Implications" (Kenneth J. Travers); "The Current Status of Science Curricula: Insights from the Second International Science Study" (Willard J. Jacobson); "Science Curricula: An International Comparison Between the United States and the USSR" (Catherine P. Ailes and Francis W. Rushing); "Developing a National Indicator System for Monitoring Mathematics and Science Education" (Richard A. Shavelson, Jeannie Oakes, and Neil Carey); "Assessing the Quality of the Science Curriculum" (Senta A. Raizen); "What's Being Taught and Who's Teaching It" (Bill G. Aldridge); "The 1985-86 National Survey of Science and Mathematics Education" (Iris R. Weiss); "Updating the Science Curriculum: Who, What, and How?" (Joanne Capper); and "Reform in School Mathematics" (Thomas A. Romberg). (TW)

This Year In School Science 1986

The Science Curriculum

NFSS

Edited by

Audrey B. Champagne
Leslie E. Hornig

American Association for the Advancement of Science

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THE SCIENCE CURRICULUM

The Report of the 1986 National Forum for School Science

Edited by
Audrey B. Champagne
and
Leslie E. Hornig

American Association for the Advancement of Science
Washington, D.C.

The AAAS Board of Directors, in accordance with Association policy, has approved publication of this work as a contribution to the understanding of an important area. Any interpretations and conclusions are those of the authors and do not necessarily represent the views of the Board or the Council of the Association.

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PREFACE

This volume is designed to provide a source of information and ideas about the future of the school science curriculum. It grows out of a conference held by the National Forum for School Science, a project of the American Association for the Advancement of Science. *Forum '86: The Science Curriculum* was held November 14 and 15, 1986 in Crystal City, Virginia. Nearly 500 scientists, teachers, science educators, and other people concerned about science education gathered to exchange information and views about what can and should be done to shape a science curriculum that will meet the future needs of the country. The papers in this book are of three types: most were written to inform the discussion at the Forum meeting (and can be equally well used to inform similar discussions elsewhere); one is a transcript of a presentation given at the meeting; and one is a synthesis of the questions and issues raised by the discussion.

The book opens with the latter two papers, which set a context for thinking about what a school science curriculum might look like in the future. The first chapter outlines some of the questions—both substantive and logistical—that affect curricular decisions. Paul Black's paper presents an extraordinarily perceptive and provocative exploration of the uses of school science and technology, followed by a discussion of some of the conditions that promote or stifle creative curricular change. The concept of the future-oriented curriculum is taken up again in Chapter 4, in which the staff of AAAS's Project 2061 outlines how that project aims to specify what science and technology every U.S. eighteen-year-old should know. Rosalie Cohen approaches the curriculum design issue from a slightly different angle. She asks how people learn science optimally, and then looks to see which learning styles are required by most science curriculum materials.

The next eleven chapters discuss the operation and results of projects whose goal is to inform us about U.S. science (and in some instances mathematics) curricula. Dorothy Gilford's paper provides an excellent overview of past, present, and even future data-gathering efforts, complete with summaries of their findings, strengths, and shortcomings. The paper by Ina Mullis provides the same kind of overview, but in greater depth, for the science and higher order cognitive skills portions of the National Assessment of Educational Progress.

A trio of papers discuss international curricular comparisons that have been made or are in progress. Kenneth Travers and Joe Crosswhite report on the findings of the Second International Mathematics Study; they reveal interesting math achievement data and tie that to findings on students' "opportunity to learn" the material. Williard Jacobson presents a similar report on the Second International Science Study. The third paper in this trio, by Catherine Ailes and Francis Rushing, reports on a comparative study of U.S. and Russian curricula that is still in progress.

A chief prerequisite to monitoring curricular advancement is the specification of success. The paper by Richard Shavelson, Jeannie Oakes, and Neil Carey, and the one by Senta Raizen, each describe efforts to develop systems of indicators by which the curriculum can be monitored. The papers include thorough discussions of the practical and philosophical problems such efforts encounter.

The past few years have seen the fruition of two major data-gathering projects on the science curriculum. Bill Aldridge's report describes the findings from his analysis of science teacher class assignment and comments on the implications they have for teacher training. Iris Weiss describes the 1985 National Survey of Science and Mathematics Education, noting, in particular, changes she found since an earlier study done in 1977.

The final two chapters, while they grow out of specific projects, do not present data in the same way that earlier papers do; rather, they return to more global discussions of how the curriculum ought to be structured and how it can get that way. Joanne Capper's paper describes a process for updating science curricula and monitoring curricular change efforts across the states. Thomas Romberg undertakes a review of the current and possible future states of mathematics curricula.

This book is meant to stimulate and inform discussion about the science curricula that are used to teach our children. It is not an exhaustive review of current research; nor does it present strongly-argued cases for particular methods, approaches, or content. We hope it will be used as a springboard for thoughful conversations, and to guide further exploration of some of the ideas and data presented here.

Publication of this volume and the production of the Forum meeting that preceeded it would not have been possible without the generous support of the Carnegie Corporation of New York. Carnegie has recognized in the past few years the importance of strong science education; for its leadership in supporting projects like the National Forum for School Science and many others, it has our thanks.

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Chapter 1

CRITICAL QUESTIONS AND TENTATIVE ANSWERS FOR THE SCHOOL SCIENCE CURRICULUM

Audrey B. Champagne and Leslie E. Hornig

Maintaining a school science curriculum that is congruent with the needs and expectations of society and individuals depends upon clear definition of what is to be achieved, how it can be achieved, and why achieving it is important. These specifications are not easy to generate, nor is the corresponding practice easy to attain. Some germane questions are:

1. What goals for school science are most congruent with the perceived needs of society? Which are appropriate to the interests and abilities of students? Who should set goals?
2. What structures of the educational system enhance the translation of goals and curricular designs into classroom practice? What can be done to achieve these structures in a majority of schools, systems, and states?
3. What information is currently available about the school science curriculum? What directions does the information suggest for future policy and practice? What information is still needed?

THE FUTURE SCHOOL SCIENCE CURRICULUM

Goals and Visions

Thirty years ago, the launch of a small satellite condensed a theretofore diffuse anxiety about the United States' scientific and technological capability. Current and future science achievement was questioned, and an urgent national goal for school science was spawned: produce top-notch, career scientists. In order to meet this goal, curricula were developed that encouraged traditional modes of scientific thought within the established disciplines. The top science students were targeted, and because they were largely a homogeneous group of white males, few people, if any, questioned whether alternative approaches to teaching science would be needed.

The impetus for science education today is very different. Fears that the nation's technological superiority is eroding are accompanied by anxiety concerning our ability to maintain a healthy, expanding economy and to compete successfully in the world market. Technological advances are more generally assumed to generate risks as well as benefits. The type and variety of concerns suggest that a single goal of producing career scientists is no longer adequate or realistic for school science.

Who will decide what goals *are* appropriate? How will they decide? What curricular approaches will help achieve these goals?

Many goals have been proposed: a productive work force that will maintain economic prosperity and security; a literate citizenry that is knowledgeable about scientific and technological issues and able to make informed decisions in their public and private lives; widespread adoption of the intellectual style of scientists, which is equated with better thinking ability; and greater ability to apply social, ethical, and political perspectives to interpretations of scientific information. These goals are different from those of the 1960s in that they encompass science competence for all students, regardless of sex, race, or economic status.

There are other, more utilitarian goals, but these lack the vision and power to drive the curriculum. Preparing students to advance to a higher level of study or to fulfill graduation requirements, for example, isolates science and reinforces the notion that science consists of discrete bits of knowledge whose mastery qualifies one only to acquire more facts. Moreover, the real question—What is science worth to people as individuals, citizens, and workers?—is just postponed to a higher level or ignored altogether.

How are proposed school science goals to be evaluated? Considerations include the importance of achieving one goal instead of another, whether goals are mutually exclusive or complementary, and the resources and circumstances that are needed to ensure achievement.

As an exercise, consider the goal of developing citizens who understand enough science to be able to recognize and resolve important issues. An underlying assumption of this goal is that virtually every student can be taught to evaluate information and reach a rational conclusion. The paper in this volume by Rosalie Cohen, however, suggests that students come to school using particular cognitive approaches that vary with sex and culture. Female students and members of certain minority groups, she says, tend to use intellectual styles that differ markedly from the analytic one that science classes encourage and reward.

If it is true that children's cognitive styles differ, then it would be futile to adopt a goal whose achievement requires that everyone be able to think in a particular way, especially if cognitive styles cannot be changed or people cannot learn to use different styles in different circumstances. Cohen, however, does not say how malleable conceptual styles are; this information would need to be found elsewhere.

For Cohen, the question is not just what is possible to achieve, but what is desirable. Why, she says, should all students be taught to "think like scientists?" She assumes that the utility and cultural relevance of diverse modes of thinking should be valued, not eradicated. But, in practice, is it likely that society will come to value all conceptual styles equally? Or would failure to teach the valued style of the dominant culture merely ensure disenfranchisement? The conclusions one draws about this depend in part on whether one believes that the role of education is to change cultural values or whether it is to acculturate people to the values that exist. They also depend on one's conception of science; many people, and almost certainly most scientists, would say that if the analytic style is abandoned, what is being taught is not science.

As another exercise, consider the goal of promoting economic advancement. The question here is not one of values, but of how well we understand what we are asking school science to do. Two assumptions are made when science education is called on to produce workers who will contribute to economic prosperity and security: (1) that the specific skills, knowledge, and competencies needed by the work force are well understood, and (2) that these abilities can be learned in science class.

Are these assumptions currently warranted? Daniel Koretz, who analyzes budget options for Congress, said at the Forum '86 conference that he knew of no convincing evidence linking science education and economic productivity, even though that has been a major justification for federal science education initiatives in recent years. Cohen argues in her paper that, contrary to predictions of a technology- and information-based economy, most workers will work in the service sector; not only will they not need the knowledge and intellectual habits valued by scientists and promoted in science class, but they will actually find them counterproductive. The observation was made several times at the Forum conference that fast-food and grocery cashiers today do not even have to deal with numbers: pictograms and laser readers require them only to select the correct button or pass the item over a scanner, and computers take care of the addition, tax, and change.

Such arguments need not eliminate worker education as a goal, but they do suggest that caution be used. What skills *will* most workers need? What sectors of the economy will grow the fastest? What sectors need to grow? Are there generic skills that will benefit all workers? Can and should these skills be taught in science class, or are they best learned elsewhere?

Approaches

Harold Hodgkinson, in his presentation at Forum '86 (the substance of which is available in his monograph, *All One System* [1985]), presented compelling statistics that, together with Cohen's suggestions about conceptual styles, argue strongly for considering how science is taught to students who do not fit mainstream assumptions. Put briefly, the white males who dominated science classes in the 1960s no longer constitute a majority of students in many jurisdictions. The largest city school systems already have what Hodgkinson calls minority majorities, and twelve states will have minority majority school enrollment within the next few years. Social values aside, it will simply be inefficient to institute science programs designed for populations that don't exist in the schools.

Moreover, Hodgkinson described an additional difficulty: the minority populations themselves are increasingly heterogeneous. Although the United States has always welcomed immigrants, never has the diversity of cultures and languages in individual classrooms been so great. Hodgkinson described one classroom he visited in which the children spoke 26 different languages, none of them English. This situation naturally produces practical problems. but there are philosophical and pedagogical issues as well. Assumptions about cultural values and intellectual habits cannot be made with the same abandon as in the past, and such a situation may have profound implications for the design and presentation of the science curriculum. Are 26 different curricula needed? Fifteen? Five? Can one curriculum be used effectively with all the children, despite their cultural and linguistic differences?

Whose Responsibility?

Who is to decide which goals are essential and what approaches should be used? This is an especially troubling question in our highly decentralized educational system.

Even though some of the school science goals that are proposed relate strongly to national concerns, the federal government has been reluctant to get directly involved in curriculum construction. Education traditionally has been regarded as a state or local prerogative, and strong pressures exist today to keep it that way. Nevertheless, many practitioners of education take the position that, because science education is so important to the growth of the nation, federal responsibility should be acknowledged and involvement increased.

At the state level, activity to set the science curriculum has increased in recent years. Since 1983, most states have increased the number of science and mathematics credits required for graduation from high school. States have goal statements for science and mathematics education, although the quality of these varies greatly, from narrowly specific or broadly sweeping to thoughtful and articulate. Many states are now moving to design and/or require statewide standardized achievement testing.

These actions are well intentioned, but whether they will have the desired effect on either the science curriculum or science achievement remains to be seen. Simply requiring more courses, without considering what they consist of or how well they will be taught, fails to address underlying issues. Moreover, there are some indications that increasing the number of credits will cause students to doubt whether they can fulfill the requirements and drive more of them to drop out of school entirely. States that require student assessment through standardized tests wrestle with the difficulty of assessing complex knowledge and abilities with pencil-and-paper tests, or with the expense of devising and administering activity-based ones. Furthermore, they must guard against letting tests unduly determine the curriculum, whether at the development or the implementation level. If teachers believe that their students' performance affects their own evaluations, they will teach the isolated content measured by the tests regardless of what other goals are specified.

While it may appear that the states are in a position to reconcile local and national concerns, aggregating the actions that states take in their own interests may not benefit the nation as a whole. Textbooks, for example, are perceived by many observers to have suffered from the state approval process. Written to cover the separate and sometimes conflicting rquirements of many states, they often end up as ill-coordinated canvasses of material. States and localities that do not require centralized approval or wield enough economic clout must accept textbooks that are written to other states' guidelines.

What about science teachers? They already bear considerable responsibility for the science curriculum that gets implemented, and many of them have a hand in designing curricula as well. There seems to exist a tension, however, about the roles and responsibilities of teachers. It is clear from comments made at the Forum '86 conference that they still look to others—notably the professional scientific societies—to set the standards and goals for learning. At the same time, they are uneasy about having curricula imposed on them.

A last option is for nongovernmental bodies—for example, the professional organizations and societies that teachers look to—to develop goals and vision. Such nationally constituted task forces represent national interests—and command expertise—but they cannot ensure that their recommendations will be accepted and acted on. AAAS's Project 2061 is attempting to specify, from the perspective of the scientific community, what science skills and knowledge every 18-year-old should possess. Other groups, representing other perspectives, might fruitfully undertake similar reviews, for students at large or for particular subgroups.

FORCES THAT INFLUENCE THE CURRICULUM

Although it may be a while before all the questions concerning curricular goals have been answered and a coherent vision exists about what school science should achieve, assume for a moment that it has happened. Assume also that model approaches have been developed to achieve the goals that have been identified. What conditions will facilitate the translation of these approaches into successful classroom practice? How likely is it that these conditions exist now or can be made to exist?

Teachers determine what goes on behind the closed doors of their classrooms, but they are influenced by many things. The resources that are available to them affect their ability to teach certain content or skills. State assessment practices exert pressure to teach in particular ways. The organization of schools, and of the education system generally, restrict contact with colleagues and the planning that might result. Finally, teachers vary in their ability and desire to teach science.

Resources

Textbooks whose goals and approaches coincide with the goals of the curriculum are obviously helpful to an effective teacher. To the students of marginal teachers, such texts are crucial because reading the text may constitute a large part of their curriculum. Some observers, at the Forum and elsewhere, believe that it is difficult in the current system to ensure the availability of textbooks that integrate science in a meaningful way. The varied demands of state approval boards encourage publishers to inject broad coverage of academic topics and, sometimes, to subordinate content to socially desirable presentation. District- or statewide purchasing plans prevent individual teachers from selecting textbooks and other materials that are compatible with their teaching styles and goals. When funds are not available for frequent purchases, teachers may be stuck with inappropriate or obsolete texts.

In his keynote address, Paul Black noted that the current textbook adoption system, which is based on marketing and not on educational vision, produces curricular materials that are beautifully produced but lacking in variety. He commented further that such a system precludes experimentation and therefore is unlikely to contribute to constructive change. This kind of ad hoc, cut-and-paste curriculum ends up serving few states or students really well *and* jeopardizes future improvement.

Can technology alleviate the problem? Videodiscs could be used to store large amounts of information, including text and visual materials from various sources; one project to establish such a database was described by Mary Budd Rowe at the Forum meeting. Teachers could use a computer-controlled system to assemble, organize, and print curriculum materials that complement their teaching style. An obvious drawback is that not every district will be able to afford the equipment, and many teachers will lack the time, motivation, or expertise to customize their curricula in this way. Nevertheless, systems like this hold promise for teachers who are unable to obtain textbooks that suit them.

Laboratory space and equipment are also believed to be crucial to effective science teaching, but some schools cannot afford adequate labs or omit them for safety reasons. Again, technology has been held up as a replacement for actual laboratories, with the promise that computer simulations will enable students to run through many more experiments per unit time, in a much safer manner. The premise that computer simulations can substitute for actual laboratory manipulation needs to be examined with care. For example, given what is known about the development of concrete and abstract reasoning skills and physical manipulation skills, one might ask whether children learn the same things from a videoscreen as they do from physically setting up an apparatus and seeing, smelling, touching, and hearing an experiment in progress. Where computers are helpful—for example, in teaching manipulation of variables, preparing students for a lab, or enhancing the lessons learned—ways need to be found for all students to have equal access to them.

Human resources are necessary, too. Lab equipment does not set itself up or take itself down, and, because of heavy teaching schedules, many teachers lack the time to get their labs in optimal order. Trained laboratory assistants would relieve some of this burden. Increasing use of technology may also require an increase in human resources, but of a different sort: a technology specialist who can help teachers to get the most out of the hardware and software, and to develop particular applications.

Environment

Discussions at the Forum and testimony from teachers reinforce the contention that science teachers feel isolated from their colleagues. In many cases, teachers in the same department seldom get an opportunity to sit down together and plan. It is even less likely that science teachers will meet with their counterparts in other disciplines, or will connect with the teachers who teach their students in earlier or future grades.

If one of the goals of science education is to help children learn to integrate knowledge, our school systems, with their isolated departments, are setting a poor example. Thought should be given to developing sequences of courses, rather than individual ones, and to designing units that integrate with other subjects. Even if courses and sequences cannot be designed collaboratively, expectations for student understanding and achievement at each stage can be clarified. This requires that teachers at all levels, from elementary through postsecondary, communicate with one another, and that school systems and postsecondary institutions provide encouragement and resources for this collaboration.

At the very least, even where collaboration is not possible, teachers need adequate time to prepare their lessons and labs. The proportion of a teacher's time spent in contact with students is much higher in the United States than in other countries. This means that a much lower percentage is spent preparing for classes and planning lessons. In a country where much is made of "quality time" for children, one has to question the quality of the time our teachers spend with our children. Those teachers who do not contribute their own time to planning lessons probably conduct less imaginative and worthwhile classes, whereas those who do eke out the extra hours may find it difficult to sustain the energy needed to conduct class after effective class. Many teachers who must work second jobs to make ends meet simply don't have the time to contribute.

Structure

The class block system that most public schools use is administratively straightforward, but it may not be the most effective design for implementing a science curriculum. Unlike some other courses, science classes should have a significant investigative component. It is difficult for these laboratories to take place in the confines of the usual 45-minute class period, but for various reasons—ranging from practicalities of scheduling to fears of accusations about disciplinary favoritism—science teachers are often required to shoehorn labs into the same time allotted to any other subject. If learning the intellectual and manipulative procedures of science is one of the goals of school science, then classes must be structured to give students practice. This includes allowing enough flexibility so that students can undertake real experiments, not just reenact tidy demonstrations timed to fit the class period.

Once having admitted that science classes may require restructuring of traditional blocks, schools may have to decide whether simple flexibility of scheduling is called for, or whether science classes actually deserve more time than other subjects. At the postsecondary level, courses with laboratories are expected to take more time than those without—sometimes as much as two or three times more. This may or may not be appropriate at the elementary and secondary levels. Thought should be given, however, to reorganizing science classes over the week or year, shifting time so that adequate blocks are available.

Assessment

Mandatory standardized testing is supposed to assess how much students are learning. When the material tested is not congruent with the goals of school science, or when it focuses excessively on factual information, such tests can actually have a deleterious effect on the curriculum. Because the reputations of districts, schools, and individual teachers can rest on their students' performance, there can be great pressure to teach to the tests. If the tests cover a wide range of material, teachers may feel forced to teach science as discrete bits of knowledge; the integrative, thoughtful aspects of science may be avoided for lack of time. Thinking and process skills may also take a back seat in the curriculum.

When standardized tests are of the pencil-and-paper, multiple-choice type—which is easier to administer to large numbers of students, and to score—complex skills and knowledge are harder to assess. They may be omitted altogether, or they may be inaccurately evaluated. In either case, the test provides little incentive to teach these things. Other forms of assessment, involving practical demonstrations, open-ended questions, or other means of demonstrating proficiency—all of which have their own drawbacks and inaccuracies—might nonetheless encourage more teaching of these skills than is done now. The National Assessment of Educational Progress is attempting to develop tests of higher order thinking skills that require descriptions and explanations rather than a simple choice of answers. Theodore Sizer has advocated the use of alternative, public demonstrations of knowledge, in the form of special projects or presentations.

KNOWLEDGE ABOUT THE SCHOOL SCIENCE CURRICULUM

State-mandated assessment is one way of generating information about the school science curriculum. The federal government also funds studies of various types. What kind of data do these studies produce, and what are the data useful for?

A review of current and recent federally supported studies on science and mathematics curricula can be found in the paper in this volume by Dorothy Gilford of the National Academy of Sciences. Current studies include international comparisons of student achievement at various ages and educational levels and their corresponding educational patterns; surveys of teachers and principals concerning classroom practice; and a national assessment of student learning.

Such broad-based research can have two justifications: educational and political. Research whose main function is to improve educational practice searches for cause-and-effect relationships between the curriculum and student achievement. Research whose function is political seeks to justify or support policy decisions, influence the allocation of funds, or establish the putative superiority of one administrative unit over another. The dual justifications can create tensions, such as when educational practice is criticized on the basis of data that are primarily designed to serve a political function. This happens annually with the Secretary of Education's "wall chart," which ranks the states according to student achievement, per-pupil expenditure, and other variables. Such a chart is a fine political tool for generating support for improvement, but it does very little to suggest what actions would create improvement and, in fact, does a poor job of isolating the variables that are responsible for good or poor performance.

This is a problem with surveys generally: although they are useful for generating hypotheses, they reveal very little causal information. It was suggested at Forum '86 that the only way to generate educationally useful data would be to get into the classroom and observe what is actually happening. Such studies are rare because they are very expensive, and it is difficult to translate interpretations from one classroom to another. In effect, the choice gets made instead to generate yet more superficial data about many situations. This may be a response to the extremely varied nature of educational systems and practice in this country.

The suggestion that studies need to move into the classroom points to a distinction that was made at the Forum among the intended curriculum, the implemented curriculum, and the achieved curriculum. It is relatively easy to generate information about the intended curriculum from state and district guidelines. Something about the achieved curriculum can be inferred from assessment of student learning. Almost nothing is known about the implemented curriculum, that is, what actually goes on in the classroom. Yet this information is particularly crucial for specifying which curricula are useful for moving students towards a greater understanding of science. In essence, one of the panelists at the Forum observed, the quantity of data gathered about the school science curriculum has been inversely proportional to the importance of the question being asked.

Is there a place for data whose sole function is political? Yes, because it stimulates action, some of which is probably in the right direction, and it stimulates investment of funds, some of which may be in good projects. But such use of data is probably most effective when it is coupled with sound data concerning educational practice. The availability of both kinds of data not only serves a stimulation function; it also provides direction about the most effective action to take. This can be crucial when funds are limited, as they are with federal investment in science education programs. A case in point is the most recent federal allocations for science education, which have been predicated on grounds of economic security and of help for minority students. Although expression of federal interest is often useful, there are no data to suggest that science education actually increases economic productivity. Furthermore, there is neither a method nor a mandate for evaluating whether the funds spent in this case will have the desired effect, and if so, how.

Regardless of the particular data they generate, research studies can have an effect on educational policy and practice by virtue of the questions they ask. Research that seeks to describe what the majority of teachers are doing in their classroom is likely to generate more of the same practice. If, however, researchers examine particular aspects of teaching or the curriculum that conform to a vision of what school science should be, future practice is likely to incorporate those effective features. In this way, said Paul Black at the Forum, research can stop education from stagnating and orient it toward the future.

CONCLUSION

The development of school science curricula cannot operate in a vacuum. Deciding what children should learn and how they will best learn it depends first and foremost on developing a clear understanding of our purposes in having them learn it. The rhetoric and reality at the current moment suggest that economic prosperity and personal responsibility are regarded as two prime objectives for learning science. These goals reflect a broader concern with learning to live in our work wisely and well.

Setting goals, however, is only the first step. The educational system must act as if it believes in those goals—that is, the structure must facilitate achievement of those goals and minimize obstructions to their attainment. Incentives, strategies, and resources will be needed that share common assumptions and support common objectives. Better information than we now have will be needed to guide this effort.

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Chapter 2

THE SCHOOL SCIENCE CURRICULUM Principles for a Framework

P. J. Black

As soon as I had accepted the kind invitation to make this presentation, I began to wonder what posture to adopt. One possibility was to be a storyteller—that's a favorite way of coming to a strange land from afar. Another possibility was to play at being a guru—to give you some grand theory which would show that I can think deep thoughts. A third possible posture was to speak in tones of a prophet. "Woe on you," I could say, "you've lost sight of the true message—listen to me so that you may recover your vision." All of these postures have their dangers, yet each of them could be a means to give entertainment and enlightenment. Because I couldn't make a decision, and because of a wish to have the best of all possible worlds, I'm going to use all three.

To start as a storyteller, I tell quite ordinary tales about things that happen in classrooms—because these should be the center stage of our concern in this meeting. Imagine first a classroom of nine- and ten-year-old children who were split into groups by the teacher and told, "I want you to look at these blocks floating in the water and observe the similarities and differences between them" (Harlen, 1985). He gave each group a large plastic bowl full of water, and some wooden blocks. The wooden blocks were of different types of wood, and they were all cut to the same size and shape. The children were asked to compare the blocks and to find out something about the way the different blocks floated. They were provided with some spring balances and some rulers to measure with, and they were told, "One of you has got to be the recorder for your group's ideas, and after a while you're going to come together and we're going to exchange these ideas and talk more about them."

The children worked away in groups with those blocks in and out of the water. They noticed that they floated to different depths, as the teacher hoped. But they noticed that one was a bit lopsided—they weren't meant to see that; it wasn't meant to be lopsided. They looked at what happened when they pushed the blocks to the bottom and let them go, and they started talking about comparing how quickly different blocks rose to the top. Some looked at how the blocks stuck on the side, because they noticed that they could stick a wet block to the vertical side of the bowl. Some also found that you could take pairs of wet blocks and stick them together. On our video of this work there's a beautiful piece of dialogue in which the children decide that such blocks must be magnetic to account for this. In one or two groups, children looked at the spring balance and said, "Let's try using that, because these blocks do seem to be different." There was a big argument in one group about whether or not one block was balsa wood.

The variety of ideas discussed was striking—the children refused to look only at the features for which the activity had been set up. It was hard for the teacher to respond when there were many ideas and issues which he had not anticipated or thought about before the lesson. The children did sit and have a lot of argument about what to record, and when they had made their written records the teacher collected the class together and they exchanged those records in discussion.

The point of this activity was that the children were learning to investigate, to look at phenomena, to seek patterns in them. They were learning to see the role of measurement in looking for patterns. When they came to compare, they could see that some had measurements that the others had not, and that with measurements you could take ideas further. They were also finding out the virtue of recording systematically what it is you think you've found, which would help to develop their skills of communication.

Above all, they were learning in a small way to be scientists. In doing so, they were actually working in a very carefully planned scenario. Their teacher, by creating the task, by the precise words which he had addressed about what they were supposed to do, by the layout of equipment, by organizing them into groups, by his way of bringing them back and managing their exchange of information, was acting as a very skilled planner, manager, and advisor, to give those children an environment in which they could develop their ability. In particular, he was helping them to develop skills of measurement, of observation, of making hypotheses, and of recording. He was not in that particular exercise trying to develop conceptual knowledge. He was not trying to give them any exposition of Archimedes' Principle, or of the principles of floating, or of the concept of density. He was creating a basis of experience out of which ideas about weight, volume, and density might be developed in the future.

So the example can be analyzed by considering what the task could contribute to what children can learn from science activities, about the content of science and about the processes and skills of science. You don't learn about either the processes or the concepts in isolation. The children's ideas about water and floating inevitably affected what they observed: their ideas about how things stick and about magnets affected the hypotheses they made up about wet blocks of wood. It is important to notice that they were using those ideas in the context of a scientific investigation, a task in which the aim was to find out how and why.

It is the interaction of processes and concepts that really represents what I would call scientific capability. Learn concepts without learning skills, and you're getting all dressed up for a party to which you'll never be able to go. If you try to learn science processes and skills without any science knowledge, you'll be engaged in a mindless activity which does not constitute science. It might be fun for a while, but it will not be a way of developing the intellectual and practical capabilities of young people because skills have to be exercised in terms of some ideas that you have about the system, or problem, or materials, that you are working with. It's the dialogue between concepts and processes that is fruitful—in learning and in being a scientist.

The diagram in Figure 1 sums this up. Notice that the unifying aim, scientific capability, is linked to the necessary resources, concepts, and skills by arrows that point in both directions. This represents the fact that whilst we may involve children in tasks so that they can use concepts and skills that they have acquired, we may also involve them in tasks which create needs and create some motivation for going back to learn more. We don't wait until we know everything before facing reality: we don't wait until they get to the stage of an M.Sc. degree before allowing learners to attempt a research project. We should be stimulating the two-way dialogue of Figure 1 the whole time, and unless we do that, we're not developing the motivation for pupils to develop concepts and skills and we may not be developing scientific capability through the experience of being involved in real investigative tasks.

It is on that pattern that I think we ought to be structuring our work, but notice how much such a pattern demands of teachers in their skills of planning and of management.

Story number two is different from the first story. A group of eleven-year olds was asked to make a model steam turbine (Department of Education and Science, 1985a). They decided to do it by trying to make a small wheel and producing a jet of steam to turn it. The process

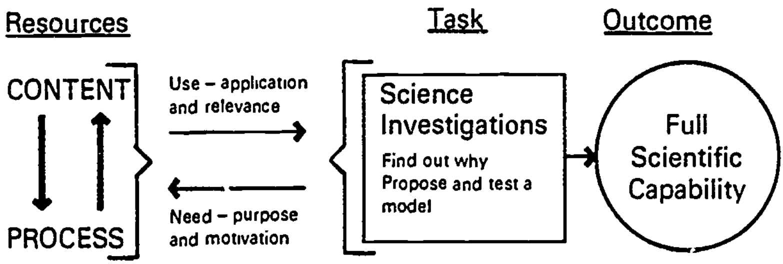

Figure 1 A model for science education

Note: Reprinted, by permission, from P. J. Black and G. Harrison, *In Place of Confusion: Technology and Science in the School Curriculum,* 1985.

started with a syrup tin. (See Figure 2.) They went into the craft department and soldered some legs onto it. They fixed the lid down and made a hole in it. Their idea was that they would fill the tin with water and warm thr water with a candle, and the steam would come out of the hole. They .nade a metal bracket to fix on top of the tin. They fitted a sawed-off nail into the bracket to serve as an axle. They then took a thin piece of aluminum and cut a wheel out of it, cutting slots into its rims and bending pieces between cuts to make the turbine blades. Lastly, they stuck the turbine on the axle and made sure it could spin easily, pressed down the lid with bracket and axle on it, put water inside, lit the candle, and waited. Nothing happened.

They thought about that for a while, and decided that there wasn't enough "heat" and that the boring old bunsen burner might have to be used after all, so they went on to Mark II. On Mark II they folded back the legs, put the whole on a tripod, and lit a bunsen burner underneath the tin of water. The water heated up, bubbled away, boiled; steam came up and came out of the hole in all directions. Nothing happened to the turbine wheel—it didn't turn. They decided the steam was going all over the place because the hole was too big, so they took the lid into the craft department again and got another piece of metal which they soldered on top of the hole. Then, with a 1-millimeter drill, they drilled a tiny hole. Then, confident that the problem was solved, they put the lid back on the tin of water and lit the bunsen burner. As the water started to boil, the lid blew off.

They argued about this for a while and decided that they must hit a mean between their two different failures. They took the lid away, drilled out the hole with a 2-millimeter drill, and came back to try again. This time when they lit the bunsen burner, water boiled, steam came out, and the turbine turned round merrily: they had succeeded.

How to make a steam turbine

We brought a 'Golden Syrup' tin and we made a large hole in the middle of the tin lid. We made a fan wheel out of a a piece of tin, and we made an axle out of a small nail by sawing the head off it. We put the wheel on the axle and, we measured the width for when we made the bracket. We put two small dents, one at each side of the bracket and we placed the wheel and axle in the bracket. We soldered the bracket to the boiler (Golden Syrup tin) and we cut three legs out of a sheet of tin. We soldered the legs to the bottom of the boiler. We thought about using a smaller tin to use for a fire box so we tried it. The legs held the boiler over the fire box.

The Problems

We soon realised that if we put a candle in the fire box there would not be enough heat to heat the water up so we scraped that idea and went back to the drawing board. We soon had an idea of folding the legs up, ~~on~~ putting on a tripod, and heating it with a bunsen burner. We did this with water in its boiler, but the hole was too big and the jet was not strong enough to drive the wheel. The steam was going everywhere

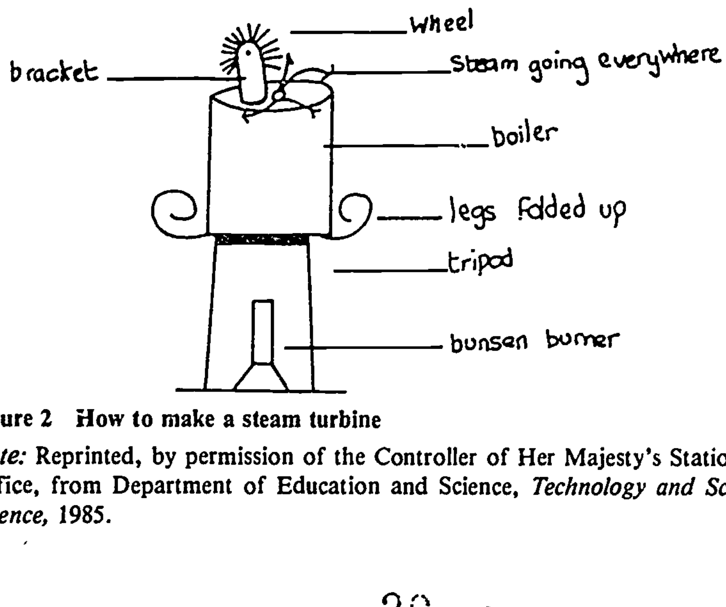

Figure 2 How to make a steam turbine

Note: Reprinted, by permission of the Controller of Her Majesty's Stationery Office, from Department of Education and Science, *Technology and School Science,* 1985.

The main point of this second story is that the purpose of the exercise was different from that in the first story. The purpose was to make something work, to meet a specification. They weren't supposed to find out why, they weren't supposed to find out how. They were meant to meet a need. That creates a big difference in the style and orientation of this second activity compared with the first.

A second feature of this story to which I want to draw attention is that pupils were not simply using the resources of the science classroom. They were using resources from other classrooms and lessons. They were having to put together ideas and skills derived from different parts of their curriculum to meet their objective.

I like to present this situation by means of another diagram (Figure 3). This is similar to Figure 1, but also significantly different because a different concept is needed in order to deal with technology instead of science. (Black and Harrison, 1985.)

Figure 3 has the same general layout as Figure 1, but the focus, technology, has as its central purpose that of meeting a need. A technology task certainly requires some skills: skills of construction and design, not just of observation and measurement. It also calls for other resources, of knowledge. In the story, children were using what they knew about steam, about "not enough heat," about "steam going everywhere," about the effect of the size of the hole, and so on. They were using several conceptual schemes, and those schemes were being modified by the experience of doing the task. So we have again an interplay between task and resources. But the nature of the technology task is es-

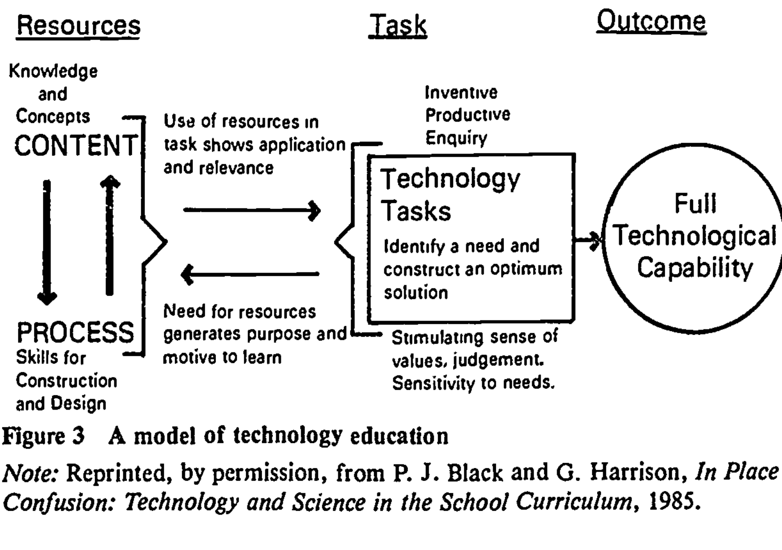

Figure 3 A model of technology education

Note: Reprinted, by permission, from P. J. Black and G. Harrison, *In Place of Confusion: Technology and Science in the School Curriculum*, 1985.

sentially different from that of a science task, and because of this difference the range of knowledge and the range of skills are different, and in particular much broader. This follows from the broader scope implied by trying to meet human needs and human purposes.

Technological capability involves a great deal more than scientific capability, and involves a fundamentally different orientation. I'm raising these points because I think in planning for the future we must be clear about these differences and we must try to plan according to a strategy which recognizes and does justice to them.

In order to expand on this point, let me just say a little bit more about the word used in Figure 3, capability. Technological capability involves using resources of knowledge and skill, but it also involves rather specific personal qualities, those to do with taking action. The children making the turbine had to originate: they had to decide to start somewhere and do something, not just sit and think about it. They had to make and stand by decisions: they had to get things done. They had to carry these decisions through and learn from their mistakes, and also they had to keep in mind their main objective, and so to plan in terms of a perception of what the objective involved.

Now, in fact, as a task chosen to develop technological skills, that particular one has serious shortcomings. It's suitable for young children as a start, but it's not good enough as a model or on its own. The reason it's not good enough is that the objective was unrelated to human purposes. Who wants a steam turbine? Who wants a thing to turn like that? What human purpose does it serve? A broader and more ambitious view of technological tasks is that they should start from such questions, particularly for older children, and so start further back in the chain of decision, to consider what the problem is in the first place, and how you decide what counts as a solution of the problem, for individuals or for society.

For my argument, the full definition of technology includes some perception and understanding of the needs required, the arguments you can have about who defines those needs, and the value judgments that are involved in deciding that a particular solution for society, whether on a local scale or a grand scale, is better than another.

I've expanded beyond my example in order to develop a full explanation of the concept of technological capability because I believe that it is an important educational aim. One of my reasons for concentrating on this is that I do not find in the other papers for this meeting any discussions that make adequately clear distinctions between science and technology. I find technology sometimes added as if it was merely an extension of science: "science and technology" trips off the tongue, whereas I think the distinction between the two, if we are orienting ourselves towards a curriculum for preparing citizens for the future, is quite vital and must be conceptually clarified.

I'd like to illustrate this argument further by a quotation from a statement by a body in the U.K. called the Royal Society of Arts, who have been trying to promote this idea in education using a published statement about it signed by an unlikely spectrum of right- and left-wing politicians, artists, and scientists—unlikely because it contains people who you would not expect to agree with one another about anything. The heart of the statement is as follows: "There exists in its own right a culture which is concerned with doing, making and organizing and the creative arts." By "culture," they mean an approach to a way of thinking about what life is for and how you act out your life. It's as fundamental as that. The statement continues: "This culture emphasizes the day-to-day management of affairs, the formulation and solution of problems and the design, manufacture, and marketing of goods and services. Educators should spend more time preparing people in this way for a life outside the education system" (Cross and McCormick, 1986).

The people who subscribed to that were subscribing to it because they felt there is an essential aspect of life which the education system is ignoring. They subscribed to it because of their belief that our education system is structured mainly by the academic disciplines which we get from higher education, and that it tends to lead pupils to value certain styles of acting and thinking which are rather restricted in their range. It leads them to give highest value to certain types of profession or career which are rule bound, academic in nature, and orderly, and to give low value to certain types of activity, whether in careers or in other roles in the community, which are risk taking, creative, and more disorderly. That concern lay behind that statement, and it is a concern that we should share.

I draw your attention to the excellent paper by Cohen (in this volume), which is profoundly thoughtful about these issues, about the type of personal orientation, the style of thinking and doing, that makes sense of the sort of life that children may adopt, and that adults have to adopt, in their occupations. Such orientations create for us a problem about what sort of culture our education represents to pupils and leads them to value, what relative importance we give to action, to risk-taking, to learning by commitment, as opposed to passivity or following set rules. In terms of these choices, what sort of balance is communicated to pupils by the image of science we deliver through all of the details of our curricula and assessments?

These are the stories. You can see that I'm not a wholehearted storyteller, I'm too much by instinct a theoretician and guru, and therefore have been piling a lot of theory on these two small bases of experience. However, it is important to put the experiences in first, because I think it's so easy to forget that all our discussions must be grounded, must be pinned back continually to the realities of children doing things in classrooms under the guidance of teachers.

Let me go on to my second section, where I shall try to play more directly at being theoretical. I want to look at our map of the science curriculum from two points of view, which I shall call the inside and the outside, respectively.

To start with the inside, we first of all have decisions and worries about the content of curricula. The one point I want to emphasize here is that we would nearly always do better by doing less. I was struck many years ago by an article about university undergraduate education of physicists, by one of your physics professors, Philip Morrison. The article was entitled "Less Would Mean More" (Morrison, 1963). I was struck a few years later working on a UNESCO conference where I was collecting data on undergraduate physics curricula from universities all over the world, and I asked their opinions about content. They nearly all said, "We try to do too much. We would do better to teach less." At the conference, everybody agreed with this, and they went away with agreed resolutions about it. But nothing has happened—nobody seems to have succeeded in cutting down the actual load of degree courses (Black, 1976).

In Britain, we actually have a national policy on this point. Our government Department of Education and Science issued a statement, drawn up after wide consultation, on the school science curriculum from ages five to sixteen (Department of Education and Science, 1985b). It covers many issues; the relevant quotation here is as follows:

> First, if science is to be taught to convey understanding, and confidence in the use of knowledge gained, as well as the necessary and central skills, both practical and intellectual, then the factual and theoretical content of many existing courses will need to be sharply pruned. This task can, and should be, carried out without reducing the intellectual demands made on pupils or the rigour with which science is taught. If it is not carried out, then the objectives set out in this paper cannot be achieved.

I think it is continually necessary to emphasize the fundamental importance of keeping content under control and of looking for a balance between content-based aims and other aims.

Based on content, arising out of it, or imposed upon it are our conceptual structures, our generalized ideas by which we make sense of and reorganize the world through science. We're now aware from a whole body of research that we're engaged, not in implanting in children their first conceptual understanding of the natural work around them, but in changing a preexistent structure of concepts, those ideas which they already have and which are different from our own (Driver, Guesne, and Tiberghien, 1985; Osborne and Freyberg, 1985; Black and Lucas, 1987). The implications of this work need to be more strongly represented in your planning, for it calls for a fundamental change of approach. We now have to plan for ways in which we can *change* pupils' ideas. The process of drawing out and building on pupils' own science theories means that we have to find new ways to pay attention to their development, and that we may have to go back to and yet rewrite the neo-Piagetian and other psychological formulae used for curriculum planning. Thus, we do now seem to have to hand some new tools for making progress, but it will take a long time to learn how to use them, and this will involve a carefully structured strategy, developed by helping children to move away from, to refine, and to see in better perspective the limited concepts with which they start and which they build out of their daily life and experience.

To these two strategic priorities, the reduction of content and the restructuring of teaching about concepts, I would like to add a third: the development of processes or skills. I need hardly say very much about this, for the notion that we should now have an agenda of skills, concerned with such issues as observation, measurement, making hypotheses, designing experiments, and selecting instruments, is widely accepted. However, in my experience, it's not sufficiently well established that people actually know what they mean by the terms used in these lists of skills. If you want a critical test of this point, then you have to ask in a school, "Where are your assessment test items for children's process skills?" and examine these items to see how the objectives are made explicit.

When we tried that in U.K. schools some years ago, we found that the aims were accepted but that the test items didn't exist. It has taken us a great deal of work to invent them (Harlen, Black, and Johnson, 1981; Assessment of Performance Unit, 1983–7). Yet they ought to be there if we take the aims seriously. However, to have these skills clear and clearly expressed in concrete activities is not enough on its own. We should not try to help children to develop them only, or even at all, as isolated exercises. Referring back to Figures 1 and 3, I repeat the point that they should be developed in relation to their use in scientific investigations and in technological tasks. Only thus can they become an effective part of pupils' scientific and technological capability.

Serious attention to Figure 3, and to the understanding of technology, demands more of us than the debates on scientific concepts and skills usually allow for. If pupils are to include serious involvement in assessing the definition of the human needs assumed in any particular project, or to evaluate their own and other people's solutions in terms of their human and social consequences, they need to support their own project work by more theoretical and generalized studies of the history of society's efforts to exploit and yet control the outcomes of science and technology.

There is a movement, strongly represented in the U.S.A., to establish studies of "science and technology in society." However, in terms of my analysis, such work lacks emphasis on two features. The first is central to Figure 3, the articulation of such study as a further resource to be linked to pupils' personal involvement in their own tasks.

The second is the need to develop and attend to specifically technological *concepts*. I am not sure what these are, but let me illustrate the idea by one theme, which can be called "understanding systems." If a problem is set up concerned with the design of traffic lights, it is important that it not be seen as a problem of building particular artifacts, but as a problem of controlling a system. You cannot determine how you should set up traffic lights unless you embed that in a plan for the transport system as a whole. Similarly, you cannot decide that it would be good to extend the Washington Metro unless you study the pattern of habitation, of work, of movement, now and in the future, of the people in the city and in its surrounding regions.

Engineers have developed systems concepts and a systems approach to tackling problems. We need, as citizens, to understand something of this systems approach, because until we do, we shall not be able to participate in that level of decision making in which systems as a whole have to be considered. I know of only one curriculum project which actually aimed to deal with this need, and because it met this need it was exciting for me when I found it. It originated in this country, but I understand it is very little known or used. The Engineering Concepts Curriculum Project produced a text about fifteen years ago called *The Man Made World* (David, Truxal, and Piel, 1971), which is the only serious attempt I've seen to develop a school curriculum based on engineering concepts, not on engineering artifacts, nor on bits of physics or electrical engineering or chemical engineering simply strung together. We would do well to go back to that text and to begin to construct again an agenda of technological concepts, for without this any work on the applications of science to meet human needs may be a set of unrelated stories, used neither to develop nor to illustrate ideas that our pupils can apply to new problems in the future.

In order to meet some of these challenges, science educators are not going to be able to work in isolation. We're not going to help children to tackle tasks in which you have to define and meet the human need, bring in craft skills, evaluate solutions in terms of how they will fit into society, as well as master the strictly physical or technical aspects, unless you begin to engage with pupils' experiences across several parts of the curriculum. Thus, we should begin to establish collaboration between different teachers and faculties in a school, to try to work together on some unified activities which will convey a coherent set of messages to the children that are engaged in them. In particular, pupils' work on technology tasks and on their wider implications should draw on and feed back to the work they do in different parts of the school.

If we were to do that, then we would change, amongst other things, the image of science and technology for pupils. I refer you again to the Cohen paper. We have to change in a profound way the image of the subject that we present to pupils: it's not just a delivery system where you learn things, not just a system where you do things to find out and become a scientist, not just a system in which you build and make things to meet needs, not just a system where you meet needs just because someone said so. Rather, it should be a system in which you inquire after who defined the needs and how they meet the whole, the broader needs of society, a system in which you refuse to make or recommend one technological fix in isolation, but insist that we look at how it fits into the broader complex of decisions in society. That's a terrifying agenda, but unless we can work to something like it we shall not be equipping our pupils to cope with the ways in which this country and others will have to change during their lifetimes.

Let's put that alongside an attempt to analyze the outside. The world outside is changing and is going to present to our pupils many different opportunities and pressures. Although I can only mention these briefly and superficially, it is clear that we must try to see how these outside changes actually throw light on and give us ideas about our inside activity.

One major outside change that is almost with us is in information technology. Soon all you need to know will be on data banks accessible from your own home through a telephone link. These will not only include the information you need, but also help to develop any understanding you may need. The world of artificial intelligence and of expert systems is growing rapidly. Already it is being claimed that a patient can diagnose his or her illness more effectively at a terminal than by going to the average doctor because the software behind the terminal has been put together by better-than-average doctors. I do not know whether that claim is correct, but it shows a beginning of a development which is clearly possible in principle. The target is to build both the understanding and the knowledge that you need into resource banks which will make possible individualized learning, at several levels and according to need for both adults and children. If this stage is reached, what will be the function of a school?

There are broader changes in technology. It already changed in past centuries from a technology where you make things yourself; individual construction is now seen as high art or craft recreation, but not as part of industrial production. There used to be a time when you could fix things yourself. You'd buy them ready made, but they'd break down and you could fix them. Those of you who engage in that sport will know that it becomes more frustrating by the year, because things are so made that you can't fix them yourself. We're coming into a technology where your only control is to choose the thing and then if it doesn't work to throw it away and buy another one.

But on the small scale in the home and in the community, there are ways in which we choose, design, and assemble our own kitchen, the layout of our house, what we do with our garden. These are skills of living that are technological skills, decision-making skills, but they are of a different order from the technology of industrial production. How do we help pupils with these? And where and how do we help them to function in a democracy, which should encourage citizens to informed choice and control of the large-scale systems technology? How do we help future citizens to engage in such debates and to see and think about the values underlying the choices involved?

Thirdly, if we look at the world outside, at employment and occupations, we should attend to the shifts in the nature of work. We're well aware of the disappearance of the work that depends on physical labor. We now have the disappearance of the blue-collar worker, and we're seeing the disappearance of the clerical and administrative white-collar worker. We now have—70 percent, is it?—of the workers in this country engaged in service and administrative occupations. That is what we're training a lot of people for. I refer you back to the Cohen paper, which more or less argues that because of such changes, the scientific culture is in fact completely inappropriate to the way most people must act. But when she's talking about the scientific culture, she's talking about the version presented in our traditional curricula, whilst I am trying to specify as a target, a gleam in the eye, something quite different which could be appropriate.

That's my guru piece. The last section that I promised is the prophet and/or Cassandra performance. This is where it gets more dangerous and more fun, and I shall presume that you will forgive me for being irresponsible. I shall start from a presumption that we have a need to know where we are and also to know where we want to be and how to get there. That's a pretty simple plan to follow.

Well, let us notice that there are many data we can collect about where we are. However, the data we collect ought to be oriented towards our vision of our goals and of how to get there, so the question we can ask of our data is this: Is it adequate to inform our goals and our ways to attain them? Essentially, any data collection is selective. It's selective according to the collector's priorities, to his or her model of what matters. The neutral descriptive posture of data collection can never actually stand scrutiny. Data collection is always to a degree prescriptive.

Let me give you an example. When we were starting the monitoring of school science on a national scale in the U.K., we could have decided to monitor what actually happened in schools and ignore all activities that were marginal or not very popular at the time. We decided that that would be wrong. The decision was to emphasize the process skills and to emphasize the capacity of pupils to tackle small practical tasks on their own. We set up monitoring instruments which included measurement of practical skills using apparatus which also involved children in small problem-solving tasks on the bench (Assessment of Performance Unit, 1983-7). The publication, in our reports, of such concrete test items, the discussion of how children are succeeding or failing on them, the publication of evidence of how children are tackling small problems on their own, has been very attractive to the best teachers, who've said, "That's what we were trying to do, thank you, you've given us some good stuff to do it better."

So the work has helped to orient the debate about what the curriculum is about and what it ought to be. This interest has moved the monitoring even further into a forward, prescriptive direction, whereas if we had dealt with only those things which were safe and already widely measured, we would have confirmed the traditional curriculum by focusing attention on its priorities, so making the monitoring an additional obstacle to reform.

Thus, it is important to look at the selection of data in any survey of assessment. What's it doing? Has it any orientation to where we want to be, or is it, by making a selection of what's apparently there and not looking at the areas of growth, in fact stopping that process and encouraging us just to debate how to go round in circles?

My second point is to beware of evidence that is based only on atomized activities or items. In any monitoring, surveying, or school assessment system the evidence should always be based on a mixture of fixed-response questions, open-ended questions, and practical activities. It should never be based only upon fixed-response questions. I assert this because of a belief that valid appraisal of pupils demands that we collect a variety of types of evidence. Any test designer must be analytic, but he or she must remember that the learning whole is greater than the sum of the assessment parts. The psychometric thirst for accuracy and precision, when combined with an attempt to pin down detail by absurdly precise behavioral objectives, can lead to very reliable data that give a seriously invalid picture of pupils' capabilities. Moreover, such data can do great damage to education by narrowing the vision of teachers. We have ample evidence that when you ask children to perform component tasks out of context, they behave very differently from the ways in which they behave when you ask them to do a whole task. Thus, narrowly focused questions in which children do not have an opportunity to explain what they are thinking tell you very little about what they have learned or might be capable of doing.

I am both flattered and overjoyed to see that in your NAEP program you are now expanding into practical problem-solving tasks by pupils drawing on some of the procedures we have developed in the U.K. That type of development must continue and be pushed very strongly. Your national tradition of standardized testing must be radically changed: its agents should start on the difficult task of trying to reflect the whole range of activities which should be on the educational agenda, and not just those that they find easy or economical to measure. But you should give three cheers only on the day when your testing agencies all have a science laboratory in their buildings. I know that not a single one of them yet has a science laboratory, yet you must have such a laboratory to design and test the equipment for effective testing of children's practical abilities. When they all know that they've got to have one, you will have begun to make educational aims dictate to assessment—it has been the other way round with you for too long.

I've said nothing about higher order thinking skills. It's a movement, obviously, of great importance, but I call your attention to the word "thinking." What about higher order action skills and higher order decision skills?

Finally, we need better data on pupils' development. Too little of our data comes from good cohort studies that follow through the later consequences of the starting points, in their understandings and apprehensions, that children have in science. And yet, looking back at some of the other arguments I have offered about the need to have a strategy which works to the progression of the child, the need for good data on the development of children is clearly a high priority.

The next part of my provocation is to ask how we study the process of change, as made for and by teachers themselves, because that is where the payoff will be. I don't see enough evidence, in your survey of your data, about how change is to be accomplished, and about how the front-line agents of change, your teachers, are to manage it. For example, if we consider in-service training for teachers, is it to be delivery systems or support systems? There are plenty of excellent in-service programs that one can organize on the "delivery" model in which the end result is the teacher going away from a course both excited and depressed. "It was terribly interesting," they say, "but they've not made my life easier." It is notorious, too, that many go away excited and optimistic, and yet in a short time their teaching shows no trace of the effects of that experience. How do you make a program that actually gives teachers support to carry through in practice the sort of changes that the reorientations that we are discussing require? What is not needed is to immerse people for a week to psych them up, and then to abandon them to make it work on their own. If we do that, we carry out the easy part ourselves and leave teachers to carry out the really hard part—for we expect them to change a lifetime's habits of working, against an unfavorable climate, with nothing like the cooperation and support that our innovative planners found essential for themselves. What is needed are systems of support in which any training will be followed through by providing teachers with a base, by forming groups which will meet regularly, by bringing extra resources in, and so on. A system where teachers are asked to change must be a system that supports them in that change, not one that just advertises it, tells them what to do, and leaves them to do it alone.

Furthermore, any system in which innovations run too far ahead of what the teaching community really understands and is prepared to go along with is a system that will fail. Innovation has got to be owned by the teachers. How does a system of recruiting teachers into this work actually help that process?

In this connection, too little is said about the inside of classrooms. There are research studies, of course, in great volumes, about the transactions inside classrooms. Let me go back to those children doing the floating and sinking, or the children with their boiler. How were these activities set up? What planning and management skills were involved? How were the teachers behaving? How were they eliciting activity and ideas from their pupils so that valuable things could happen without telling them what to do and so losing the point of the exercise? It's through the careful design of such work that valuable changes are going to happen. It's through the delivery and management skills that such changes will bear fruit. In spite of the volume of research, I don't think we have enough data about the skills needed for these purposes.

And finally, a framework. The research and surveys that have been conducted in this country and internationally are not as useful as they ought to be, because they're not on a common framework. Every time people start a new survey, they say, "We should reinvent the wheel, we have a better system, we have a better way of doing it, those other things were wrong." In a small, short-term way they're often right, but in the long term, in terms of the greater needs of the community, they are wrong. For that reason I suggest to you that you should have more uniformity of purpose, less commitment to each new project's doing it better "our way," less commitment to reinventing the wheel, less commitment to the better that always drives out the good. There is a need for greater uniformity of purpose amongst you. There is a need for agreed aims on a national scale. Experiments on new aims and on a variety of ways of pursuing these aims are very important, but agreed national aims would go a long way to clarifying and giving a framework within which people could start to work consistently instead of running off in all directions.

You do have, of course, a set of agreed aims. I think they arise by default of planning, and they are imposed on you by the assumptions and practices of textbook writers and of their publishers. When I come to a meeting, say an NSTA meeting, and look at all of the publishers' exhibitions, I see that you have beautifully produced school textbooks from the various large publishers, and they're all more or less the same. The lack of variety in your school textbook publishing is very striking to one coming from outside. That lack of variety is because you have a system of marketing, linked in some areas to state adoption and approval, which makes experimentation difficult and dangerous and which drives you to a least common denominator. That has to be changed. You must have a system that produces materials more under the control of the educational needs of the community. How you do it I do not know, but the present system does not do you justice, and in particular, will stop you from ever making any radical changes in the system.

Overall, we do need a system of science education that has within it a certain breadth, a certain balance between the technological and scientific, which is designed to carry through the notions of progression that research and other studies are now giving us a hold on. We need a way in which you can offer children a menu of tasks which builds up year by year, to develop their ability and stretch them further at each stage.

That must mean that the science curriculum must be planned, and planned as a whole. You already know that science teachers have to work across different curriculum areas, whether they start as physicists, biologists, or whatever. Whether that should happen or not, I think we must say that in any school the scientists should get together and, in view of a shared and comprehensive vision, plan their curriculum as a whole. I'm not saying that this means that you must therefore cease teaching physics, chemistry, biology, and earth sciences separately. It does mean that such separate teaching must be coordinated, unified in a common purpose and a common strategy for progression of pupils. In any plan like that, I cannot see how your year-block system could ever survive, for it does not seem consistent with any rational planning of a coordinated curriculum in science and technology. It astonishes your friends from outside, from all over the world, that you do it, because there doesn't seem to be any educational reason for it. If you are to start planning afresh, you will have to get rid of that system. That won't solve your problems, but it will at least remove one of the totally artificial constraints which prevents you from tackling them.

Finally, you must aim for science for all, and you must aim for technology for all. That means that in fact you should be committed to providing a science offering to all pupils, and not putting it on the menu of a cafeteria-type of curriculum system. We've been providing such "free" choice in Britain for years. We're now trying to get rid of it because we know it requires adolescents to make choices, that determine their future as citizens, and in their careers that they're not capable of making and that in fact polarize them in most unfortunate ways. We must stop that. The one thing it does for us, as I'm sure it does for you, is to prevent large numbers of girls from ever being prepared to study physical science. It's quite clear to us, and I think it should be clear to you, that the only way we can increase, dramatically and in a short time, the pool of talent equipped in science and engineering, is to find a way of recruiting into those fields as high a proportion of women as we do of men. One way to do that is to cut out the cafeteria-system and to make sure that boys and girls all study science up to age sixteen. There are some schools in the U.K. where that has already been done, and in those schools the effect has been to almost double the proportion of girls going on to advanced school studies in the physical sciences, which are the basis for degree and other courses in both those sciences and in engineering.

Education is inherently a conservative process. We're all living in a system which is very, very good at protecting itself from change. Let me quote for you, to close, Adam Smith's comment on education in the *Wealth of Nations*: "A sanctuary in which exploded systems and absolute prejudices find shelter and protection after they have been hunted out of every corner of the world." Why do you laugh? You should be offended at anyone insulting you in that way. I think we all laugh because we know it's partly true.

If we think of education as a dialogue between the generations, then it is quite appalling that there could be any truth in this cynical quotation. Let us make it an encounter where our generation helps the next generation to meet the past and to understand the present in order to journey into the future. That, as I see it, is the orientation of this exercise, and I am proud and honored to take part in it.

From the audience: What alternatives to the block plan would you suggest?

Black: The alternative is a straightforward one. It's that all children study science for a certain proportion of their time up to the school-leaving age, and that the science program be a common one. There can be differentiation according to ability within it, and that's under the control and the design of the science teachers of the school. Within that framework they may switch from the different subject components and back to them over time as seems the best plan, or perhaps study several topics in parallel. It's a matter of removing the constraint. So, for example, we are now thinking in U.K. schools in terms of a proposed national framework: 10 percent of time to be spent studying science for ages eleven to twelve, 15 percent of time for thirteen to fourteen, 20 percent of time for fifteen to sixteen. Within that, there would be a generalized unified science in the younger ages. The older ages may split into parallel tracks so that all are studying in the separate sciences using common terminology and approach for shared concepts, and having some common lessons where problem-solving and applications, cutting across the discipline boundaries, are studied. There's a variety of plans possible once you've created a framework in which the science teachers acting together can share out amongst themselves an agreed proportion of the timetable.

From the audience: What is the difference between scientific literacy and scientific capability?

Black: The difference is a little subtle, but, to me, very important. Scientific literacy is a stand-off, reflective study. Scientific capability is getting into it, doing it, and so learning a little bit about what it's like at first hand. I don't want to set up an opposition between those two. I think you actually need to engage in both; they feed one another, and to do the one without the other is a little bit dangerous. I don't think that the distinction may matter very much in science. I think it matters desperately in technology. Technological capability and technological literacy are so important that we have to pay attention to both. The experience of taking decisions, making things, evaluating them, finding out why they don't work, seeing there are wider issues involved in the way they are used, is something we should give everybody. With such experience, pupils ought then to reflect on it and relate it to wider issues about the world. So I see capability feeding literacy, and that literacy without it is a rather remote, unreal study to all but the brightest children. The brightest children can always take remote, unreal studies, but the average child will say, "Oh, he's going on about science and society again," the way they used to say, "He's going on about momentum, or about cell structure again."

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Chapter 3

A MATCH OR NOT A MATCH A Study of Intermediate Science Teaching Materials

Rosalie A. Cohen

Modern societies are heavily dependent on science and technology for space exploration leadership, for competition on a world economic market, and for internal development, environmental protection, and national defense. Producing a science-literate population from which to draw creative human talent has been a national priority in the United States. Two decades of innovation in elementary school science education have been disappointing, however, either in producing outstanding science innovators or in locating and developing valuable science talent among children.[1] Talent loss is most marked among girls and children from low income homes, large numbers of whom appear to avoid science in school and do not choose and are not chosen for science careers.[2] This study examines one possible source of that differential survival of interest in science books and materials used in the middle, or intermediate, grades—the latest point at which all children have science in their curricula. It asks if these materials are broadly enough defined and taught and of sufficiently varied application in a rapidly changing economy to stimulate science interest among all children.[3]

METHODS

A content analysis of intermediate grade science teaching materials addressed the questions above. Two preliminary studies produced working definitions, set time and sample limits, identified the publishers of science materials and the categories of products available, and defined limitations on the possible impact of these materials on children. Findings that are reported here are drawn from the central study that followed, the content analysis of science teaching materials.

The Preliminary Studies

The first preliminary study provided a working definition of "middle," or "intermediate," grades, and it identified the time frame of the modern science curriculum for later sample selection. Editions of *El-Hi Books and Serials in Print*[4] from the 1960s through 1986 were used for both purposes. Grades 4–6 emerged as the irreducible intermediate grade designation, and these grades comprise our working definition of middle, or intermediate. These years represent the latest grades in which all students are exposed to similar material; General Science has not yet been differentiated into component sciences, and pupil assignment to separate curriculum tracks has not yet taken place. These years also precede the disparate physical and social growth patterns of puberty, and we later learned that they are important to the learning theory used in the modern science curriculum as well. Our working definition of the modern science curriculum time frame began with the earliest publications still being used (those published in 1968 and 1969), and it ended with the latest revision in the field. In that time, major revisions had appeared every five to seven years, a fact that was later confirmed by publishers. The latest revision was not included in our time frame, because, although it had been completed and adopted, it had not yet been implemented in the schools.

El-Hi Books and Serials in Print was also the source of publication categories for later analysis. Publishers of books and materials for the intermediate grades are of three types: (a) those major textbook publishers that provide integrated, full-series science textbooks for all grades, including grades 4–6; (b) publishing houses that provide specialized reference books and supportive materials for hands-on/activity curricula; and (c) those that publish discovery texts on scientific topics, tools, or materials. In 1986, this list encompassed more than six dozen publishers and several hundred books; traditional textbook publishers represented about one-fourth of those listed, the publishers of discovery materials an additional one-fourth, and those of specific reference materials the remainder. The relative impact of these three categories is not apparent in their numbers, however. Individual lesson or unit materials or individual reference materials that had to be assembled into courses of study comparable to those of the texts greatly reduced their effective numbers. Time-sequence analysis of these lists confirmed the later 1960s emergence of the activity/discovery science curriculum and its continued development into the more common contemporary multiple-method materials.

A second preliminary study was designed to identify the middle school population that could be impacted by science books, and then, through approximate use and distribution ranges of these materials, to identify for our analysis those books most widely used by that population. Confidential, semistructured interviews of a progressive sample of publishers' managing or science editors and of developers of teaching and evaluation materials were used to achieve these ends.

It was apparent from these interviews that, although there was general agreement on the rank ordering of the publishers' materials according to their relative share of the adoption market, the boundaries of that market were less clear, and the implementation range of the materials that had been adopted was even less well defined. Some adopting units had rejected the modern science curriculum in its entirety and new publishing houses had arisen to produce texts for alternative schools. Users of these different materials ranged from conservative Christian and Black Muslim schools to secular private schools that prefer to teach logical inference through literature rather than through science. Populations served by such non-conventional publishers appear to be concentrated in the Southeast and in large urban centers in the Northeast and Midwest. Reasons given for their rejecting conventional material involve both its content and teaching methods, its pacing, its "information overload," the levels of abstraction it requires, and its expectations that children theorize and intervene rather than merely observe.

Many postadoption rejections were also reported, and they appear to affect activity-centered programs more than others. On intermediate administrative levels, reasons for rejecting conventional material are based on the activity programs' comparative building space needs, the cost of basic and expendable equipment, insurance hazards of using hot plates and corrosive chemicals, restrictive state, city, or school district laws, inadequate supervision of the equipment, and danger of theft, loss, or illegal or improper use of equipment or materials stolen from the classrooms. These problems are exacerbated by special dangers when the equipment is used by physically and mentally handicapped children, who appear in larger numbers in some districts, and by t[illegible]ceived cost/benefit dimension of discovery for them.

Failures by teachers to implement adopted science programs also reduce the pupil population impacted by the programs. Among teachers, live animal lessons create special problems of sanitation, of responsibility for animal care, and, during vacations when animals may be lent to children, of guilt about the psychological costs of unintended harm to animals while they are in pupil custody. Some live specimens (spiders, rats, and worms) may also be seen as intrinsically unattractive, and live animal lessons that call for "animal sacrifice to science" as particularly distasteful. Some publishers mentioned that work overloads limit time for teacher preparation, and others cited political pressure on teachers to devote class time to reading mechanics. Disappointed publishers mentioned reports in one state of postadoption science involvement among teachers that is limited to only 20 minutes a week.

Multiple-method teaching materials were designed to minimize postadoption rejections and to appeal directly to various pupil subpopulations to choose science for their careers. Such multiple-method materials mix text and activity materials for maximum flexibility, they incorporate home exercises and school projects, and (while inner-city illustrations and references are conspicuous by their absence) they are designed to appeal to many special populations, through Spanish and Braille editions, and through illustrations and career references, to girls and members of various race and ethnic groups and to pupils with special interests in art, music, and physical education. Such materials did reduce postadoption rejections in some complex districts. Paradoxically, however, the development of multiple-method materials was accompanied by rejections based on that very complexity, and geographical and social class biases had already appeared in differential adoptions of multiple-method materials versus simple activity designs.

Mixed activity and traditional methods appear to dominate in the less than half of the nation's states that adopt texts and materials for their entire states. These states are predominantly those with developing state economies in the South, Midwest, and West, and their populations are primarily growing, new, and young. The reverse side of that adoption bias is that some large, urban, residual, old ethnic, northeastern school districts with large Black, Hispanic, and economically disadvantaged pupil populations and tax bases stressed by multiple service needs, whose pupils do not share the reinforcing advantages of Boy Scout activities and summer camps, have recently chosen the less methodologically varied, activity-centered programs. With these, books are not used in the primary grades at all and only for reference and enrichment in the middle grades. Thus, equal pupil access to varied science materials is restricted by the tendency for some adopters to have made important science program decisions solely or primarily on the basis of a district's dominant social class.

Such decisions reflect underlying assumptions that the ability of children from low income homes is limited, that programs limited to hands-on lessons are necessary for such children because they keep pupils busy but do not rely upon advanced reading skills, and that, in any case, such pupils cannot be evaluated by the same performance measures that apply to other children. Withholding important science materials from them is also based on narrow interpretations of comparative program evaluations, which report that economically disadvantaged pupils are more successful in hands-on science programs and that these pupils rate more highly on curriculum reference performance measures than on standardized tests.[5]

Biased adoption decisions affect our research questions by compounding the impact of the different materials. For instance, total substitution of activity materials for books may dampen pupils' desire to learn in conventional ways, especially among those children whose environments are already limited. The impact of limiting their science programs to discovery materials may be likened to that of television, being attention- and affect-centered, dependent on visual imagery, continuous in time, isolating in space, discontinuous in content, and immediately and intrinsically gratifying. It may also encourage immediacy of response to a constantly changing field, rather than reflective attitudes and deep concentration, and an authoritarian, rather than a speculative, attitude.[6] Limiting learning to that obtained from personal discovery may also encourage such pupils to accept the limits of that knowledge available to them directly—a process that characterized learning before reading made it possible vicariously to learn what others knew. Thus, biased adoption and implementation decisions might account in part for the observed differential success of science programs by systematically restricting some pupils' access to a wide range of science teaching materials.

Study of the impact of science materials on intermediate grade children is limited, thus, both by pupil access to science materials at all and, among those to whom access is provided, by the availability of similar materials to all children. Both adoption and postadoption rejections reduce the pupil population that can be affected by teaching materials. To the extent that the effect of such refusals to adopt and/or implement the science curricula are systematic by gender, ethnicity, social class, or geographical region, they affect our research questions because children cannot be equally affected by teaching materials unless equal access to them is provided.

In summary, the two preliminary studies reported above produced working definitions, set time and sample limits, identified publishers of science materials and the categories of products available, and defined limitations on the possible impact of these materials on children. Study materials were then selected for analysis of their content to determine how they affect the children who do have access to them.

The Central Study—The Content Analysis of Teaching Materials

While a larger range of materials was examined in the earlier phases of the study, a limited purposive sample was drawn for our content analysis to include the available revisions of these modern science curriculum materials. This sample consisted of materials produced by one of the two major suppliers and two of four publishing houses of secondary dominance. To account for the segments of the population to which those materials are not available, sample materials published by two series publishers who continue to produce activity program lessons were added along with their design descriptions and evaluation guides and several district programs that use them as guides, although some district materials were incomplete. A large number of individual reference, enrichment, and discovery materials and numerous programs for outcome evaluation were examined as well. Although unusual or reactionary materials were also sought for purposes of contrast, a sufficient number were difficult to obtain, and they do not enter into the analysis below.

Our sample materials were then subjected to content analysis, a form of document study used to derive "grounding theory." Descriptive categories emerge from this analysis rather than guide it, and theory is generated by this process rather than tested in it. That is, rather than performing a document counterpart to survey research, in which manifest content is transformed from qualitative to quantitative data (Bailey, 1982, pp. 313-14), recurring themes were sought for analytic, rather than descriptive, research purposes, using a naturalist paradigm to build theory, not to test it (Lincoln & Guba, 1985). On the research continuum proposed by Goetz and LeCompte (1981), methods are category constructive rather than enumerative and theory generative as opposed to verificatory, and their logic is inductive rather than deductive. This method deals with meaning context rather than manifest content, and decisions concerning theme selection follow the constant-comparison method first described for building grounding theory by Glaser and Strauss (1967). Because we were concerned with recurring themes, earlier versions of the books in the sample were also examined to ensure that those themes identified were persistent characteristics of the science curricula they represented. The analysis also makes certain assumptions common to document analyses, i.e., because documents are first-person individual or team presentations, (a) the science lessons and curriculum structures that appear in the sample of books and activity materials are valid representations of the designers' intents and (b) valid representations of the designers' theories and objectives will be apparent in those documents.

FINDINGS

Persistent and recurrent themes found in the sample of books and materials focus on particular theories of learning and of the nature of the learner, and on content expectations that embody implicit assumptions about the acceptable nature of reality. Discussion of each of these recurring themes appears below.

Themes Concerning Theories of Learning and of the Learner

Stage-Development Theories of Learning. Despite differences in specific content, plans of knowledge development that progressed from the concrete to the abstract were apparent in the sample, and, whether the programs were methodologically varied or solely activity based, such plans were often explicitly stated in the teachers' editions of books or in preambles to individual curriculum designs. These plans reflect assumptions about the nature of the learner not previously tested in large and heterogeneous populations. For instance, lessons designed to present information in contexts that progressively advance from the concrete to the abstract over the elementary school years are based on theories that hold that pupils' cognitive ability to conceive of and manipulate abstractions develops to maturity during those years and that learning is enhanced by lessons designed for each stage of that process. Indeed, such theories are made explicit in the most widely used publishers' products, and their curricula are described as relying on such assumptions.

An example of such a progression is found in the intermediate Physical Science "matter" units selected from a widely used textbook series. In the pre-intermediate grades, stated objectives include the classification of objects by their indepedent, concrete descriptive characteristics (colors and shapes), observable physical and chemical changes in matter are described, and the process of ordinal linearization of such properties as size, volume, and weight and the use of comparators is begun (bigger, heavier, etc.). In the intermediate grades, that process continues in fourth grade to include a focus on those linear properties that "can be used to describe matter," and on measuring more abstract "hidden dimensions" such as mass, volume, and density. In fifth grade, using "indirect evidence to guess about the structure of matter," still more abstract characteristics of matter that categorize elements are presented, and molecules and compounds are described. Completely abstract symbols are used on this level to refer to elements. Grade six reinforces the conceptual independence of these hidden properties, drawing distinctions between mass and weight, for instance. The characteristics of elements for grouping in the periodic table are described, along with what atomic numbers mean in terms of hidden properties of atoms, and an introduction to acids, bases, and salts is provided. In that same series' "taxonomy of science skills" for the intermediate grades, explicit objectives include identifying objects and phenomena, describing and classifying them, comparing and contrasting them, and sequencing them to estimate, predict, and discover cause-and-effect relationships. According to this explicit curriculum plan, by the end of the intermediate grades, pupils should be ready to locate and manipulate the necessary abstractions to make inferences, form hypotheses, design experiments, control variables, draw conclusions, create models, and propose theories. This progression to the abstract is also apparent in these materials, because the intermediate-grade content is progressively communicated in the abstract language of science, as properties, serial relations, quantification, variables, interaction, systems, energy, organisms, populations, life cycles, environments, communities, and ecosystems. Comparison of the actual lessons with the explicit objectives found them to have been rationally designed to accomplish the progression to the abstract. Comparison of the lessons of other publishers with those objectives also found a high degree of concordance in expectations for this progression to the abstract, despite differences in the specific content of different publishers' lesson units.

This concrete-to-abstract curriculum design is consistent with cognitive stage-development theories of the learning process and with their implicit assumptions about the nature of the learner. Unlike Behaviorist theory, stage-development theories assume that "mind" mediates between stimulus and response, and that its abilities to conceive of and manipulate abstractions develop in fixed, progressive stages. While stage theories of cognitive development differ somewhat from one another, all share the pattern and pacing of Jean Piaget's general theory, which holds that children's cognitive capacity to manipulate abstractions is realized at puberty (at the end of the intermediate grades).[7]

Two of Piaget's stages overlap in the middle grades—his Concrete Operational Stage, in which he proposes that cognitive operations related to such stimulus properties as weight, speed, and number or quantity, cause and effect relationships, and rule creation are learnable only when couched in concrete content, and his Formal Operational Stage, which, according to his theory, should be reached at the end of the intermediate grades, when children can conceive of complete abstractions, manipulate them, reason logically from premises to conclusions, and construct and apply theories. While the content of science lessons varies considerably from one publisher to another, cognitive expectations of their science lessons appear to be paced by such a plan.

The science materials examined also specify lesson objectives in action terms, such as observing, classifying, communicating, measuring, inferring, predicting, extrapolating, judging, interpreting, experimenting, defining, and transferring, on the basis of which lesson objectives are to be evaluated. Such objectives confirm their conformity with other Piagetian assumptions (e.g., that learning is an active process), and they differ from those associated with Behaviorism, which sees the learner as passive. The theories of learning and of the learner apparent in the science materials appear as persistent and recurring themes in science spin-off course materials, such as "life experience" and "values clarification" courses, as well.[8]

"Nature" Theories of the Learner Extensions. In addition to [illegible]ce curriculum designs in which theories of learning and of the lea[illegible] appear to be intentionally activated, we find some apparent extensions of theory about the nature of the learner that were not intended by the theorists. For instance, Piaget and Inhelder (1969) allowed that their theory applied to capacity alone and that it did not presuppose the cultural content of a child's experience. Many science curriculum designers who apply stage development theory, however, tend not to draw a distinction between physiological capacity in children and its application to the designers' own selection of cultural and subcultural blueprints.[9] Limiting the learning process to fixed-stage progressions from the concrete to the abstact and linking this process to narrowly defined content suggests "nature" assumptions about the learner. This link encourages the belief that, where children reject the program's content, or develop at a slower rate or in a different pattern, causes of poor science performance may be found in genetic, tissue memory, and other "nature" explanations of learner inadequacy, thereby bypassing issues of inadequate schools and programs.

The stage development theory of learning has not been demonstrated as valid among large, heterogeneous populations, nor has its application to science teaching produced outstanding science innovators or increased the number of children who choose science as their careers. Rather, it may account for postadoption rejections of science materials and science avoidance by teachers. While it lends itself to mechanical notions of teaching science that are convenient to "engineer" the curriculum, it is foreign to and inconsistent with the Behaviorist theory, in which teachers have been prepared. It also changes the teachers' role from that of professional to technician, it forfeits their classroom autonomy, it measures their expertise with factory-model outcomes, and it suggests that "master teachers" are no more than forepersons to regulate "pupil processing." Alienating teachers and subordinating valuable concrete aspects of science programs to attempt untried abstract objectives, thus, may prematurely or inappropriately deprive many children of necessary science knowledge, and it may account for some of the disappointing outcomes of the program.

Themes Concerning Content of Teaching Materials

The Language and Culture of Science. The most significant characteristic of the Content of intermediate science materials is that, for the most part, the Content is intended to be relatively context-free and manipulable only in abstract form. This recurring theme appears to be irrelevant to the teaching methods in which it is couched, because it is dominant in both mixed-method and activity materials. Specifics of each lesson are intended to be relatively transitory, an objective that is met, in part, by discontinuity among the lessons—a characteristic of all the materials in our sample. Pupils are expected to pass over idiosyncratic contexts in which Content is couched to seek in it common, hidden "properties," and to use these to assemble "evidence," to establish "relationships," and to build "models," no matter in what context they may be found.

The stable characteristic of Content is culturally controlled in that specific, culturally valued cognitive tools must be used to separate the Content of each lesson from its idiosyncratic context, thereby yielding only the information obtainable in this way. Cognitive rules called "analytic abstraction" and "field extraction" are the tools to be used for this purpose. They are described in later sections. By using those cognitive tools and not others, the pupils' task is to seek abstract (context-irrelevant) characteristics of their world, that is, to locate its hidden structures and systems, properties, interaction patterns, and processes of change. Those are its Content. It is irrelevant, for instance, whether Life Science lessons are about rabbits or brine shrimp—important information is located and communicated about them abstractly as life forms, organisms, and populations in life cycles, environments, communities, and ecosystems. This important Content is communicable only in the special language of science and in graphic and statistical terms and tables that require the linear isomorphism of that Content and an acceptance of probabilism, uncertainty, and fate control.

All languages are products of their cultures; they are carriers of specific definitions of reality. The language of science is no exception. Its persistent and recurring Content themes suggest that it provides a socialization process in a particular subculture, entry to which may be obtained by communicating in its own abstract analytic language. Assuming that all children have equal access to that process, given the Piagetian time schedule, resocialization is scheduled to be complete by the end of the intermediate grades.

The Cooling-Out Function of Intermediate Science Requirements. A second significant Content theme is found in that science lessons require the same cognitive rules—analytic abstraction and field extraction—to locate Content as do standardized intelligence and achievement tests. As a result, both science materials and standardized tests appear to take the same undeclared epistemological position. Both science curricula and standardized tests also expect the accumulation of denotative information (context, or, how do brine shrimp and rabbits live?), of course. Its demotion in science to the level of "context," however, emphasizes (a) the designers' view of its nature as transitory and (b) how central the analytic cognitive skills are to success in science. Because the same cognitive tools are used to measure science success as are used to measure native ability (Witkin & Goodenough, 1981, p. 61), poor science performance might prematurely be interpreted as evidence of limited native ability.

The first rule, abstract analytically, instructs the user to find hidden properties, name them, and give them meaning in themselves. Primary-grade science lessons begin to develop this skill at once in their "describing" lessons, in which pupils learn to identify shape, color, and size and to linearize these attributes, if possible, as bigger, heavier, and so forth. Intermediate-grade lessons focus on characteristics of the physical world that require special instruments or theories before they can be identified or measured, developing concepts of density and mass and describing atomic structure. Standardized tests of intelligence and achievement are also designed to reward the use of that rule as an important performance measure, and in the Piagetian developmental process, its use is seen as a "higher order" skill.

The second rule, "extract," is called Field Articulation. It requires that the pupil separate himself as observer from his field of observation and then impose structure on an ambiguous field. For example, in perceptions of being "upright," subjects sitting in a chair that can tip and turn in a room that can tip and turn either change themselves to suit the room or control the room in relation to their own positions. Those who can conceptually separate themselves from their "field" and control it to suit their own positions do so by using the extracting rule. Those who do not "extract" themselves from their fields tip their chairs to suit changes in the position of the room, perceiving themselves to be "upright" despite their sense of gravity (Witkin & Goodenough, 1981). Imposing order on the field requires its parts and characteristics to be extracted as well. All of those science lessons, from kindergarten up, in which the focus of analysis and description lies outside of the observer, develop skill in extracting. Among them are those that teach directions from "it" in a defined field, e.g., North or South of "it" (not "me"), or that use polar coordinates to locate "it" above or below or right or left of "it" (not "me"). This process separates both self and "it" from an otherwise ambiguous field and removes "it" to a distance at which "it" can be studied, tested, manipulated, and controlled without affecting the observer. Many discovery materials describe how tools designed for this purpose may be used. This theme is so persistent in all of the science materials examined that extracting appears to be seen as the heart of current concepts of scientific objectivity and as the basis of control of one's external world.

Extract and control are culturally defined rules, and there are many groups that do not value them. Girls, who represent roughly half of the population, typically do not extract (Cohen, 1971, 1980; Witkin & Goodenough, 1981). Certain Hispanics also do not extract, and their culture denigrates doing so. For example, the San Antonio Mexican American Cultural Center chart "Comparative Overview of Anglo-Saxon and Mexican Historical Cultural Patterns" focuses on Mexicans not sharing this particular view of reality. It contrasts the Anglo mode of "immediate and constant action . . . to modify the environment to fit our needs" with the Mexican mode of "passive endurance and resistance . . . modify ourselves to fit the environment"; and the Anglo "fundamental values" of "Control . . . of oneself, of others, of nature" are contrasted with the Mexican ones of "Harmony. Within oneself, among others, within nature" (in Garreau, 1981, pp. 230–231). Mexican Hispanics represent a substantial pupil minority, particularly in certain states. Combined with the national subpopulation of girls alone, these required science rules, extract and control, may be the most important discriminators between pupils who will enter scientific careers and those who will neither select nor be selected into them.

Because science books and discovery materials appear to be grounded firmly in the same methods of cognitive processing that standardized tests measure, the science curriculum is, by and large, a structured course of study in developing those skills needed for related aspects of test performance. While advantageous in some ways, this reinforcement of analytic expectations may have unintended consequences for science as a field of study. It may improperly equate differential science success with intelligence, and given the Piagetian focus on the intermediate grades, it may transfer the school's sorting and selecting functions for the distribution of life chances from external tests to intermediate science curricula. This role may appeal to cost-effective managers in inappropriately encouraging their belief that, for most pupils, science programs need not be extended beyond puberty.[10] Because other aspects of the curriculum reward alternative skills, however, success in abstract aspects of the science culture appears to be less a matter of individual achievement than of how good the "match" is between (a) pupils' cognitive patterns and those expected by the science curriculum and (b) those expected by the curriculum and those usable in other fields and in society. Such cultural matches are considered briefly below.

Cultural Themes: The Pupil/Curriculum Match

Analytic abstraction and field extraction require that qualities or properties of stimuli be conceptually abstracted independently, and then extracted from their embedding contexts, named, and given meaning in themselves. This same process is applied to concepts of time, space, and causality and, in English language study, to component paragraphs in essays, parts of speech in sentences, and syllables and letters in words. Learning to think of such common characteristics as height, weight, specific gravity, and density as being like straight lines (linearizing them) makes measurement and linear comparison possible. The rule, extract, requires that the pupil pull all of those separate properties out of their embedding contexts independently, name them, and give them separate identities that are unrelated to the contexts from which they have been separated. It also requires that observers extract themselves from their fields of observation (scientific objectivity) and distance themselves from their perceptual "fields" sufficiently so that they can examine the characteristics of objects in those fields without being affected by them. Together, analytic abstraction and extraction form the Analytic conceptual style required by the science materials examined (Table 1).

Table 1. Four Conceptual Styles

Type	Cognitive rules: Mode of abstraction	Cognitive rules: Mode of field articulation
Analytic	Analytic	Field Extraction
Flexible	Analytic	Field Embedding
Concrete	Descriptive	Field Extraction
Relational	Descriptive	Field Embedding

Conceptual Styles. "Conceptual style" differs from the more commonly used notion "cognitive style" in that it deals with the performance interaction of the two independent cognitive rules that are used by standardized tests to measure cognitive achievement, rather than treat them independently.[11] Individuals become "carriers" of their conceptual styles, or rule-sets, which appear to have been learned preverbally as rules of group process (Cohen, 1969, 1971; Witkin and Goodenough, 1981). Three non-Analytic rule-sets are contrasted with the Analytic one in Table 1. Such rule-sets or styles are apparent in individuals' differential language use, in the creation of their social patterns, in their values and perceptions of self and others, in their self placement in space and time, and in numerous other manifestations of their uses. Relationships among the four conceptual styles and selected choice behaviors appear in Table 2 and among conceptual styles and taxonomies of other researchers in Table 3. Conceptual styles are not characteristics of the individual but are rather culturally determined models of reality. Given the limited focus of contemporary science materials, users of non-Analytic rule-sets could be expected to have differential success in coping with their expectations.

The Flexible style shares the analytic mode of abstraction with the Analytic model. It also shares the rule "embed" (do not extract) with the Relational style, however. It is possible to find distinctions between the two styles that embed by considering the different mode of abstraction used by each. Users of the Flexible style abstract the hidden characteristics of a stimulus analytically, but then they embed what they have abstracted into specific contexts (rather than extract them, name them, and give them meaning in themselves). These users could be expected to do well in science lessons that require analytic abstraction but poorly in those that require extraction, and to avoid those sciences in which extracting is required. Users of the Relational rules deviate completely from the science model. They also embed, but they do not share the analytic mode of abstraction from which Flexible style users "benefit." They embed global, descriptive characteristics of a stimulus, and they embed them in the same field over and over again. Their chances of success in any abstract science lessons are poor.

Relational-style users share their global, descriptive mode of abstraction with Concrete-style users, who extract. Selecting global, descriptive characteristics of a stimulus (rather than its parts and characteristics), as both Relational- and Concrete-style carriers do, can be expected to prevent carriers of both of those styles from moving to higher levels of analytic abstraction and from fulfilling the Piagetian transition. Although Concrete-style users benefit from their extracting

Table 2. Four Conceptual Styles and Related Variation in Some Selected Choice Behaviors

Conceptual Styles	Church Style	Political Style	Ideal Health Services	Age-Status Elite	Orientation to Past & Present	Planning Time—Space Means-Ends
Analytic	Large; Secularized doctrine	Liberal Conservative	Rehabilitative	Middle age range (those actively participating)	Present: relevant range, near past to near future	Short-term: highly rationalized plans; means focus
Flexible	Large; Social identity, social responsibility doctrine	Liberal	Preventive	The young and the very young	Future	Long-term plans: intuitive, open to constant modification; ends focus
Concrete	Small; Traditional doctrine	Conservative; but also radical on both ends of the spectrum	Treatment	Elders	Past (from the beginning)	Present and future viewed as emergent
Relational	Small; Affective Faith-in-God doctrine	Convential participation low; indigenous pol. orient. highly personalistic	Nonconventional, faith healing, occult, neighbors, and corner pharmacist		Present: NOW	Planning is viewed as dysfunctional to self-realization

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Table 3. The Association of Four Conceptual Styles and Their Cognitive Components with Modes of Self-Identification, Referrent "Others," Positive or Negative Attitudes Toward the Norms of Formal Organization and Ego-Involvement in Them, Value Realms, Brain Hemisphere Mental Functions, Language Style and Perceptual Distance: A Synthesis of Some Relevant Taxonomies

Conceptual Style and Cognitive Skill Components	Modalities of Self-Identification[1]	Referent "Others"[1]	Positive or Negative Attitudes Tow. the Norms of Formal Org. & Ego-Invlvmt. in Them[2]	Value Realms[3]	Brain Hemisphere Mental Functions (Propositional or Appositional)[4]	Language Use	Perceptual Distance (Distance of Observer from His "Fields")
ANALYTIC Mode of Abstr.: Formal Field Artic.: Extract	Status	Generalized "others" (George Herbert Mead)	Positive, Ego-Involved	Isolative Personal	Propositional	Standard English of controlled elaboration	Close enough to study and manipulate; not so close as to be affected by it
FLEXIBLE Mode of Abstr.: Formal Field of Artic.: Embed	Individualized Action	Significant "others" (Harry Stack Sullivan)	Positive, Non-Ego Involved	Inclusive Interpersonal		Standard English highly elaborated	Perceptual distance manipulable

CONCRETE Mode of Abstr.: Descriptive Field Artic.: Extract	Concrete	No group "others"; Naturally or biologically defined "others" (e.g., species, race, family) or accidental "others" (community)	Negative, Non-Ego Involved	Simplistic		Standard English of little elaboration	Great unmanipulable except by manipulating the laws of Nature
RELATIONAL Mode of Abstr.: Descriptive Field Artic.: Embed	Transcendental	Universal "others"	Negative, Ego-Involved	Comprehensive	Appositional	Non-Standard English	Observer is immersed in his "fields," and cannot escape constant response to them

1. Taxonomy of M H Kuhn and T S McPartland. Elaborated by W G Hartley and R Cohen.
2. Shenffian Attitude Anchor Framework—Taxonomy developed by Lloyd Ward and Barbara Jameson
3. Taxonomy of Otto von Mering
4. Distinction of Jos E Bogen and Associates

Charts reproduced from Cohen, Rosalie "Conceptual Styles—New Educational Strategies for Cultural and Linguistic Minority Children," (Position Paper Commissioned by and prepared for the Nat'l Inst. of Education, Wash DC, 1974)

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skills, both can be expected to be handicapped in science lessons that rely on Analytic abstraction for performance.

In all cases, because the science curriculum does not give much reward for specific content, it is more restrictive than standardized tests, which do. As in science lessons, Flexible and Concrete conceptual style users "score" on one or the other skill aspects of standardized tests as the result of their sharing one of the two analytic cognitive skills with the Analytic style, and also on their knowledge of specific information. While Relational-style users share neither of those skills—unlike science expectations that permit no variations from the progression to the abstract—standardized tests provide such pupils with many opportunities to exhibit their concrete information, which benefits their performance.[12]

The above modes of selecting and categorizing information are also linked in various ways to the different concepts of time, space, and causality on which the science materials take fixed positions. For instance, individuals who linearize weight and height also linearize time and space, producing isomorphic constructs, as opposed to those individuals who identify only global essences of a field and who see time and space as discrete, bounded dimensions. Along with the "space-time continuum," "efficiency" and "achievement" are Analytic concepts. They assume that time is a linear resource, that it "runs" in the same direction as relevant, linear space paths, and that it is possible to cover more space by saving time. These rule-sets mark significant, subculturally determined, epistemological differences that are identifiable by the different combinations of cognitive skills they require. Such differences as appear in these conceptual styles are as old as written references, and, in philosophy, they share equal value with those on which the elementary science curricula are based. Those who abstract globally and descriptively are called "essentialists" rather than "existentialists," and their assumptions about the nature of reality are Platonic and Augustinian rather than Aristotelian and Thomian. The four conceptual styles are also associated with different subgroups in society, the Flexible style appearing most commonly among women, and the other three styles, differentially, among men in various occupational and ethnic subcultures. Because women share the Flexible style's embedding rule with subculturally different men, that rule is culture related, and not gender related, as has been theorized.[13]

In brief, regardless of what teaching methods are used, science materials focus on the same Analytic conceptual style for performance as do standardized tests of intelligence and achievement. This style presents an undeclared position concerning the nature of reality (i.e., it is that reality locatable by using analytic cognitive tools and no others) into which children are to be (re-)socialized, and a Piagetian calendar limits the time available for that process to take place. Rule-sets created by combinations and permutations of the two cognitive rules used in standardized tests identify three nonanalytic conceptual styles, however, whose carriers present systematic but different problems in dealing with the relatively content-free abstractions that characterize the science materials examined. Because the cognitive skills necessary for standardized tests form the cognitive bases for science curriculum design, and because the development of abstract Analytic capacities is expected to have been achieved by puberty, the intermediate grades appear as the watershed for patterns of science rejection and science avoidance in later grades. The match between science curriculum and standardized tests is fairly good, therefore; but the match between the science curriculum and its related tests, and children's cognitive capacities is partial and limited to certain children.

Cultural Themes: The Curriculum/Occupations Match

Differential cultural themes are also apparent in the match between the science curriculum and skills needed by the general population. The General Science curriculum and its materials are limited to the Earth/Life/Health Sciences and the Physical Sciences, restricting the concept "science" to those specialties. It does not include the Social and Behavioral Sciences, for instance, although they use the theories, methods, and meta-language of the selected sciences, they are growing rapidly, and they appeal to women and members of economically disadvantaged minorities. Although the Earth/Life/Health Sciences and the Physical Sciences are still essential for the small number of pupils they attract, neither their Analytic conceptual style nor the high levels of analytic abstraction they require are central to most contemporary occupations. As a result, school science is less relevant to economic development and for large segments of the population than it might be.

The Earth and Life Sciences arose out of the dominant pre-twentieth century "primary industries," the products of which are used as they come from nature (farming, fishing, forestry, mining), and the Physical Sciences characterize the "secondary industries" of industrial dominance that followed. Our economy has been postindustrial for more than a generation, however. Primary industry has not been central to the nation's occupational market since the nineteenth century, and secondary industry not since 1956. In that year, employment dominance shifted from the older technologies to that of third-sector (services) and fourth-sector industries (the production of intangibles). The structural unemployment of this transition is felt most by white, middle class, and working class men who were central to the early industries, while women have a virtual monopoly over services.

Different industry products and their technologies require different cognitive tools. Primary and secondary industries produce objects; they require the person-object models of interaction to which elementary science materials are limited and the Concrete and Analytic conceptual styles that are associated with them. Service industries produce interpersonal products, however. They require the person-person models of the Flexible conceptual style. Fourth-sector industries produce intrapersonal products, whose dimensions are still largely unexplored, through the Relational conceptual style. Each industry sector produces relative homogeneity among its employees through generating selection, entry, and performance requirements for new recruits that are derived from that industry's related conceptual style.

Each conceptual style creates its own conceptually consistent work environment as well, and these environments often characterize the dominant culture of an era. The industry-based Analytic cognitive skills that analyze and extract, linearize, name, and give independent meaning to height and weight also differentiate separate occupational subtasks and their functions, place them within a linear authority framework that is isomorphic with time and other resources on the one hand and with prestige and salary on the other, to create the bureaucratic structure that has dominated industrial society. The Flexible-style work pattern has eroded that structure, however, to create the horizontal networks that characterize the now dominant service sector.

Flexible-style users have developed a unique cognitive capacity by which both service tasks and work settings are defined—that of holding multiple processes in mind at the same time, each one rising into consciousness as necessary. Because unique items and processes do not lend themselves to generalization, carriers of this style are generally unwilling to make general statements or to commit themselves to fixed positions They are similarly unwilling to plan far into the future, because each process, embedded in its own context, moves in its own pattern at its own rate, and configurations of these multiple processes at different points in time cannot be predicted. Users' thoughts move freely among those multiple processes, and total recall of discrete moments may be triggered unplanfully, with the result that their conversation is characterized by apparent non sequiturs. Flexible-style users speak highly elaborated standard English characterized by much processural, motivational content, many references to color, mood, and tone, and with much meaning carried in vocal intonation, gesture, and other nonverbal forms of communication. They personify; they are theory generators; their natural logic is inductive rather than deductive; and, like others who embed, they are survivors rather than controllers.

Services have been defined by the Flexible style users who dominate these fields in a fashion consistent with their style. For example, nurses can keep in mind multiple processes unique to each of multiple patients, each process moving independently, configurations of which have certain meanings which either do or do not require their attention, and act on those configurations before they are evident in other ways. Similar skills characterize the teacher of small children whose cues are often not definable in common terms, of the secretary who is responsible for multiple, qualitatively different projects for multiple bosses and who manages a family as well, and of the social worker whose case load concerns many clients, each unique, and each embedded in a unique field of interacting conditions. These skills were learned initially in external nonformal and informal educational environments, because they are not yet taught in elementary school science courses. Flexible cognitive rule-sets are built into higher education programs, however, generating new technologies, limiting access to service occupations, and maintaining the cognitive homogeneity of the service fields.

Both higher education and the developing economy reward non-Analytic conceptual styles that the intermediate science curriculum does not acknowledge. As a result, the match between that restrictive Analytic science curriculum and the more heterogeneous occupational market is limited. All styles can be taught and learned, however; practice models can be designed in them, and they can be simulated for teaching purposes. Any style that can be defined by rules can be used as an avenue to teach subject content in a different way, to conceive of different approaches in existing fields, to create new fields, and to produce new knowledge not obtainable in other ways. Narrow definitions of the sciences, therefore, in the fashion presented in intermediate science materials not only limits the utility of school science for most students, but it also forces children motivated to postindustrial occupations to rely on nonformal and informal avenues of early education outside of public regulation and control. Finally, the greater the dissociation between science teaching and external science learning, the less relevant the content of, and the more broadly based the rejection of, the school.

SUMMARY

A content analysis of recurring and persistent themes in a sample of intermediate grade science texts and learning materials was conducted, along with interviews of selected editors and other specialists. Although its purpose was to determine whether such materials were balanced so that they appeal to children equally, it was evident that they appeared also to be relevant to science avoidance and rejection among pupils and teachers alike. Matches between the expectations of science curricula and standardized tests and between the science curriculum and the occupational market were also considered. We found that, in addition to numerous problems of implementation, intermediate science materials are designed to develop and reward only the use of the same two cognitive skills that are used in standardized measures of intelligence and achievement, and to related concepts of time, space, and causality. These expectations are also exacerbated by a time schedule based on stage developmental theories which hold that "cognitive maturity," defined as the ability to manipulate abstractions and to form and test theories, be achieved by the end of the intermediate school years.

Matches between these narrow objectives and both the range of cognitive skills they develop and their occupational uses are poor. Indeed, the limitations of the Analytic conceptual style to find and develop talent among children has been central in the opportunity-equalization literature for several decades. Children come to school with already developed conceptual styles, some of which are not only different from the Analytic style but incompatible with it. More important, these "deviant" styles have been and continue to be not only salable on the occupational market, but the demand for them is growing more rapidly than for the Analytic; and the match is poor and becoming progressively poorer between the science curriculum and the market for human skills. Moreover, because the science curriculum has become the day-to-day "carrier" of these restricted Analytic expectations, its dampening effect on users of other styles of cognition appears to have been transferred from the standardized tests to classroom materials. A form of curriculum control of the sorting and selection function of those tests has developed, such that the separation of those who will "succeed" in school from those who will not takes place in the elementary school science classroom. Current expectations to impose the same Analytic style on art, music, and physical education and to actively engage teachers in this process can be expected to extend this "cooling out" effect into other aspects of the elementary curriculum as well.

This study arose because of concern that school is less effective than it might be in developing the talent necessary for a rapidly changing society. Unfortunately, the limited focus of science materials has become less balanced than the curricula it was designed to replace. Although it is possible to engineer learning environments to achieve almost any desired objective, as a nation we have rejected educational "total environments," allocating instead parts of each day and year in the life spans of children to nonformal and informal learning. Those alternative environments continue to produce in children conceptual styles at variance with those required by science materials and standardized tests. We also maintain the notion that economic markets should be responsive to human demand. Many children who aspire to services and fourth-sector occupations cannot choose school science in its present form. Finding and using that talent in some structured way remains the challenge of educators and curriculum designers, who continue systematically to overlook it. As long as the match between science materials and standardized tests in their present form is so good and the match between that combination and the occupational market so bad, the dissocation between intermediate science objectives and outcomes can be expected to persist.

NOTES

1. The reference most frequently cited to support this is the report of the National Commission on Excellence in Education, *A Nation at Risk: The Imperative for Educational Reform* (1983).
2. Such findings were reported by the Center for the Assessment of Educational Progress in the National Assessment of Educational Progress reports of 1978 and 1979.
3. This study was commissioned by the Science and Technology Education Office of the American Association for the Advancement of Science. The findings were presented at the AAAS "Forum '86" meetings held in Washington, DC, in November 1986.
4. *El-Hi Books in Print* was first published as part of *Publishers Weekly* and later as *American Educational Catalogue*. In 1956, it became *Textbooks in Print*, in 1970, *El-Hi Textbooks in Print*, and in 1985, *El-Hi Books and Serials in Print*. It lists the "textbooks, other pedagogical books, teaching aids and programmed learning materials of 374 publishers." Each publisher was treated independently, although some activity materials and reference book publishers were textbook house subsidiaries, and some mergers took place during the study.
5. A summary of studies on which these findings are based appears in Bredderman (1982).
6. Postman (1981) describes these and other characteristics of television as "a competing learning system" to that of the school.

7. See the full discussions in Piaget (1950, 1954) and Piaget and Inhelder (1969).
8. In their studies of moral development generated by these new programs, Kohlberg (1981) and Gilligan (1982) also make stage-development and Analytic-conceptual-style assumptions about the nature of the learners.
9. Piaget held that, while capacity to manipulate abstractions is reached at puberty, the content of those abstractions would be determined by one's culture. See Piaget and Inhelder (1969). Piaget's use of the term "child" is generally synonymous with "boy"; he reports few studies of girls.
10. This timing is consistent with the Eleven Plus Examination in England and its counterparts in central Europe. Based on "nature" theories of the learner, they are designed to perpetuate existing social class systems. All students must take this examination between 11 and 12 years of age; the outcomes control entry into academic or alternative school systems. Thus, that examination determines at puberty the students' adult placement in society.
11. The literature on cognitive style is very large. Kagan, Moss, and Sigel (1963) on analytic abstraction and Witkin and Goodenough (1981) on field articulation are excellent sources, and they frame the period of time in which research and theory developed in this area. The research on cognitive style, however, deals with each of those skills as independent processes. The author contributes to this field by studying the interaction of those two skills, mode of abstraction and field articulation, as "conceptual styles," in Cohen (1969, 1971, 1973, 1975, 1980, and others). Behaviors of the carriers of the polar styles, Analytic and Relational, are contrasted in some detail in the appendices of Cohen (1969).
12. Skill-specific performance characteristics on standardized tests include those of Far Eastern children, whose cultures generate the Concrete style. Since their common learning method involves rote memorization, they achieve high scores on the arithmetic, spelling, and grammar subroutines and low scores on the literature and language-meaning sections, which require a thematic orientation. Flexible-style users exhibit reverse performance characteristics. Inner-city black and Hispanic children who use the Relational style do poorly on all of the skill-specific items. Since their language styles provide large, varied repertoires of

specific information, however, they do well on the subroutines that require denotative content.

13. These forms of explanation are based in neo-Freudian personality theories, as in Chodorow (1974). Gilligan (1982) also discusses these and other theories in her effort to explain why female cognitive processing is so different from the conventional model.

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Chapter 4

PROJECT 2061
Education for a Changing Future

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The terms and circumstances of human existence can be expected to change as much and as unpredictably from 1986 to 2061—the next human lifespan and coincidentally the next cycle of Halley's Comet—as they did from 1910 to 1986 or from 1835 to 1910. Science and technology have been and will continue to be at the center of change—causing it, shaping it, responding to it. Learning about science and technology becomes, therefore, ever more central to education.

The identification of science and technology learning goals appropriate for high school graduates is the starting place for Project 2061. It is not, however, the end. Project 2061 will also translate those learning goals into educational specifications, and then provide strategies and leadership for the reform process. Thus Project 2061 is divided into the following three phases, each with its own goals: (1) content identification; (2) educational formulation; and (3) educational transformation.

PHASE I: CONTENT IDENTIFICATION

The purpose of Phase I is to build a rationale for science education and to produce a compelling statement of what ought to constitute the science, mathematics, and technology content of learning for all children in elementary and secondary school. This phase has set out to elicit—from people who do science, use science, or reflect on the nature of science—a rich, informed, and operationally useful answer to the question: "Out of all of the possibilities, what science, mathematics, and technology should all young people know by the time they leave high school?"

Phase I is intended to identify goals for learning, not to specify a curriculum. Examining the question of which topics to take up, in what way, and at what grade level will come later.

PHASE II: EDUCATIONAL FORMULATION

Phase II of Project 2061 will engage the most thoughtful and inventive members of the educational community and the larger interested community in an effort to transform the content recommendations of Phase I into educational guidelines for sustained and purposeful reform. Phase I can be thought of as an effort to lay out and rationalize specific learning goals without reference to how they can be reached. Phase II will draw up practical specifications for action.

This phase will entail working out a description of what needs to be done in education with respect to curricula, school organization, instructional materials, teacher training, teacher support systems, and testing methods to bring about the kind and quality of learning in science recommended in Phase I. The goal would be to create specifications, not actually to construct the curricula or make and administer the examinations.

PHASE III: EDUCATIONAL TRANSFORMATION

In Phase III, the strategies and mechanisms needed to reform American schooling in the light of the intellectual framework of Phase I and the educational guidelines of Phase II will be established and monitored. This phase will have to be a highly cooperative, nationwide effort which will mobilize resources, monitor progress, and, in general, provide direction and continuity of effort. Scientific, engineering, and educational professional associations will need to be engaged in this phase, along with legislators and other policy makers.

The goal of Phase III will be to use the products and momentum of Project 2061 as levers for helping to raise the quality, improve the relevance, and broaden the availability of education in science, mathematics, and technology for all elementary and secondary students.

THE NEED

In recent years, there has been a growing concern in the United States that young people are not being adequately prepared to deal with science and technology and the issues they raise for our society. A series of reports and studies have claimed two interrelated trends that bring into question the adequacy and relevance of present educational efforts in this field. The first is the decline of expectations and results in science and mathematics teaching, as reflected in sinking test scores, limited student interest, and poor teacher morale. The second notable trend is the relative decline of the United States as the world's economic and technological leader and its sluggish response to the challenges posed by Japan and Western Europe in scientific and technological affairs.

While these earlier reports raised an alarm for educators and the public, they did not attempt to provide anything but the most general advice for elementary and secondary schools to follow in seeking improvement. Their recommendations tended to focus on procedural changes, such as lengthening school days and years, adding courses, increasing testing of students and teachers, and so on. The clear consensus was that children should learn more about mathematics, science, and technology, but there was no agreement as to the content, contexts, and level of sophistication of that learning.

Project 2061 proposes to develop an intellectual framework necessary for a fundamental and continuing restructuring of science and technology education in our schools. It is the first large-scale attempt in many years to undertake a searching examination of what science is most worth learning and what knowledge of technology is most necessary for people to have in our society.

GOALS

Content

The substance under consideration in Phase I is broadly defined to cover understandings about how the world works, including the world of nature and the world created by human beings, insights concerning the sciences as ways of knowing, skills that are useful in acquiring scientific knowledge, and knowledge of the limits and risks of science and technology, and of their impacts on society. Project 2061 is more concerned with ideas that cut across the disciplines than with the boundaries that separate the disciplines. It is not confined to drawing only on particular school science disciplines (namely, mathematics, physics, chemistry, biology, and the earth sciences), but instead cuts across all science and engineering fields. The eventual sorting of content into curriculum—the courses, topics, and grade levels—may turn out to be very different from the present configuration.

Scope

No distinction is being made—as far as the identification of basic content is concerned—between those students who expect to go to college and those who do not, nor between those who may end up in science or engineering and those who will not. The first task of the project is to lay out specifications for learning that will serve all young people well regardless of their vocational aspirations. This can be done by recommending content that is significant for every student and that is also suitable as a solid base for those interested in additional study. The intent is not to limit learning for anyone, but to ensure a foundation for growth for everyone.

Impact

The comprehensive analysis begun by Project 2061 will serve a double purpose: first, to stimulate new educational initiatives, and second, to start a process of review and renewal that will continue beyond this project's completion. Project 2061 does not seek to impose a uniform national science education agenda. Its purpose is to develop guidelines that state and local districts can use for generating their own curriculum.

Educational Criteria

The recommendations of Project 2061 will reflect one or more of the five criteria listed below. Each is an expression of the broad goals that underlie universal public education in a free society and that emerge from shared beliefs about the value of learning. By the very nature of the project, it is possible that additional criteria may be generated in the deliberations.

1. *Utility.* At work and at leisure, life is increasingly shaped by science and technology; knowledge of both has become necessary to make the most of the opportunities offered by modern society.
2. *Social responsibility.* A successful democracy depends on the judgment of the voters and elected leaders, most of whom are not scientists. If they are to make informed decisions, they must be capable of understanding the scientific issues that will inevitably affect all of our lives.
3. *The intrinsic value of knowledge.* Some aspects of science and technology are so important in human history or so pervasive in our culture that a general education is incomplete without them.
4. *Philosophical context.* Throughout history, people have pondered their place in the universe. Scientific discovery enlarges the context of philosophical thought.
5. *Enrichment of childhood.* Childhood is a time of life that is important for its own sake, for the value of what happens then and

not solely for what it may lead to later in life. The fascinating workings of nature inspire a child's imagination and sense of wonder. Science, quite simply, can be fun.

ORGANIZATION

Project 2061 is a collaboration among five groups: (1) the American Association for the Advancement of Science Board of Directors, which has institutional responsibility for the conduct and quality of the project; (2) the National Council on Science and Technology Education, which has an advisory function through all phases of the project; (3) panels, which are the creative working groups during each phase; (4) consultants from every part of the scientific and educational community, who will provide technical advice and a variety of perspectives to the staff, panels, and council; and (5) the project director and staff.

The panels are the key creative elements in Project 2061. The membership of the panels will be different in the three phases. The focus in Phase I is on the nature and use of science and technology and the knowledge and skills they involve. Accordingly, the Phase I panels are composed of scientists, engineers, and mathematicians. The focus in Phases II and III will be on the school curriculum, the improvement of teaching, and the learning characteristics of children. Teachers and other educators will have a primary role on these panels.

Each of the five panels in Phase I is composed of a chair and about eight other members. The membership of each panel is widely representative of its scientific domain, including scientists and engineers from private industry as well as academia, those who are relatively young as well as those who are senior, and women and minorities.

The disciplines have been loosely grouped into five categories, providing for panels on biological and health sciences; physical sciences and engineering; social and behavioral sciences; mathematics; and technology. Each panel will present its drafts to the other four panels for their criticisms and suggestions. Exchanges among panels—besides providing criticism from colleagues who operate from different perspectives—will provide an opportunity to look for common ideas and cross-cutting themes and to identify unresolved issues that might not otherwise surface.

The conclusions of the panels will be summarized in a final report of Phase I. This report will also highlight wider themes emerging from the panel deliberations, explain the reasoning behind the conclusions, and outline plans for Phase II.

Chapter 5

DATA RESOURCES TO DESCRIBE U.S. PRECOLLEGE SCIENCE AND MATHEMATICS CURRICULA*

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A review of the data resources related to elementary and secondary curricula in science and mathematics in the United States would, on first thought, appear to be a relatively simple task. But concern about science and mathematics education during the past few years has stimulated a number of efforts to provide better data to aid in understanding the status of science and mathematics education, to guide policy initiatives to improve the situation, and to track the effects of those initiatives. Most of these new efforts are reviewed in this paper.

The data sets discussed in this paper are limited to those that provide national data. This scope includes data sets for cross-national studies in which the United States was a participant. Cross-national studies provide another dimension for viewing the U.S. education system because they collect information on alternative educational systems and their effectiveness relative to the U.S. system. The importance of good curriculum data at state and local levels is self-evident, but a review of such data is too large a task for this paper.

Another question that comes to mind immediately is how to define curricula and what types of data elements relating to curricula should be covered. The following two criteria were used for including a data set in this paper: (1) Does it describe *what* is covered in the curricula, or in a

*The conclusions, opinions, and recommendations contained in this article are those of the author and do not necessarily reflect the views of her employing organization, the National Research Council.

course?, or (2) Does it describe the decision process for determining what is in the curricula? These criteria led to the inclusion of three major data categories: (1) offerings and enrollments, (2) curriculum content, and (3) decision processes and locus of decision making about curricula. Examples of types of data elements in these three categories include the following:

1. Offerings and enrollment data
   a. Secondary schools
      - Lists of courses offered
      - Number of, or percentage of, students enrolled by course or by field (disaggregated by gender, ethnicity, geographic region, or state)
      - Average number of science or mathematics courses taken during a period of schooling (junior high, senior high, or both)
      - Distribution of students by years of mathematics or science taken during a period of schooling
   b. Elementary schools
      - Time spent on mathematics and science by grade
2. Curriculum content
      - Lists of textbooks used
      - Age of textbooks
      - Topics studied within a course
      - Opportunity-to-learn measures
      - Class time spent on instruction
3. Decision process concerning curricula
      - Specification of years of study required in a subject
      - Specification of required courses
      - Selection of textbooks
      - Administrative level at which decisions are made

Note that the criteria selected exclude many data items related to the curriculum. In particular, data elements that pertain to *how* a curriculum or course is taught are excluded. Examples of data elements of this type are frequency of demonstration of an experiment in a science course, use of calculators in mathematics classes, amount of homework assigned, and type of science laboratory facilities used in a science class.

DATA SETS

Curriculum-related data in nineteen data sets are discussed in the following sections. Fourteen of the data sets are currently available; two are in development, in either the data collection or data processing phases; and three are in the planning phase.

1973 Survey of Public Secondary School Offerings, Enrollments, and Curriculum Practices.

Although this survey was conducted over a decade ago (by Applied Management Sciences, under contract to the National Center for Education Statistics), it constitutes an important link in the history of science and mathematics curricula in the United States because comparable data are available for both earlier and later years. The sample, stratified by location, enrollment size, and school grade span, consisted of 8,193 of the universe of 22,737 public schools. Over 90 percent of the schools in the sample provided information on offerings and enrollments using the list of over 500 courses and programs provided with the survey. National estimates of the number of courses offered in public secondary schools in 1972–73, the types of courses offered, and the enrollment in these courses were produced from the data (Osterndorf, 1975). The 1983–84 issue of the *Digest of Education Statistics* (Grant & Snyder, 1983) provides trend data on enrollment in public secondary schools relating data from this survey to earlier data for 1948–49 and 1960–61 (Table 1).

1977 National Survey of Science, Mathematics, and Social Studies Education.

This study, supported by the National Science Foundation, provides comprehensive information on science and mathematics education, including state and local district supervision and coordination activities, course offerings, federally funded curriculum materials, use of textbooks and programs, instructional techniques and classroom activities, facilities and equipment, teacher qualifications, sources of information, and factors that affect instruction. The study is based on a survey of a national probability sample of approximately 400 public school districts, a sample of 1,411 elementary and secondary schools within the districts, and a sample of 6,378 teachers in those schools. Questionnaires were sent to state supervisors, superintendents, district supervisors, principals, and teachers. The report of survey findings (Weiss, 1978) includes several types of information relevant to curricula. The percentage of states that require less than one year, one year, and more than one year of mathematics, science, and social studies courses for high school graduation is tabulated by region of the country and size of the state (Table 2). Comparable information on state and district guidelines for time to be spent in subjects for grades K–6 is also provided.

On the topic of offerings and enrollments, there is information on time spent on mathematics and science by grade range for elementary

Table 1. Number of students enrolled in various subject areas compared with total enrollment in grades 7–12 of public secondary schools: United States, 1948–49, 1960–61, and 1972–73

Subject areas	1948–49		1960–61		1972–73	
	Number	Percent of total	Number	Percent of total	Number	Percent of total
1	2	3	4	5	6	7
Total enrollment, grades 7–12	**6,907,833**	**100.0**	**11,732,742**	**100.0**	**18,577,234**	**100.0**
English language arts	7,098,770	102.8	12,972,236	110.6	24,079,059	129.6
Health and physical education[1]	7,794,671	112.8	12,081,639	103.0	21,517,330	115.8
Social sciences	6,981,980	101.1	11,802,499	100.6	18,898,794	101.7
Mathematics	4,457,987	64.5	8,596,396	73.3	13,240,326	71.3
Natural sciences	4,031,044	58.4	7,739,877	66.0	12,475,429	67.2
Music	2,484,201	36.0	4,954,347	42.2	6,111,223	32.9
Business education	3,186,207	46.1	4,667,570	39.8	6,376,633	34.3
Industrial arts	1,762,242	25.5	3,361,699	28.7	5,726,138	30.8
Home economics	1,693,825	24.5	2,915,997	24.9	4,651,535	25.0
Foreign languages	1,234,544	17.9	2,576,354	22.0	4,510,947	24.3

Art	1,219,693	17.7	2,383,703	20.3	5,115,981	27.5
Agriculture	373,395	5.4	507,992	4.3	374,622	2.0
Vocational trade and industrial education	369,794	5.4	344,704	2.9	484,484	2.6
Distributive education	([2])	([2])	38,363	.3	129,549	.7
Other	111,053	1.6	106,467	.9	[3]9,126	([4])

Note. Pecentages may exceed 100.0 because a pupil may be enrolled in more than one course within a subject area during the school year.

Source. U.S. Department of Education, National Center for Education Statistics. *Summary of Offerings and Enrollments in Public Secondary Schools, 1972-73.*

Note: Reprinted from W. Grant and T. Snyder, *Digest of Education Statistics 1983-84,* 1983.

[1]Includes driver education and ROTC.

[2]Data not reported separately.

[3]Includes bilingual education only.

[4]Less than 0.05 percent.

Table 2. Percent of states requiring less than one year, one year, and more than one year of each subject in grades nine through twelve for high school graduation, by region and size of state

	Mathematics			Science				Social studies			
	Less than one year	One year	More than one year	Less than one year	One year	More than one year	Unknown	Less than one year	One year	More than one year	Unknown
Nation	22	57	21	12	53	21	15	2	17	68	13
Region[1]											
Northeast	57	29	14	0	38	13	50	13	25	38	25
South	7	53	40	6	56	38	0	0	13	81	6
North Central	18	82	0	25	42	8	25	0	25	58	17
West	20	60	20	15	69	15	0	0	9	82	9
Size of state											
Small	21	64	15	12	57	18	13	0	21	74	6
Medium	13	62	25	11	55	23	11	6	17	77	0
Large	33	44	24	13	46	21	21	0	13	52	35
Sample N		43				49				47	

Note: Reprinted from I. Weiss, *Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education*, 1978.
[1]Refer to Appendix A for a description of these reporting variables and the sample size in each reporting group.

Table 3. Average number of minutes per day spent in elementary school mathematics, science, and social studies lessons, by grade range[1]

	Subject					
	Mathematics		Science		Social studies	
	Minutes	Standard error	Minutes	Standard error	Minutes	Standard error
K–3 (N = 801)	38	2.53	19	4.12	22	1.84
4–6 (N = 805)	44	2.09	35	1.73	40	4.62

Note: Reprinted from I. Weiss, *Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education,* 1978.

[1]Classes in which the most recent lesson was not on the last day school was in session were assigned zeros for number of minutes spent in the lesson.

schools (Table 3). Information for secondary schools includes the percentage of schools offering each of the most common science and mathematics courses by grade range (Table 4) and total enrollments in major high school science and mathematics courses by grade range (Table 5). Although Table 5 does not provide data on *total* enrollments in courses, it can be estimated by adding the enrollment data for "schools with only grades 7–9" and that for "all schools with grades 10–12." Surprisingly, the report does not provide an estimate for the number of or proportion of secondary students enrolled in science and mathematics courses.

In the area of curriculum content, the report contains lists of the most commonly used textbooks in science (Figure 1) and mathematics (Figure 2), and information on the copyright dates of the textbooks in use (Table 6).

This study obviously contains a wealth of other information closely related to curriculum data. The study has special value because it can serve as the base year for measuring change, since the study was repeated with little change in 1985.

1976-77 Science Assessment, National Assessment of Educational Progress, and 1981–82 Science Assessment, Science Assessment and Research Project, University of Minnesota.

National assessments in science were conducted by the National Assessment of Educational Progress (NAEP) program at the Education Commission of the States in 1969–70, 1972–73, and 1976–77. These assessments provide extensive information on student knowledge of and attitudes toward science (NAEP, 1978, 1979), as does the science assessment conducted by the University of Minnesota's Science Assessment and Research Project (SARP) in 1981–82, with technical assistance from

Table 4. Percent of schools offering each of the most common science, mathematics, and social studies courses, by sample grade range

I. Science courses	Percent of schools offering course: Schools with only grades 7–9	Schools with grades 7–9 and higher	All schools with grades 7–9	Schools with only grades 10–12	Schools with grades 10–12 and lower	All schools with grades 10–12
General science, grade 7	76	37	65	0	28	23
General science, grade 8	66	36	57	0	31	26
General science, grade 9	6	56	21	0	55	46
General science, grades 10–12	0	19	6	18	11	12
Earth science	20	46	28	28	39	37
Life science	21	24	22	9	20	18
Physical science	13	47	23	39	40	40
Biology I	5	85	30	91	96	95
Chemistry I	0	74	23	99	86	89
Physics	1	72	22	94	75	78
Astronomy	0	5	2	18	4	6
Physiology	0	4	1	19	2	5
Zoology	0	1	0	12	1	3
General science, any grade	79	74	78	19	69	60
Biology II, advanced biology	0	31	10	57	45	47
Chemistry II, advanced chemistry	0	9	3	58	15	23
Physics II, advanced physics	0	2	1	14	3	5
Environmental education, ecology	0	7	2	15	16	16
Sample N	212	79	291	90	163	253

II. Mathematics courses	Percent of schools offering course: Schools with only grades 7–9	Schools with grades 7–9 and higher	All schools with grades 7–9	Schools with only grades 10–12	Schools with grades 10–12 and lower	All schools with grades 10–12
General math, grade 7	98	45	82	0	41	34
General math, grade 8	90	49	78	0	43	36
General math, grade 9	17	80	36	1	71	59
General math, grades 10–12	0	40	12	78	34	42
Business math	2	50	17	77	47	52
Elementary algebra	35	98	54	85	89	88
Advanced algebra	5	76	27	87	87	87
Geometry	9	89	33	100	97	97
Trigonometry	0	45	14	64	52	54
Probability, statistics	0	10	3	18	5	7
Computer math	0	24	7	37	23	25
Advanced senior math	0	54	16	65	55	56
Calculus	0	24	7	49	27	31
General mathematics, any grade	100	95	98	79	90	88
Any algebra	37	100	56	99	97	97
Any geometry	9	89	33	100	97	97
Calculus or advanced mathematics	1	68	21	83	74	76
Sample N	212	79	29[illegible]	90	163	253

Note: Reprinted from I. Weiss, *Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education*, 1978.

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Table 5. Total enrollments in major high school science, mathematics, and social studies courses

I. Science courses	Schools with only grades 7–9 enrollment	Schools with grades 7–9 and higher enrollment	All schools with grades 7–9 enrollment	Schools with only grades 10–12 enrollment	Schools with grades 10–12 and lower enrollment	All schools with grades 10–12 enrollment
General science, grade 7	2,547,797	334,468	2,882,264	0	403,846	403,846
General science, grade 8	2,255,604	353,622	2,609,225	0	428,236	428,236
General science, grade 9	408,917	922,300	1,331,218	0	1,119,400	1,119,400
General science, grades 10–12	14,218	289,259	303,477	69,005	150,232	219,237
Earth science	867,794	485,597	1,353,392	64,090	620,766	684,856
Life science	1,000,557	265,915	1,266,472	36,503	258,661	295,164
Physical science	745,091	582,029	1,327,121	86,471	602,367	688,838
Biology I	158,141	1,490,214	1,648,355	881,266	2,072,200	2,953,466
Chemistry I	2,417	566,572	568,989	383,359	812,781	1,196,140
Physics	22,169	257,035	279,204	155,313	356,297	511,611
Astronomy	0	14,147	14,147	23,478	22,898	46,375
Physiology	0	15,540	15,540	38,174	12,356	50,529
Zoology	0	8,243	8,243	52,099	6,845	58,943
General science, any grade	5,239,780	1,928,490	7,168,270	72,052	2,119,303	2,191,355
Biology II, advanced biology	2,927	176,278	179,204	83,206	220,511	303,717
Chemistry II, advanced chemistry	3,379	28,899	32,279	74,914	62,040	136,954
Physics II, advanced physics	0	8,256	8,256	13,977	39,587	53,564
Ecology, environmental education	4,841	78,015	82,855	53,616	116,075	169,691
Sample N	212	79	291	90	163	253

II. Mathematics courses	Schools with only grades 7–9 enrollment	Schools with grades 7–9 and higher enrollment	All schools with grades 7–9 enrollment	Schools with only grades 10–12 enrollment	Schools with grades 10–12 and lower enrollment	All schools with grades 10–12 enrollment
General math, grade 7	3,540,876	384,514	3,925,390	0	541,802	541,802
General math, grade 8	3,205,751	452,187	3,657,938	0	570,732	570,732
General math, grade 9	644,094	862,316	1,526,410	1,512	1,068,914	1,070,426
General math, grades 10–12	0	608,112	608,112	351,685	476,074	827,759
Business math	35,883	292,285	328,168	214,056	358,808	572,864
Elementary algebra	796,319	1,605,947	2,402,266	373,194	1,655,499	2,028,693
Advanced algebra	122,858	546,582	669,440	412,981	781,298	1,194,279
Geometry	83,901	1,003,867	1,087,768	606,240	1,208,288	1,814,528
Trigonometry	0	168,363	168,363	134,923	324,617	459,541
Probability, statistics	0	32,863	32,863	18,613	21,087	39,700
Computer math	1,058	122,099	123,157	34,896	117,630	152,525
Advanced senior math	0	139,750	139,750	72,719	152,688	225,407
Calculus	0	52,337	52,337	36,421	68,929	105,349
General math, any grade	7,436,574	2,396,485	9,833,060	354,453	2,711,503	3,065,956
Any algebra	1,022,759	2,545,802	3,568,561	895,637	2,817,559	3,713,196
Any geometry	83,901	1,007,674	1,091,575	617,608	1,215,845	1,833,453
Sample N	212	79	291	90	163	253

Note: Reprinted from I. Weiss, *Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education,* 1978.

Figure 1 Most commonly used science textbooks and programs[1]

K–6 Science

Concepts in Science (Brandwein)
Science: Understanding Your Environment (Mallinson)
New Laidlaw Science Program (Smith)
Today's Basic Science Series (Navarra)

7–9 General Science

Intermediate Science Curriculum Study: Probing the Natural World
Principles of Science Series (Heimler)
Modern Science Series (Blanc)

7–9 Earth Science

Focus on Earth Science (Bishop)

10–12 Biology

Modern Biology (Otto)
Biological Science: An Ecological Approach, BSCS Green
Biological Science: An Inquiry Into Life, BSCS Yellow (Moore)

10–12 Chemistry

Modern Chemistry (Metcalfe)

Note: Reprinted from I. Weiss, *Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education,* 1978.

[1]In classes that are using multiple textbooks and programs, only the one designated "used most often" was included in these analyses.

the NAEP. Only the 1976–77 and the 1981–82 assessments collected enrollment data, but the availability of data for these two years made it possible to measure changes in enrollment. Analysis of these assessments (Welch, Harris, & Anderson, 1984) provides data on changes in enrollment in junior and senior high schools by course (Tables 7 & 8). For 1981–82, course enrollment data are also available by grade and as a percentage of grade enrollment. Regional science enrollment data by grade, by subject, and as a percentage of a grade enrolled in science courses are also available for 1981 32. Welch, Harris, and Anderson summarize the trend in percentage enrollment in eight science courses between 1948–49 and 1981–82 in a graph (Figure 3).

1980 High School and Beyond Survey.

In 1980 the National Center for Education Statistics (NCES) contracted to collect base year data for its High School and Beyond Survey from more than 58,000 high school students (over 28,000 seniors and over 30,000 sophomores) in more than 1,000 public and private schools.

Figure 2 **Most commonly used mathematics textbooks and programs**[1]

K–6 Mathematics
Holt School Mathematics (Nichols)
Mathematics Around Us: Skills and Applications (Bolster)
Modern School Mathematics: Structure and Use (Duncan)
Elementary School Mathematics (Eicholz)
The Understanding Mathematics Program (Gundlach)
Investigating School Mathematics (Eicholz)

7–9 General Mathematics
Holt School Mathematics (Nichols)
Exploring Modern Mathematics (Keedy)
Modern Mathematics Through Discovery (Morton)
Mathematics Around Us: Skills and Applications (Bolster)
School Mathematics (Eicholz)
The Understanding Mathematics Program (Gundlach)

7–9 Algebra
Modern Algebra: Structure and Method (Dolciani)
Elementary Algebra (Denholm)
Modern School Mathematics: Pre-Algebra (Dolciani)

10–12 Algebra
Modern Algebra and Trigonometry: Structure and Method (Dolciani)
Modern Algebra: Structure and Method (Dolciani)

10–12 Geometry
Modern School Mathematics: Geometry (Jurgensen)
Geometry (Jurgensen)

Note: Reprinted from I. Weiss, *Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education,* 1978.

[1]In classes that are using multiple textbooks and programs, only the one designated "used most often" was included in these analyses.

Data on the years of mathematics and science courses completed during grades 10–12 by gender and race or ethnic group are summarized (Table 9) in the 1983–84 issue of the *Digest of Education Statistics* (Grant & Snyder, 1983).

1982 Course Offerings and Course Enrollments Survey, and Transcripts Survey.

As part of the 1982 first follow-up of the longitudinal High School and Beyond Surveys, the National Center for Education Statistics (NCES) obtained full transcripts for approximately 12,000 high school graduates in 1982. These transcripts were analyzed to ascertain course

Table 6. Percent of classes using textbooks with copyright dates before 1971, 1971–73, and 1974–77, by subject and grade range[1]

		Mathematics					Science					Social studies				
Grade Range	N	Before 1971	1971 to 1973	1974 to 1977	Un-known	No text used	Before 1971	1971 to 1973	1974 to 1977	Un-known	No text used	Before 1971	1971 to 1973	1974 to 1977	Un-known	No text used
K–3	838	8	19	43	21	8	19	13	10	21	37	29	12	7	16	35
4–6	829	21	23	38	14	4	24	24	25	18	10	36	24	19	13	9
7–9	1538	24	27	26	18	5	22	31	25	16	6	17	29	18	26	11
10–12	1624	38	27	21	9	5	28	26	18	21	8	23	31	21	14	11
Sample N		1,672					1,679					1,478				

Note: Reprinted from I. Weiss, *Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education,* 1978.

[1]The copyright date of the textbook designated as "used most often" in a particular class was used for these analyses.

Table 7. Changes in science enrollment, grades 7–9, 1977–82

	1976–77		1961–82		Change	
Course	N (1000s)	Ratio[1]	N (1000s)	Ratio	N (1000s)	Ratio
General science	3,655	29.5	2,707	26.7	−948	−2.8
Life science	1,902	15.4	1,939	19.1	+ 37	+3.7
Earth science	1,721	13.9	1,459	14.4	−262	+0.5
Physical science	1,955	15.8	1,493	14.7	−462	−1.1
Biology	724	5.8	533	5.3	−191	−0.5
Integrated science	265	2.1	246	2.4	− 19	+0.3
Environmental science	114	0.9	115	1.1	+1	+0.2
Other	367	3.0	208	2.0	−159	−1.0
Total	10,703	86.4	8,700	85.7	−2,003	−0.7

Note: Reprinted, by permission, from W. Welch, L. Harris, and R. Anderson, "How Many Are Enrolled in Science?", 1984, *The Science Teacher* (a publication of the National Science Teachers Association).

[1]Ratio is defined here as the subject enrollment divided by the grade 7–9 enrollment. In 1976–77, total enrollment was 12,200,000 (NCES). In 1981–82, it was 10,600,000 (NCES).

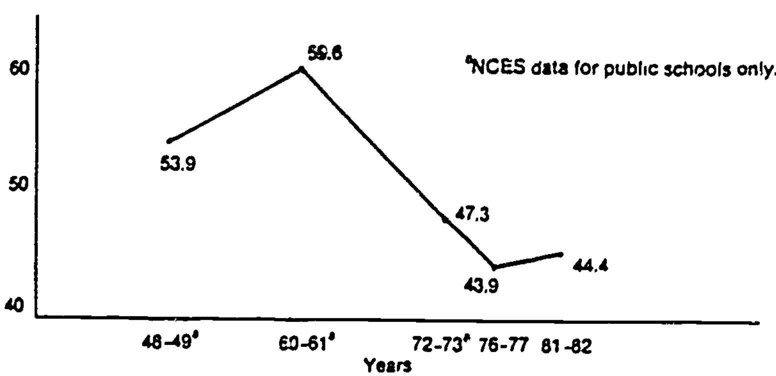


Figure 3 Percentage enrollment in eight science courses, grades 9–12
Note: Reprinted, by permission, from W. Welch, L. Harris, and R. Anderson, "How Many Are Enrolled in Science?", 1984, *The Science Teacher* (a publication of the National Science Teachers Association).

Table 8. Changes in science enrollment, grades 10-12, 1977-82

	1976-77		1981-82		Change	
Course	N (1000s)	Ratio[1]	N (1000s)	Ratio	N (1000s)	Ratio
General science	164	4.3	224	7.0	+ 60	+2.7
Biology	2,675	63.0[2]	2,261	67.2[2]	−414	+4.2
Chemistry	1,121	29.3[2]	1,132	35.5[2]	+ 11	+6.2
Physics	487	14.6[2]	504	16.3[2]	+ 17	+1.7
Life science	135	3.6	199	6.2	+ 64	+2.6
Environmental science	206	5.4	151	4.7	− 53	−0.7
Physical science	260	6.8	220	6.8	− 40	0.0
Earth science	167	4.4	118	3.7	− 49	−0.7
Integrated science	37	1.0	19	0.6	− 18	−0.4
Astronomy	23	0.6	26	0.8	+ 3	+0.2
Anatomy/ physiology	127	3.3	90	2.8	− 37	−0.5
Oceanography	24	0.6	40	1.2	+ 15	+0.6
Horticulture	11	0.3	8	0.2	− 3	−0.1
Geology	42	1.1	58	1.8	+ 16	+0.7
Zoology	53	1.4	28	0.9	− 25	−0.5
Botany	35	0.9	10	0.3	− 25	−0.6
Advanced biology	129	3.9[2]	90	2.8[2]	− 39	−1.1
Advanced chemistry	27	0.7[2]	22	0.7[2]	− 5	0.0
Advanced physics	9	0.2[2]	7	0.2[2]	− 2	0.0
Other	153	4.0	157	4.9	+ 4	+0.9
Total	5,885	51.6[3]	5,365	55.7[3]	−520	+4.1

Note: Reprinted, by permission, from W. Welch, I. Harris, and R. Anderson, "How Many Are Enrolled in Science?", 1984, *The Science Teacher* (a publication of the National Science Teachers Association).

[1]Ratio is defined as the total enrollment divided by the average enrollment in grades 10-12. In 1976-77 this was 3,802,000; in 1981-82 it was 3,212,000.

[2]The divisor for biology, chemistry, physics, and advanced placement is the grade enrollment for the grade where the course is usually taught.

[3]Divisor is the sum of grades 10-12 enrollment.

work in mathematics and science completed by U.S. high school students (NCES, 1984). The analyses provide data on percentages of 1980 sophomores who graduated in 1982 and who took at least three years of mathematics or science, by high school program (Figure 4). Subsequent analyses of questionnaire information (grade point average, socioeconomic status, and educational aspirations) for students with incomplete and

Table 9. Selected statistics on the educational experiences and extracurricular activities of high school seniors: United States, spring 1980

Item	High school seniors							
	Total	Boys	Girls	White, non-Hispanic	Black, non-Hispanic	Hispanic	American Indian/ Alaskan native	Asian or Pacific Islander
1	2	3	4	5	6	7	8	9
Type of high school program:								
General	36.4	37.4	35.4	36.6	34.5	40.5	44.1	28.7
Academic	38.2	38.5	37.9	39.3	32.4	26.2	23.7	51.8
Vocational-technical	24.0	22.8	25.2	22.8	31.1	30.6	29.0	18.3
Not reported	1.5	1.4	1.5	1.3	2.1	2.6	3.0	1.1
English or literature courses completed, grades 10-12:								
Less than 1 year	.8	.9	.7	.6	1.8	2.1	.5	1.7
1 or 1½ years	2.6	3.2	2.1	2.4	2.6	5.1	7.3	2.5
2 or 2½ years	14.6	15.3	13.8	15.1	10.3	14.6	12.8	19.0
3 years or more	81.0	79.3	82.6	81.0	82.8	76.2	76.6	76.8
Not reported	1.0	1.3	.8	.7	2.6	2.2	2.9	.1
French courses completed, grades 10-12:								
Less than 1 year	81.0	82.8	79.2	80.6	82.0	85.2	86.3	78.3
1 or 1½ years	7.2	6.2	8.0	7.3	7.0	4.6	5.6	6.3
2 or 2½ years	5.2	4.1	6.2	5.5	3.4	2.8	1.2	8.1
3 years or more	2.7	1.9	3.4	2.9	1.6	1.3	.5	3.7
Not reported	4.1	5.0	3.2	3.8	6.0	6.1	6.5	3.6

(continued)

Table 9. *Continued*

Item	High school seniors							
	Total	Boys	Girls	White, non-Hispanic	Black, non-Hispanic	Hispanic	American Indian/ Alaskan native	Asian or Pacific Islander
1	2	3	4	5	6	7	8	9
German courses completed, grades 10-12:								
Less than 1 year	89.5	88.0	90.9	89.1	91.0	91.0	88.1	87.7
1 or 1½ years	2.2	2.5	1.8	2.3	1.3	.9	1.8	2.8
2 or 2½ years	1.9	2.3	1.6	2.2	.3	.6	1.0	4.4
3 years or more	1.0	1.3	.8	1.2	.2	.4	.7	.8
Not recorded	5.4	5.9	4.9	5.1	7.1	7.1	8.4	4.4
Spanish courses completed, grades 10-12:								
Less than 1 year	68.5	71.0	66.1	70.0	66.0	54.8	79.5	60.8
1 or 1½ years	13.0	11.4	14.6	12.5	13.5	18.4	9.4	13.8
2 or 2½ years	9.8	8.8	10.6	9.2	9.5	14.0	3.6	18.5
3 years or more	3.9	3.3	4.4	3.4	4.4	7.8	2.7	3.5
Not reported	4.9	5.6	4.3	4.8	6.7	5.2	4.8	3.5
History or social studies courses completed, grades 10-12:								
Less than 1 year	1.4	1.6	1.2	1.1	3.1	2.9	1.9	1.6
1 or 1½ years	16.1	15.7	16.5	15.8	16.8	19.6	25.2	14.1
2 or 2½ years	41.8	40.8	42.7	42.4	38.4	40.0	37.8	46.1
3 years or more	39.1	40.1	38.2	39.2	38.4	34.7	33.4	37.0
Not reported	1.5	1.8	1.4	1.3	3.2	2.8	1.7	1.2

Mathematics courses completed, grades 10-12:								
Less than 1 year	7.2	6.3	8.0	7.5	5.2	8.1	9.3	5.4
1 or 1½ years	25.7	22.8	28.5	26.5	21.6	27.8	39.9	10.6
2 or 2½ years	32.8	30.6	34.8	32.3	36.0	35.3	28.2	36.0
3 years or more	33.4	39.1	28.0	33.0	35.2	27.4	22.0	47.5
Not reported	.8	1.1	.7	.7	1.9	1.4	.5	.4
Science courses completed, grades 10-12:								
Less than 1 year	9.7	9.1	10.4	10.2	8.6	9.8	9.6	5.3
1 or 1½ years	35.7	32.4	38.9	35.7	34.9	41.1	49.3	27.5
2 or 2½ years	29.9	29.6	30.1	29.2	32.6	31.7	26.7	32.0
3 years or more	22.3	26.5	18.5	23.1	19.3	14.2	12.1	32.2
Not reported	2.4	2.6	2.1	2.0	4.6	3.3	2.1	2.9
Business-sales courses completed, grades 10-12:								
Less than 1 year	44.9	58.9	32.0	44.8	43.1	47.8	50.9	51.3
1 or 1½ years	25.5	24.3	26.6	25.6	26.1	23.4	22.9	25.5
2 or 2½ years	14.8	9.0	20.2	14.8	15.6	15.6	9.2	12.5
3 years or more	12.0	4.3	19.4	12.4	10.6	9.6	12.6	8.2
Not reported	2.7	3.6	1.7	2.4	4.6	3.6	4.4	2.5
Trade-industry courses completed, grades 10-12:								
Less than 1 year	74.4	59.2	88.6	74.6	71.5	72.5	64.3	80.8
1 or 1½ years	9.2	14.2	4.6	8.9	10.6	10.4	15.9	9.0
2 or 2½ years	6.5	10.9	2.4	6.6	6.5	6.5	6.0	5.1
3 years or more	6.5	11.9	1.4	6.7	5.8	6.5	8.1	1.9
Not reported	3.5	4.0	3.0	3.1	5.7	4.1	5.6	3.3

Note: Reprinted from W. Grant and T. Snyder, *Digest of Education Statistics 1983-84*, 1983.

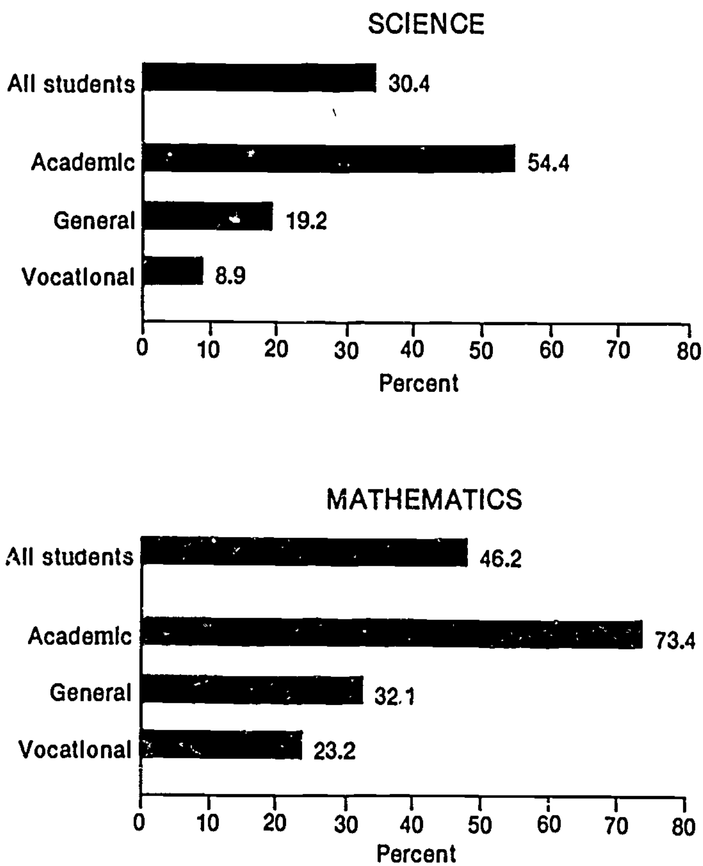


Figure 4 **Percentages of 1980 sophomores graduating in 1982 who took at least three years of mathematics and science, by high school program Mathematics**

Note: Reprinted from National Center for Education Statistics, *Science and Mathematics Education in American High Schools: Results from the High School and Beyond Study,* 1984.

complete transcripts suggest that these figures are probably overestimates, due to the exclusion of incomplete transcripts. The percentages would obviously have been even lower if students who dropped out of school (approximately one-seventh of the original sample) had been included. The report also includes data on the percentages of 1980 sophomores graduating in 1982 who took specific science and mathematics courses. Other tables include similar data disaggregated by student characteristics such as sex, race or ethnic group, high school program, socioeconomic status, and educational aspirations. Data are also provided by school type (public, Catholic, other private) and by region.

The NCES contracted with Evaluation Technologies, Inc. (ETI) to conduct a trend study of high school offerings and enrollments using the 1973 survey described above and the Course Offerings and Course Enrollments Survey and Transcripts Survey included as part of the High School and Beyond First Follow-up Survey. The analyses were directed toward the following goals:

> . . . to identify the courses and subject areas offered in U.S. public secondary schools, and to identify the enrollments in these courses and subject areas for the two school years. These data were to be used to determine changes in the curricula of secondary schools and in student participation over the nine-year period covered by two NCES surveys. (West, Diodato, & Sandberg, 1984, p. A-9)

Extensive adjustments were required to obtain comparable data for 1973 and 1982, including nonresponse adjustments, adjustments to compensate for school sample design inconsistencies, and course title and subject area inconsistencies. In making these adjustments, ETI developed a useful taxonomy of courses and an aggregation of courses and programs for 1981-1982 that used the course coding structure of the 1973 survey as a foundation.

Tables 10 and 11 provide data for 1982, on mathematics and science respectively, for specific courses, including the number and proportion of schools offering the courses, total enrollment in the courses, and course enrollment as a percentage of total secondary enrollment. The report (West, Diodato, & Sandberg, 1984) includes comparable tables for 1973. Table 12 provides trend data on the number of course enrollments and the percentage of students enrolled in mathematics and natural science courses.

West, Diodato, and Sandberg list sixteen course titles that were much more widely offered in 1981-82 than in 1972-73. The only science courses in the list are "general science" and "chemistry and physics, college level." Among the course titles less widely offered in 1981-82 than in 1972-73 is Physics I/II, offered by 74 percent of the schools in 1972-73 but by only 36 percent in 1981-82.

1982 Study of Requirements and Achievement in Public High Schools.

In 1982 the NCES surveyed a stratified national sample of about 550 school districts to obtain information including requirements for graduation and time spent in schools. The final report of this survey

Table 10. **Public secondary schools offering specific courses, enrollments in the schools and courses, and their percent of U.S. totals by course title: United States, 1981-82**

	Number of schools offering this course	As percent of all secondary schools	Total enrollment in schools offering this course	As percent of total secondary enrollment	Total enrollment in this course (thousands)	As percent of total secondary enrollment	As percent of total enrollment in schools offering this course
Mathematics, total	15,632	99.8	12,593	99.5	9,850	77.8	78.0
General math, N.E.C.	2,439	15.6	3,097	24.5	180	1.4	5.5
General math, grades 9-12, elementary and advanced	14,264	91.0	11,925	94.2	2,567	20.3	21.3
Pre-algebra	4,476	28.6	5,141	40.6	549	4.3	10.7
Algebra, elementary	14,950	95.4	11,831	93.4	2,290	18.1	19.2
Algebra, intermediate	13,405	85.6	11,001	86.9	895	7.1	8.1
Algebra, advanced/ trigonometry	3,862	24.7	4,383	34.6	238	1.9	5.7
Applied mathematics, business/shop	8,125	51.9	7,419	58.6	464	3.7	6.1
Consumer mathematics	6,140	39.2	6,042	47.7	351	2.8	5.7
Computer mathematics	4,200	26.8	4,571	36.1	136	1.1	3.0

Geometry, plane/solid	14,749	94.1	12,218	96.5	1,445	11.4	11.8
Math analysis/ elementary functions	4,620	29.5	5,067	40.0	141	1.1	2.8
Probability and statistics	1,865	11.9	2,239	17.7	33	0.3	1.5
Trigonometry	6,319	40.3	6,023	47.6	200	1.6	3.4
College level mathematics	6,030	38.5	5,584	44.1	226	1.8	4.2
Calculus 1st/2nd year/advanced geometry	5,249	33.5	6,9211	54.7	138	1.1	2.1

Note: U.S. total secondary schools = 15,667; U.S. total secondary enrollment = 12,660,537

Note: Reprinted from J. West, L. Diodato, and N. Sandberg, *A Trend Study of High School Offerings and Enrollments,* 1984.

Table 11. Public secondary schools offering specific courses, enrollments in the schools and courses, and their percent of U.S. totals by course title: United States, 1981–82

	As percent of total secondary enrollment	Total enrollment in this course (thousands)	As percent of total secondary enrollment	As percent of total enrollment in schools offering this course	Number of schools offering this course	As percent of all secondary schools	Total enrollment in schools offering this course
Natural science, total	99.5	8,278	65.4	65.6	15,626	99.7	12,595
General science, grades 9–12	72.0	1,836	14.5	20.1	10,315	65.8	9,118
Biological sciences, N.E.C.	13.2	59	0.5	3.2	1,187	7.6	1,668
Anatomy/anthropology/genetics	10.1	36	0.3	2.8	1,293	8.3	1,273
Ecology/entomology/conservation	17.2	81	0.6	3.5	1,930	12.3	2,180
Physiology/biophysics	37.1	156	1.2	3.4	4,434	28.3	4,696
Technical applications/applied biology	4.0	23	0.2	4.8	467	3.0	512
Zoology	10.3	49	0.4	3.5	1,309	8.4	1,305
Botany	12.3	65	0.5	4.2	1,382	8.8	1,561
Biology I, college level/microbiology	98.1	2,875	22.7	23.1	15,317	97.8	12,421
Life science	1.1	2	0.0	1.2	109	0.7	142

Physical science 1st/ 2nd year	57.3	1,081	8.5	14.8	8,711	55.6	7,255
Chemistry I/II/ applied/study	96.1	962	7.6	8.0	13,999	89.4	12,167
Chemistry and physics, college level	72.0	285	2.3	3.2	9,471	60.5	9,118
Physics 1st/2nd year	44.3	129	1.0	2.4	5,576	35.6	5,614
Electricity/electronics/ applied physics	3.4	12	0.1	3.0	357	2.3	429
Earth-space sciences/ meteorology/ astronomy	44.4	483	3.8	8.6	5,430	34.7	5,625
Aeronautics	4.1	9	0.1	1.4	317	2.0	516
Earth sciences	4.3	21	0.2	4.2	430	2.7	540
Space science	1.9	18	0.1	7.9	285	1.8	246
Geology	13.4	59	0.5	3.7	1,236	7.9	1.701
Oceanography	7.8	36	0.3	3.4	700	4.5	990

Note: U.S. total secondary schools = 15,667; U.S. total secondary enrollment = 12,660,537

Note: Reprinted from J. West, L. Diodato, and N. Sandberg, *A Trend Study of High School Offerings and Enrollments,* 1984.

Table 12. Course enrollments in subject areas and their percentages of the total public secondary school students enrolled in grades 9–12: United States, 1972–73 and 1981–82

Subject area	1972–73[1] Number (thousands)	1972–73[1] Percent	1981–82[2] Number (thousands)	1981–82[2] Percent
Total pupils, grades 9–12	11,975	100.00	12,661	100.00
English language arts	15,605	130.3	17,716	139.9
Health and physical education	8,679	72.5	11,859	93.7
Social sciences	11,710	97.8	15,008	118.5
Mathematics	6,619	55.3	9,850	77.8
Natural sciences	6,119	51.1	8,278	65.4
Music	3,004	25.1	2,733	21.6
Business	5,763	48.1	5,874	46.4
Industrial arts	2,903	24.2	2,980	23.5
Home economics	2,439	20.4	3,024	23.9
Foreign languages	3,067	25.6	2,953	23.3
Art	2,143	17.9	3,061	24.2
Agriculture	322	2.7	420	3.3
Vocational trade and industrial education	447	3.7	1,874	14.8
Safety and driver's education	3,297	27.5	2,026	16.0
R.O.T.C.	142	1.2	172	1.4
Computer science	—	—	344	2.7
Allied health	—	—	80	.6

Note: Reprinted from J. West, L. Diodato, and N. Sandberg, *A Trend Study of High School Offerings and Enrollments,* 1984.

[1]These numbers and percentages differ from those previously reported for this survey in L. Osterndorf, *Summary of Offerings and Enrollments in Public Secondary Schools, 1972–73,* because the data have been reprocessed after modifying the sample to make it more similar to that used in the 1981–82 study (see Appendix c).

[2]Estimates are based on student transcript data.

provides data by district enrollment, geographic region, and metropolitan status (Wright, Tomlinson, & Ferris, 1985).

1984 Minimum High School Graduation Course Requirements in the States, and 1985 Changes in Minimum High School Graduation Requirements—1980 to 1985.

Since 1980 the Education Commission of the States (ECS) has been monitoring changes in minimum high school graduation requirements. During that time, 39 states and the District of Columbia increased their requirements in science, mathematics, or both, or set state requirements for the first time. Washington is the only state that reduced requirements during that period. Local school boards still determine mathematics and science requirements in four states. The requirements for science instruction range from one to three years, as do the requirements for mathematics. (For details on the changes and their effective dates, see Education Commission of the States, 1985.)

1981–82 Second International Mathematics Study, and 1983 Second International Science Study.

Cross-national studies of educational achievement have been carried out under the aegis of the International Association for the Evaluation of Educational Achievement for over twenty years. Twenty-two countries participated in the Second International Mathematics Study, which was conducted in 1981–82. This survey " . . . focused on two populations: 1) all students in the grade in which the majority of students have attained the age of 13 by the middle of the school year, and 2) all students who are in the normally accepted terminal grades of secondary schools and who are studying mathematics as a substantial part (approximately five hours per week) of their academic programs" (Travers & McKnight, 1985, p. 408).

In the United States, data were collected from 7,000 eighth grade students and 5,000 students enrolled in twelfth grade mathematics (note the interpretation of the focal populations), and from teachers from approximately 500 classrooms in about 250 public and private schools (Crosswhite, Dossey, Swafford, McKnight, & Cooney, 1985). In addition to the achievement tests administered to the students, this study collected data from the teachers on teacher coverage of the various content areas by asking the teacher to respond to the following questions *for each item* on the test:

1. During the school year, did you teach or review the mathematics needed to answer this item correctly?
2. If you did not teach or review the mathematics needed to answer this item correctly, was it because
   a. it had been taught prior to the school year,
   b. it will be taught later (this year or later),
   c. it is not in the school curriculum, or
   d. for other reasons.

From these questions, it is possible to report opportunity-to-learn (OTL) measures for material "taught this year" and "taught up to and including this year." The OTL measures are of particular importance in cross-national studies because of the variation among countries in the mathematics curriculum, but OTL measures can also reveal a great deal about the content of the curriculum in the United States. Table 13 shows the opportunity to learn various topics in eighth grade mathematics. Table 14 provides more detailed information on when twelfth grade students in precalculus and calculus classes had the opportunity to learn various topics. Versions of this OTL rating scale were also used in the first mathematics assessment in 1964, and in the science assessments conducted in 1970 and 1983.

Table 13. Average percent of items on the international test reported taught and learned in eighth grade mathematics: United States and nineteen other countries, 1981–82

Topic (number of items)	United States			
	Opportunity to learn[1]	Mean pretest score	Mean post-test score[2]	Mean post-test score for 20 countries[3]
Arithmetic (62 items)	87	42	51	51
Algebra (32 items)	69	32	43	43
Geometry (42 items)	44	31	38	41
Measurement (26 items)	70	35	42	51
Statistics (18 items)	73	53	57	55

Note: Reprinted, by permission, from Crosswhite, Dossey, Swafford, and Cooney, *Second International Mathematics Study Summary Report for the United States*, 1985.

[1]Opportunity-to-learn by the end of eighth grade—that is, up to and including eighth grade.

[2]Post-test data are based on 280 classes in the United States.

[3]The international means are based on a restricted set of 157 items in common between the international test and the U.S. national version of the test. The number of items by topic on the 157 item international test were: arithmetic, 46; algebra, 30; geometry, 39; measurement, 24; and statistics, 18. In all cases, the United States results differ less than one percent from those in the table above when restricted to the set of 157 items. The countries included, in addition to the United States, were Belgium (Flemish), Belgium (French), Canada (British Columbia), Canada (Ontario), England and Wales, Finland, France, Hong Kong, Hungary, Israel, Japan, Luxembourg, the Netherlands, New Zealand, Nigeria, Scotland, Swaziland, Sweden, and Thailand.

Table 14. Percentage of cognitive test items taught to twelfth grade students: United States, 1981–82 (average percent across items)

Content area (N items)	Precalculus (number of classes, 191) Taught before	Taught this year	Never taught	Calculus (number of classes, 46) Taught before	Taught this year	Never taught
Sets and relations (7 items)	31	50	19	50	40	10
Number systems (17 items)	39	42	19	75	14	11
Algebra (26 items)	34	52	14	53	41	6
Geometry (26 items)	21	40	39	41	26	33
Elementary functions and calculus (46 items)	8	37	55	9	83	8
Probability and statistics (7 items)	29	14	57	50	6	44
Finite mathematics (4 items)	29	21	50	62	8	30

Note. Reprinted, by permission, from Crosswhite, Dossey, Swafford, and Cooney, *Second International Mathematics Study Summary Report for the United States,* 1985.

The first phase of the Second International Science Study was conducted in the United States in 1983 by researchers at Teachers College, Columbia University. The following four populations of students were studied: (1) fifth grade students, (2) ninth grade students, (3) twelfth grade students taking physics, and (4) twelfth grade students not taking physics (Jacobson & Doran, 1985). A second phase of the SISS that included a science processes test was administered by the Research Triangle Institute in 1985–86.

1984 Survey of Elementary School Principals, and 1985 Survey of Public High School Principals.

The Association for Supervision and Curriculum Development (ASCD) plans to carry out studies, which will be replicated every five years, to trace curriculum changes in elementary, secondary, and middle schools. The first survey of elementary school principals was conducted in 1984. Secondary school principals were surveyed in 1985, and the ASCD studied middle schools in 1986.

A random sample of 4,000 elementary school principals was surveyed in 1984, but only 38 percent responded. Although data based on such a small response rate cannot be considered national data, it is informative to look at the variability in time allocated to mathematics and science in the 1,522 schools that responded, as shown in Figure 5 (Cawelti & Adkisson, 1985).

The ASCD survey of 1,600 public high school principals also suffered from nonresponse with only 571 (36 percent) of the principals responding. Of the 571 responding schools, three-fourths of the schools had increased requirements for graduation since 1983 (Cawelti & Adkisson, 1986). Figure 6 compares the requirements for graduation in the 571 schools with data from the National Center for Education Statistics for high school seniors in 1982, and with the requirements recommended by

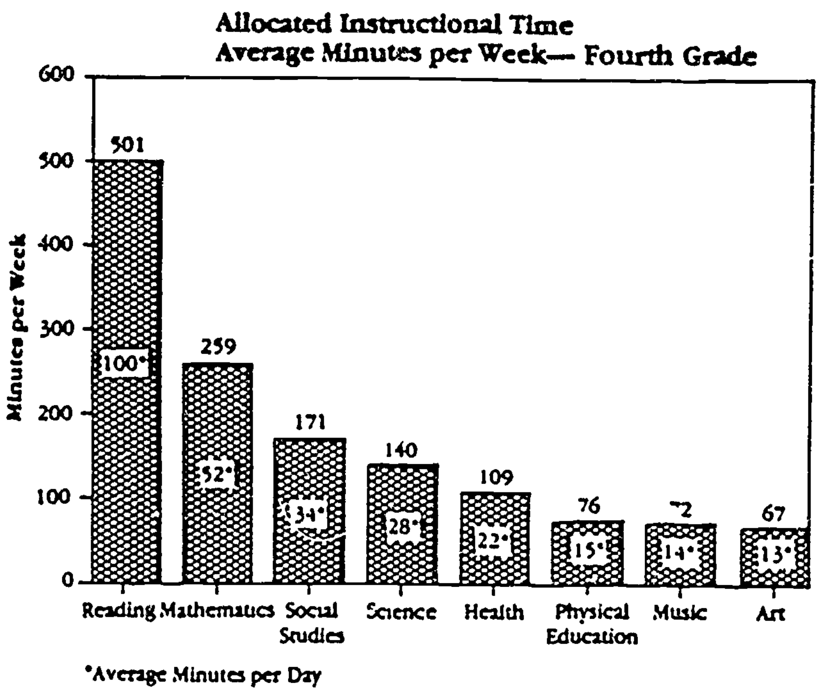
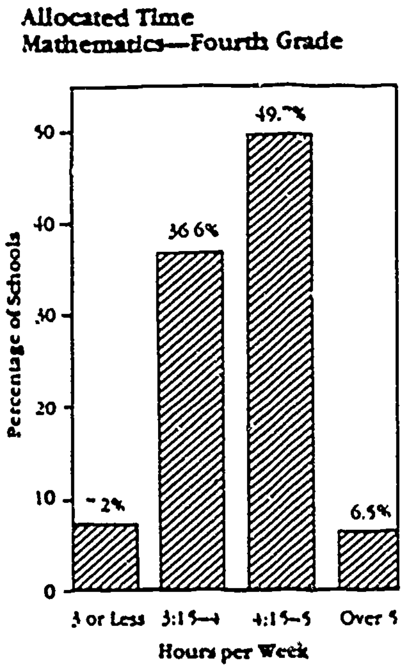
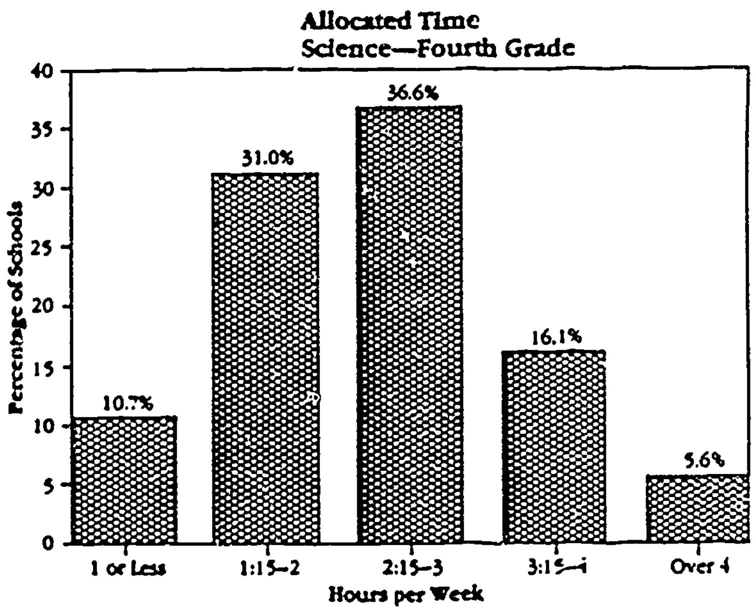


Figure 5 Allocated instructional time for science and mathematics, fourth grade
Note: Reprinted, by permission of the Association for Supervision and Curriculum Development, from G. Cawelti and J. Adkisson, "ASCD Study Reveals Elementary School Time Allocations for Subject Areas: Other Trends Noted," *Supplement to ASCD Update*. Copyright 1985 by the Association for Supervision and Curriculum Development. All rights reserved.

Figure 5 *(Continued)*





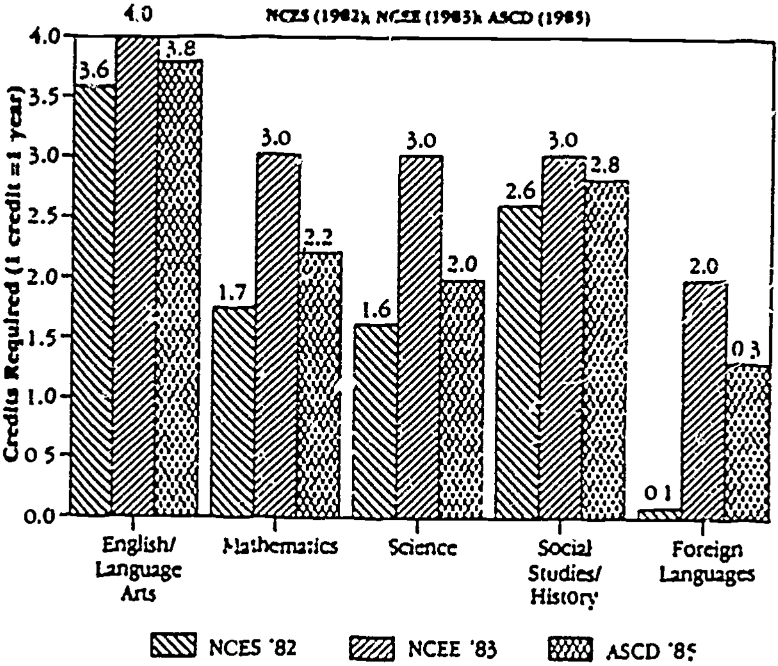


Figure 6 Recommended credits for graduation
Note: Reprinted, by permission of the Association for Supervision and Curriculum Development, from G. Cawelti and J. Adkisson, "ASCD Study Documents Changes Needed in High School Curriculum", *Supplement to ASCD Update.* Copyright 1986 by the Association for Supervision and Curriculum Development. All rights reserved.

the National Commission on Excellence in Education. Figure 6 may be of interest to the 571 responding principals, although inferences about national trends should not be made from such data.

1985 National Survey of Science and Mathematics Education.

The 1985 National Survey of Science and Mathematics Education will fill major data gaps on curriculum in elementary and secondary schools. The survey, carried out by Iris Weiss at the Research Triangle Institute and sponsored by the National Science Foundation, will provide extensive curriculum data for 1985 collected in a manner comparable to that for the 1977 survey described above. Topics surveyed include science and mathematics course offerings and enrollments and use of curriculum materials. The sample consists of 1,200 principals and 6,000 teachers from 400 school districts. The report of this study is expected to include and skills to be taught and the sequence in which content, topics, and skills will be taught for the third, seventh, and eleventh grades;

- which of a list of twelve mathematics courses and eleven science courses are currently taught;
- which of a list of ten mathematics topics (and seventeen science topics) is taught in grades six, seven, and eight;
- which textbook, textbook series, or commercially prepared workbooks are most commonly used to teach science and mathematics and the publisher's date of text material for seventh grade;
- how many semesters of course work in science and mathematics are required for graduation from the twelfth grade;
- which of five advanced mathematics and four advanced science topics are taught in the school.

1986–87 Transcript Study of the Eleventh Grade Sample in the 1985–86 NAEP Assessment.

According to staff at the Center for Statistics (formerly the National Center for Education Statistics), the Center may do a high school transcript study of the eleventh grade sample from the 1985–86 study conducted as part of the National Assessment of Educational Progress program. Transcripts for all four years of high school would be analyzed using the transcript study for the High School and Beyond Survey as a model.

1988 National Education Longitudinal Study.

The Center for Statistics has contracted with the National Opinion Research Center and Westat, Inc. to design and conduct the National Education Longitudinal Study of 1988, the third in the Center's series of longitudinal studies of students. This study will obtain information from a sample of 28,000 eighth graders from 1,050 schools, public and private. There will be supplemental samples of Hispanics and Asians. Students in the sample will be surveyed again in the tenth and twelfth grades. The study will also obtain information from parents, teachers, and schools. The current plan is to implement the survey in February, 1988. The study is expected to provide data on course offerings and enrollments similar to the data obtained from the High School and Beyond Survey. In addition, the 1988 study will provide data for students during their eighth and ninth grades and will introduce opportunity-to-learn measures for the items in the cognitive achievement tests that will be given to students.

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A transcript study for high school seniors is envisioned for 1993. (Center for Statistics staff members, personal communication, May 1, 1986).

1988 Elementary and Secondary Integrated Data System.

In 1985, the Center for Statistics began a project to review and redesign the Common Core of Data program, the Center's data collection program for basic statistical data about elementary and secondary educational institutions. Plans for a new Elementary and Secondary Integrated Data System (ESIDS) are being reviewed. Plans call for phased implementation of the components of ESIDS between Fall, 1986 and Fall, 1989 (Center for Statistics, 1986). According to Center staff, the plan provides for obtaining curriculum data by securing transcripts for the prior four-year period, for fourth, eighth, and twelfth grade students using a sample of roughly 1,000 schools for each of the three grades.

PROBLEMS WITH THE AVAILABLE DATA

Although numerous survey and assessment projects have collected data on curricula, the data generated by these activities are far from adequate to describe the current status of, or trends in, science and mathematics curricula in the United States. Some of the problems with the data are enumerated below.

Different Surveys Collect Different Data.

It is apparent from the descriptions of the different surveys that they collect different items of data. For example, the National Research Council's Committee on Indicators of Precollege Science and Mathematics Education noted that secondary school enrollment data are "... reported in three different ways: percentage of seniors who have taken 1, 2, or 3 (or more) years of science or mathematics; percentage of seniors who have taken some specific course; and percentage of the total numbers of high school students (or of a particular grade) taking a specific course." (Raizen & Jones, 1985). Some surveys collect data on opportunity-to-learn measures, but most do not. Even within a series of surveys, a question may vary in different years. For example, the opportunity-to-learn question discussed in the 1981-82 Second International Mathematics Study, conducted by the International Association for the Evaluation of Educational Achievement (IEA), differs from the question used in the 1970 IEA science study and the 1964 IEA mathematics study. The 1985 survey contracted by the National Assessment of Educational Progress has yet another version of the question.

Different Surveys Cover Different Populations.

Different surveys sample students at different grade levels or different grade spans. Some surveys cover only public schools; others survey both public and private.

Cycle for Repeating Surveys is Long.

There are few opportunities for measuring change in curriculum data. The 1985 National Survey of Science and Mathematics will provide the opportunity for comparisons with 1977 data. The National Assessment of Educational Progress science assessments in 1977, 1982, and (when published) 1985 provide data on enrollment trends. The three longitudinal studies of the Center for Statistics, with their supplementary offerings and enrollment surveys and transcript studies, provide data for high school seniors for 1972, 1980, and, in time, for 1993. The International Association for the Evaluation of Educational Achievement evaluated mathematics education in 1964 and 1982 and science education in 1970 and 1983; the time between these studies is even greater than the time between Center for Statistics studies. Because of the differences in the grades covered and the data items in these survey series, data from different series cannot be used to provide time series data.

Lack of Standardization of Terminology for Courses.

When conducting a survey, course titles may be collected from students, teachers, or principals, or obtained from transcripts. Since there is no standard set of course titles, the data collected from thousands of schools cannot be compared. Some surveys seek more comparable data by inquiring whether each of a list of topics is included in a course. Other surveys inquire about the book used to obtain a better understanding of course content.

Nonresponse Problems.

Nonresponse problems are evident in varying degrees in National Assessment of Educational Progress studies, Center for Statistics longitudinal studies, National Survey of Science and Mathematics surveys, International Association for the Evaluation of Educational Achievement (IEA) assessments, and Association for Supervision and Curriculum Development (ASCD) surveys. When the nonresponse is too large, as in the ASCD surveys and the recent IEA science assessment, the quality of the data is questionable because of the potential for significant bias. Authors have a responsibility to discuss nonresponse and potential bias in publishing such data. There are many reasons for nonresponse: lack of experience in survey administration, inadequate funds for follow-up of nonrespondents, lack of appreciation of the significance of nonresponse, and overly burdensome questionnaires. School principals may also feel that there are too many surveys.

Data Published Late or Not at All.

The 1977 science assessment conducted by the National Assessment of Educational Progress (NAEP) collected enrollment and other background data. The enrollment data were first published in conjunction with the 1981–82 Science Assessment and Research Project conducted by the University of Minnesota. It is hoped that the other background data will provide a base for trend data when the curriculum data in the NAEP 1985 assessment are analyzed. Frequently, the resources available for analysis and reporting are too limited to permit full analysis of the data. This has been a problem, for example, with the 1981–82 Mathematics Assessment conducted by the International Association for the Evaluation of Educational Achievement, which has not yet released the detailed national report for the United States and does not have the resources required to carry out the analyses originally contemplated. In a period of rapid change, data that are out-of-date lose much of their value.

RECOMMENDATIONS

A few recommendations are proposed below. Additional problems with curriculum data, accompanied by recommendations to address those problems, are discussed in a broader context in the report of the Committee on Indicators of Precollege Education in Science and Mathematics (Raizen & Jones, 1985).

Standard Set of Data Elements for Curriculum Surveys.

Since the Center for Statistics now has responsibility for the National Assessment of Educational Progress program, the CS longitudinal surveys, and the planned Elementary and Secondary Integrated Data System, the Center should devote effort to developing a standard set of core data elements to ensure comparability across surveys. It would be desirable to involve representatives of the International Association for the Evaluation of Educational Achievement and the National Survey of Science and Mathematics in this process.

Standard Terminology for Secondary School Course Offerings.

The Center for Statistics, working with state education agencies, should take the lead in establishing a standard terminology for course offerings. This should include the major topics that would be covered in each course. The intent is not to standardize courses but to make it possible to measure the extent to which a course in a given high school matches a standard course definition in terms of percentage of topics covered. The terminology handbook, *A Classification of Secondary School Courses,* prepared for the Center for Statistics in 1982 by Evaluation Technologies, Inc., could serve as a starting point.

Coordinate Survey Cycles to Spread Response Burden.

The growing nonresponse problem in education surveys might be alleviated by spacing more evenly over time the following major surveys: The National Assessment of Educational Progress Surveys, the Center for Statistics longitudinal and transcript studies, and the National Survey of Science and Mathematics, sponsored by the National Science Foundation. Survey designers should tailor the length of survey questionnaires to match the resources that will be available for analysis.

Provide Time Series Data at Frequent Intervals.

It should be possible to develop time series data for curricula at frequent intervals by using selected data items from each of the three survey series mentioned above. This would require three actions: (1) use of standard definitions and a core set of curriculum items in all three surveys, (2) agreement on an integrated schedule for the three surveys so that they are evenly spaced over time, one of the three surveys occurring every three or four years, and (3) collection of curriculum data (not assessment data) for additional grades, particularly in the NAEP surveys. Special attention should be paid to elementary curriculum data, which has been in short supply. The 1985 National Assessment of Educational Progress and the plans for the Center for Statistics Elementary and Secondary Integrated Data System should help fill this gap.

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Chapter 6

THE SCIENCE REPORT CARD
A Description of the 1985–86 NAEP Science Assessment and the Higher Order Skills Assessment Pilot Study

Ina V. S. Mullis

The National Assessment of Educational Progress (NAEP) is an ongoing, congressionally mandated project established to conduct national surveys of the educational attainments of young Americans. Its primary goal is to determine and report the status of and trends over time in educational achievement. NAEP was initiated in 1969 to obtain comprehensive and dependable national educational achievement data in a uniform, scientific manner. Today, NAEP remains the only regularly conducted national survey of educational achievement at the elementary, middle, and high school levels.

Since 1969, NAEP has assessed nine-, thirteen-, and seventeen-year-olds. In the 1983–84 reading and writing assessments, NAEP began sampling students by grade as well as by age. In addition, NAEP periodically samples young adults. The subject areas assessed have included reading, writing, mathematics, science, and social studies, as well as citizenship, literature, art, music, and career development. Assessments were conducted annually through 1980 and have been conducted biennially since then. The 1985–86 effort included in-school assessments of mathematics, reading, science, and computer competence, along with special probes of U.S. history and literature. All subject areas except career development have been reassessed to determine trends in achievement over time To date, NAEP has assessed approximately 1.4 million young Americans.

From its inception, NAEP has developed assessments through a consensus process. Educators, scholars, and citizens representative of many diverse constituencies and points of view design objectives for each subject area assessment, proposing general goals they believe students should achieve in the course of their education. After careful reviews, the objectives are given to item writers, who develop assessment questions appropriate to the objectives.

All exercises undergo extensive reviews by subject matter and measurement specialists, as well as careful scrutiny to eliminate any potential bias or lack of sensitivity to particular groups. They are then administered to a stratified, multistage probability sample. The students sampled are selected so that their assessment results may be generalized to the entire national population. Once the data have been collected, scored, and analyzed, NAEP publishes and disseminates the results. The objective is to provide information that will aid educators, legislators, and others in improving education in the United States Some of the questions used in each assessment are made available to anyone interested in studying or using them. The rest are kept secure for use in future assessments for the examination of trends over time.

There have been five national assessments of science, in the 1969-70, 1972-73, 1976-77, 1981-82, and 1985-86 school years. Each has included the assessment of nine-, thirteen-, and seventeen-year-old students on a variety of science attitude and content questions. Some of the questions were readministered in successive assessments in order to gather information about trends in science performance over time. The 1981-82 national assessment of science was made possible through a grant from the National Science Foundation to the University of Minnesota. The results from that assessment indicated an improvement on science achievement items at age nine, no significant change in achievement at age thirteen, and continuing declines on content items at age seventeen (University of Minnesota, Science Assessment and Research Project, 1983).

All five NAEP science assessments used a deeply stratified three-stage sampling design. The first stage of sampling entailed defining primary sampling units (PSUs), which were typically counties, but sometimes aggregates of sparsely populated counties; classifying the PSUs in strata defined by region and community type; and randomly selecting PSUs. For each age level, the second stage entailed enumerating, stratifying, and randomly selecting schools, both public and private, within each PSU selected at the first stage. The third stage involved randomly selecting students within a school for participation in the assessment.

1985-86 SCIENCE ASSESSMENT

In keeping with NAEP practice, the 1985-86 science objectives were formulated through a consensus process intended to be responsive to a broad range of opinions, interests, and priorities concerning science education. Scientists and educators from across the country, including college teachers of science, specialists in science education, school science coordinators, classroom teachers, and school administrators, reviewed the existing NAEP science objectives. Their comments and suggestions for revisions were considered by NAEP's Science Learning Area Committee. Successive drafts of the objectives booklet were reviewed not only by NAEP's science committee but also by teachers, administrators, and other individuals representative of groups interested in science education.

The material that follows presents the framework and specifications used to guide item development for the 1985-86 assessment (NAEP, 1986).

FRAMEWORK FOR NAEP'S SCIENCE OBJECTIVES

A matrix in three dimensions—content, context, and cognition—represents the broad objectives of science education. Figure 1 presents the

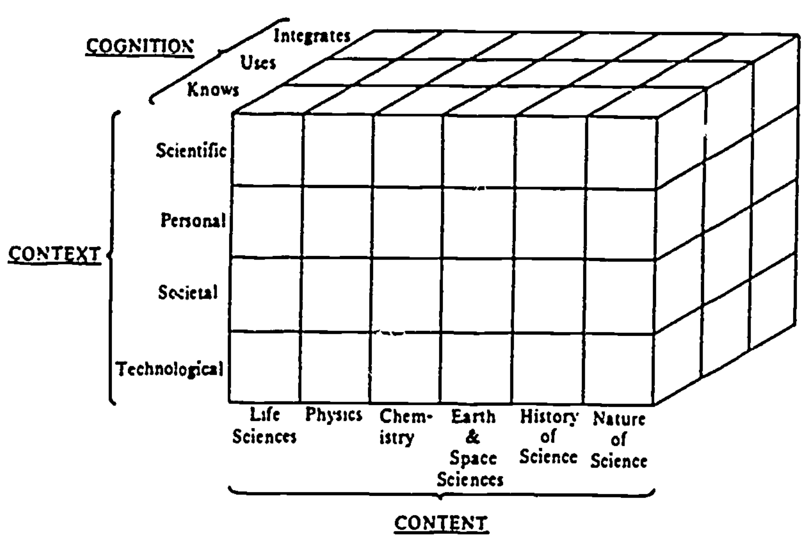

Figure 1 Framework for science assessment exercises

matrix in visual form, showing that each dimension is divided into major categories. Each exercise in the assessment can be classified into a cell of the matrix that matches the category of content it assesses, the context in which it is presented, and the cognitive skill it measures. However, exercises do not exist for every cell because for a few combinations, such as history of science in a personal context, meaningful exercises are difficult to imagine.

This three-dimensional framework is a departure from the two-dimensional one developed for the 1976-77 assessment and used again for the 1981-82 assessment. The concepts underlying the two frameworks, however, are similar enough to permit easy reclassification of previously administered exercises into cells of the three-dimensional matrix. Thus, it is possible to maintain continuity in reporting trends over time by reusing a subset of previously administered exercises in the new assessment.

Content

The content dimension of the matrix includes both the body of knowledge in the traditional disciplines of science and knowledge about science, its nature and processes, and its history. The content dimension contains six major categories: life sciences, physics, chemistry, earth and space sciences, history of science, and nature of science.

Context

The context dimension of the matrix defines four types of situations for presenting assessment exercises: scientific, personal, societal, and technological.

Scientific Context. These exercises assess students' understanding of the body of knowledge of science. This category includes the descriptive facts, principles, conceptual schemes, models, and inquiry skills needed to acquire mastery of the disciplines and to attain an intellectual appreciation of the natural world.

Personal Context. These exercises assess the students' knowledge of the ways in which scientific facts and principles are useful in their everyday lives and the extent to which their decision making is based on the application of science to matters related to general safety, health, well-being, habits, and life style.

Societal Context. These exercises deal with the role and use of the content and methods of science in decision making on societal issues and questions of public policy. This category also includes exercises that deal with the impact of scientific and technological developments on people, both individually and collectively, through the management or manipulation of the biological and physical worlds. These exercises require an understanding of the potential benefits, risks, or both to individuals and to society that various scientific and technological endeavors can have.

Technological Context. These exercises focus on the application of the knowledge and methods of science to commercial or utilitarian purposes. Technology, which is both the process of development and the products of that development, relies on concepts from science and mathematics to create new products and procedures. It includes tools, devices, and techniques that can have considerable influence on individuals and the environments in which they live. Examples of technology include biotechnology, food production, medical care, energy production and consumption, transportation, communication, and nuclear power. Tools and devices include such things as windmills, microscopes, X-ray machines, television, computers, and nuclear submarines.

Cognition

The NAEP Learning Area Committee designed the cognition dimension of the matrix so that exercises could be classified according to the cognitive processes required to deal with science content at different levels of complexity. The committee defined three generic categories—knows, uses, and integrates—and based the following descriptions of these categories on cognitive theory that defines three types of knowledge, each of which has a different function in problem solving.

Knows. These exercises test primarily factual knowledge. Successful performance depends on the ability to recall specific facts, concepts, principles, and methods of science; to show familiarity with scientific terminology; to recognize these basic ideas in a different context; and to translate information into other words or another format. This category generally involves a one-step cognitive process.

Uses. These exercises test the ability to combine factual knowledge with rules, formulas, and algorithms for a specified purpose. Successful performance depends on the ability to apply basic scientific facts and principles to concrete or unfamiliar situations; to interpret information or data using the basic ideas of the natural sciences; and to recognize relationships of concepts, facts, and principles to phenomena observed and data collected. This category generally involves a two-step cognitive process.

Integrates. These exercises test the ability to organize the component processes of problem solving and learning for the attainment of more complex goals. Successful performance depends on the ability to analyze a problem in a manner consistent with the body of scientific concepts and principles, to organize a series of logical steps, to draw conclusions on the basis of available data, to evaluate the best procedure under specified conditions, and to employ other higher order skills needed for reaching the solution to a problem. This category generally involves multistep cognitive processes. In particular, it requires such mental processes as generalizing; hypothesizing; interpolating and extrapolating; reasoning by analogy, induction, and deduction; and synthesizing and modeling.

STUDENT, TEACHER, AND SCHOOL BACKGROUND QUESTIONS

Since the 1981–82 science assessment, there have been many significant additions to the NAEP design. In an effort to provide relevant information for educational policy makers, NAEP has increased the amount of background information collected from students, teachers, and school administrators. For example, as part of the 1986 science assessment, students were asked about their previous science experiences in and out of school, the help they received in science from their teachers, activities in their science classes, the amount of time they spent studying science, the science topics they studied in school, their course work, and their attitudes toward their science courses and the general value of scientific study.

Teachers were asked for descriptive information about their training and experience, how they spent their time in class, what topics they covered, and what instructional methods they used. Administrators were asked about their training and experience, their involvement in the instructional process, curriculum and graduation requirements, testing requirements, school facilities, and school policies relevant to the recent educational reform movement.

Given that teacher and school responses can be linked to student achievement data, it is hoped that NAEP will be able to provide instructionally relevant information as a result of the background questions included in the 1986 science assessment. The implications of relating achievement to student responses to background questions are demonstrated in *The Writing Report Card,* which links student achievement to eleven factors about writing instruction and practice (Applebee, Langer, & Mullis, 1986). For example, NAEP found that students who reported doing more planning, revising, and editing are better writers than those who reported doing less. However, NAEP results also indicated that instruction in the writing process has little relationship to student achievement.

BALANCED INCOMPLETE BLOCK SPIRALLING

In the standard matrix sampling procedure formerly employed by NAEP, the total assessment battery, typically about six to seven hours of assessment material per subject, was divided into mutually exclusive booklets. Students were allocated about 45 minutes to complete each booklet. Since no students were administered more than one booklet, this simple matrix design allowed calculation of correlations and cross-tabulations among exercises within the same booklet, but not among exercises in different booklets.

The new NAEP design instituted for the 1983-84 assessment remedied this deficiency by using a powerful variant of matrix sampling called Balanced Incomplete Block (BIB) spiralling. Using this procedure, the total assessment battery was divided into blocks of approximately fifteen minutes each, and each student was administered a booklet containing three blocks as well as a six-minute block of background questions identical for all students. Thus, the total assessment time for each student was still about the same.

The balanced-incomplete-block aspect of the method assigned blocks of exercises to booklets in such a way that each block appeared in the same number of booklets and each pair of blocks appeared in at least one booklet. This, of course, generated a much larger number of different booklets. The spiralling aspect of the method then cycled the test booklets for administration so that typically no two students in any assessment session in a school—and at most only a few students in schools with multiple sessions—received the same booklet. Using this procedure, each block of exercises was administered to approximately 2,000 students in each age or grade sample and each pair of blocks to about 200 students.

The introduction in 1985-86 of routine assessment in four subject matter areas—science, mathematics, reading, and computer competence—presented major logistical problems in that NAEP could not attempt a BIB design across all four subject areas. This would have required approximately 900 booklets. Since this was clearly not feasible, the design for the assessment conducted in the spring of 1986 was fully balanced within each of the four subject areas and partly balanced among areas.

More specifically, each block required sixteen minutes of administration time, fourteen minutes for cognitive exercises, and two minutes for background and attitude questions. Each student received a booklet comprising three blocks as well as a six-minute common block of background items for a total testing time of approximately fifty-four minutes. The design required 46 booklets for nine-year-olds in grade three to accommodate six reading blocks, seven math blocks, seven science blocks, and three computer blocks. For thirteen-year-olds in grade seven, 62 booklets were required for six reading, nine math, nine science, and six computer blocks. For seventeen-year-olds in grade eleven, 86 booklets were required for six reading, eleven math, eleven science, and six computer blocks. More blocks were assigned to math and science at successive age and grade levels because of the increasing range of course work in those areas with advancing grades. With the constraint of 2,000 students per block per each age and grade level, the 1986 design entails approximately 433 students per booklet and for between-block correlations at ages nine and thirteen, and 371 students per booklet and for between-block correlations at age seventeen.

NAEP assessments are always administered using a well-trained, professional data collection staff. WESTAT, Inc. was responsible for the 1985–86 data collection. Quality control was provided through site visits by NAEP and WESTAT staff.

TRENDS IN PERFORMANCE OVER TIME

Incorporating BIB spiralling in NAEP science assessments is a significant change that will improve both sampling efficiency and analysis potential. However, the matrix-sampled booklets used in the first four science assessments were accompanied by paced audio recordings. With BIB spiralling, many different booklets—and thus different sets of exercises—were administered in a particular session, and the booklets could no longer be accompanied by audiotapes. This, along with the changes in the sample design, represented another change from past procedures. To provide the necessary links with past assessments, bridge assessments were incorporated into the 1985–86 assessment. Previously assessed science items were administered using procedures identical to those used in past assessments. The target populations were defined as in past assessments, and the items were administered at the same time of the school year as in previous assessments.

The bridge studies in science and mathematics included 20,000 students. To allow a disentangling of method variance (associated with taped versus BIB administration) from the variance due to the conjoint changes in age definition and testing time, the bridge studies in these subjects were conducted in two parts. The results of these bridge samples will be used by NAEP to report trends in science performance and to estimate the differences in performance resulting from NAEP's new procedures.

ITEM RESPONSE THEORY SCALING

NAEP data obtained in the 1985–86 assessment has been scored and weighted in accordance with the population structure. The analysis will include computing the percentages of students giving various responses, and NAEP will continue to provide the percentage of respondents answering a given item acceptably as one measure of achievement. The trend results will be computed by averaging the percentages of correct responses across exercises to provide a general picture of student achievement and how it has changed across time. For the 1986 BIB data in grades three, seven, and eleven, however, NAEP will use item response theory (IRT) technology to estimate science proficiency levels for the nation and various subpopulations. IRT defines the probability of answering an item correctly as a mathematical function of proficiency level or skill.

The main purpose of the IRT analysis is to provide a common scale on which performance can be compared across age or grade levels and subpopulations within grade levels. In the past, the average performance of one age level could not be compared to the average performance of another, since the results were based on different sets of items. With IRT analysis, all three age groups are placed on the same proficiency scale, and average proficiency levels can be compared across time *and* levels. For the 1986 science assessment, NAEP hopes to provide proficiency levels for subscales in accordance with the content dimension described in the objectives.

An additional benefit of IRT methodology is that is provides for a criterion-referenced interpretation of levels on a continuum of proficiency. Each level is defined by describing the kinds of questions that most students attaining the proficiency level would be able to perform successfully; each level is exemplified by typical benchmark exercises. In this scale anchoring process, NAEP selects sets of items that are good discriminators between proficiency levels. The criterion used to identify such items is that students at any given level would have at least an 80 percent probability of success with those tasks, while the students at the next lower level would have less than a 50 percent probability of success. Thus, NAEP will report the average proficiency results for mathematics and science as well as data giving the estimated proportion of each grade level and subgroup at or above each of the proficiency levels.

The standard error, computed using a jackknife replication procedure, provides an estimate of sampling reliability for NAEP measures. It is composed of sampling error and other random error associated with the assessment of a specific item or set of items. Random error includes all possible nonsystematic error associated with administering specific exercise items to specific students in specific situations.

ASSESSING HIGHER ORDER THINKING SKILLS

The planning for NAEP's 1985–86 national assessment took place as public concern focused on the quality of elementary and secondary education in the United States. A number of prestigious reports critical of the schools sparked unprecendented public debate and calls for improvement across the country. For example, *Educating Americans for the 21st Century,* the report of the National Science Board Commission on Precollege Education in Mathematics, Science and Technology (1983), stated

> We must return to the basics, but the basics of the 21st century are not only reading, writing, and arithmetic. They include communication and higher problem-solving skills, and scientific and technological literacy—the *thinking* tools that allow us to understand the technological world around us. These new basics are needed by *all* students. (p. v)

The Assessment Policy Committee, which governs NAEP and includes teachers, school superintendents, state legislators, school board members, and representatives from business and industry, also called for increased emphasis on problem-solving and higher order skills in the 1985–86 assessment.

From one perspective, the design of the 1986 NAEP assessment is well-suited to investigating relationships in higher order thinking skills. The inclusion of such exercises in the BIB-spiralled, cross-block pairings will permit NAEP not only to explore relationships within reading, math, science, and computer competence, but also to examine the transfer of higher order thinking skills across areas. To this end, staff and consultants set out to emphasize higher order thinking skills in the assessment. However, from another perspective, the complex design with its many booklets, tight time constraints, and the restrictions of self-administered paper-pencil technology were very frustrating. NAEP staff and consultants continually raised ideas based on the procedures used in the first two science assessments, when NAEP had the resources to conduct assessments of individual students in interview situations using more sophisticated apparatus.

Much of the impetus for the national concern about weak performance in the area of thinking skills stemmed from NAEP findings. For example, NAEP results indicated more improvement in the basic skills of reading, writing, mathematics, and science at the three age levels than in making inferences from printed material, solving math problems, supporting hypotheses, or interpreting the meanings of scientific data. This evidence, however, was more apparent in the areas of reading and writing than in mathematics and science. Further, it seemed that it would be difficult to gather additional information about higher order thinking skills, particularly in science, without the resources to conduct an assessment using science equipment. NAEP, therefore, proposed a focused research project to the National Science Foundation to investigate higher order thinking skills that may be used in science and mathematics and to develop innovative measures of these skills.

ASSESSING THINKING SKILLS

At the planning conference for the thinking skills assessment project, consultants developed a very interactive and inclusive framework based on the premise that, at the most general level, higher order thinking skills are used to formulate a question, design and perform an analytical procedure, and reach a conclusion to a problem. Further, such thinking was considered to be continuously self-monitored and evaluated as it occurs during the course of working through a problem or situation. Finally, subject matter knowledge, beliefs, and environment also affect how effectively an individual employs thinking skills in a particular situation. The model for higher order thinking in science and mathematics that was developed by the group is shown in Figure 2. The possible ir relationships among the various aspects of higher order thinking are shown, as is the impact a person's knowledge, beliefs, and environment can have on his or her thinking about a problem.

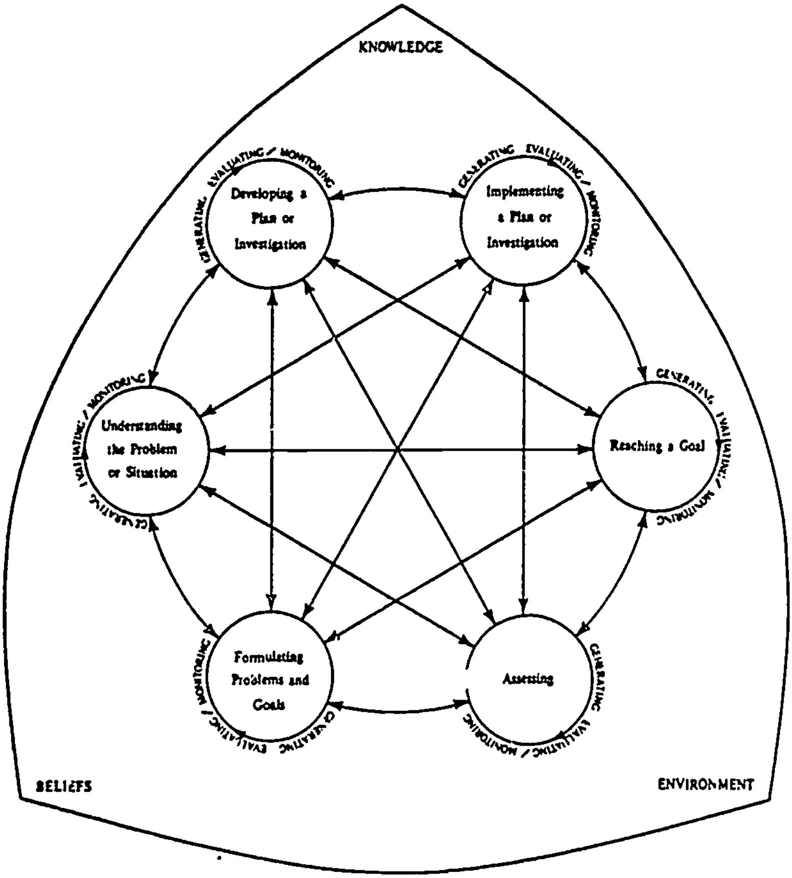

Figure 2 Higher order thinking in science and mathematics

That the model reflects the dynamic and interactive nature of thinking is both its strength and its weakness. As a global representation of thinking, it is accurate in that problem solving can take a variety of forms and does not occur via a single sequential set of steps. However, fuzzy distinctions between skills made this model very difficult to use as a guide for developing discrete assessment measures.

At a second panel meeting, it was decided to be mindful of the components of the framework but to concentrate on tasks that students should be able to perform as part of their study of science and mathematics. Using that strategy, the panel suggested a number of ideas for assessment activities using contexts in mathematics and science. A major issue discussed throughout the meeting was the potential confounding of subject matter background knowledge with the ability to solve a given problem. Consequently, in developing tasks, staff and consultants decided to try to minimize the potential effect of prior knowledge on successful performance. This was, of course, difficult. At the conclusion of the meeting to develop prototype tasks, the ideas for assessment activities were reviewed and evaluated with particular attention given to administrative feasibility, administrator training, and equipment needed. All participants were struck by the difficulties involved and were concerned about the short time frame proposed for the project. It was agreed that it would be desirable to try and benefit more fully from the higher order skills activities and administration procedures developed earlier by the Assessment Performance Unit (APU) Science Team in Great Britain.

ASSESSMENT PERFORMANCE UNIT IN SCIENCE

NAEP had invited a representative from the Assessment Performance Unit (APU) Science Monitoring Team to each of the planning conferences for the higher order skills project. From the descriptions of the work done by the APU and previous visits between NAEP and APU staff members, it became apparent that the higher order skills science and mathematics hands-on assessment planned by NAEP had many aspects in common with the APU science assessment.

Table 1 presents the skill categories and question descriptors for the APU Science Assessment Framework. Three of the categories are measured using hands-on assessment techniques: Category 2, Use of apparatus and measuring instruments; Category 3, Observation; and Category 6, Performance of investigations.

Because the APU had seven years of experience in developing and assessing performance tasks similar to those envisioned by the NAEP staff and consultants, a visit to the APU to see their assessment materials seemed appropriate. The staff of the APU was more than gracious in preparing for NAEP's visit, having set up a basketball gymnasium full of their performance tasks. On display were the questions, administration directions when appropriate, complete sets of the apparatus, and scoring guides. NAEP staff were left to "self-administer" the many hands-on tasks, and the APU staff were available to answer questions.

Although NAEP staff were very experienced in test development, the overwhelming nature of developing and assessing materials of such quality and complexity became clear. Considering that designing the apparatus for each task is very difficult, it was apparent that NAEP could only develop a relatively small number of such tasks in the short time proposed for the higher order skills project. Thus, NAEP entered into

Table 1. Assessment performance unit science assessment framework: Categories of science performance

Category	Subcategory	Mode of testing
1 Use of graphical and symbolic representation	Reading information from graphs, tables and charts Representing information as graphs, tables and charts	Written tests
2 Use of apparatus and measuring instruments	Using measuring instruments Estimating physical quantities Following instructions for practical work	Practical tests
3 Observation	Making and interpreting observations	Practical tests
4 Interpretation and application	Interpreting presented information Applying biology, physics, and chemistry concepts	Written tests
5 Planning of investigations	Planning parts of investigations Planning entire investigations	Written tests
6 Performance of investigations	Performing entire investigations	Individual practical tests

Note: Reprinted, by permission, from Assessment of Performance Unit, Department of Education and Science, *Science in Schools, Ages 13 and 15,* 1985.

an arrangement for further support from the APU for both consulting help and use of some of its copyrighted materials. This arrangement enabled NAEP to benefit from using some already validated materials in its pilot study and to focus on developing new exercises, such as those involving computers and those assessing higher order skills in mathematical contexts.

THINKING ABOUT MATHEMATICAL AND SCIENTIFIC RELATIONSHIPS

The combined work of the NAEP panels and staff and the excellent work and guidance of the APU eventually resulted in a set of tasks that primarily asked students to think about a variety of relationships in mathematics and science (National Assessment of Educational Progress, 1987). At perhaps the easiest level of the hierarchy, students were asked to classify and sort birds, seeds, and vertebrae according to characteristics of their own choosing. While biologists have given such schemes much thought and it was hoped that students would "think" like biologists, students were basically given credit for flexibility and an ability to think of alternative ways of sorting or classifying. The pilot tests were very limited, but it appears that students were relatively successful on these tasks.

At the next level, students were given materials, equipment, and apparatus that exemplified particular mathematical or scientific phenomena or relationships and were asked to observe, infer, and formulate hypotheses. For example, a whirlybird apparatus was used to demonstrate that placing weights farther from the center of a rotating arm will decrease the speed of the arm. Tubes of sand were used to show the relationship between the amount of sand in a tube and the speed at which it would roll down an incline. A wig-wag was used to show the relationship between the amount of weight placed in the wig-wag and the speed and amplitude of its swing, and the double staircase was used to show the relationship between the height of the staircase and the total number of blocks required to build it. Again, the pilot test data must be interpreted with caution. They did indicate, however, that students were not generally familiar with these relationships. Further, in making their observations, students did not appear to search for relationships or at least they did not volunteer those kinds of responses. If they were explicitly asked to determine a relationship, they generally did so. However, if the directions were not explicit and they were simply asked to write down what they noticed, the responses tended to be descriptive, step-by-step records rather than generalizations of the relationships they had observed.

Another set of tasks was designed to measure student ability to detect patterns in data sets and interpret the results. For example, students were asked to collect and interpret data about the effect of different size and shaped wands on the number and size of soap bubbles; to collect and interpret data about the ratio of green to red gumballs in a gumball machine; and to interpret data about participant scores on several athletic events. Students generally seemed to understand and be able to complete these tasks.

Finally, individual students were asked to conduct complete experiments. They were asked to determine if sugar cubes dissolve faster than loose sugar and if stirring makes a difference. They were asked to determine which fabric, plastic or wool, would keep a person warmer in cold, dry weather. They were asked to determine which of several different materials weighed the most given that their volumes were equal. They were asked to use pegboards of different lengths and widths to determine how length and width affected the rate of pendulum swing. For these tasks, observers marked student behaviors on a checklist. While the pilot data indicated some difficulties with the checklist marking procedures, it appeared that students were not adept at conducting these investigations and manipulating the variables that were involved. On the other hand, similar to the results obtained in the United Kingdom, students did recognize the major variables and take measurements in conducting their experiments.

FEASIBILITY OF ADMINISTERING HANDS-ON ASSESSMENT TASKS

Because a major part of this pilot project was to judge the feasibility of more innovative and complex assessment procedures, NAEP developed as many different prototypes of administration formats as possible. These can be classified into the following three major modes of administration: group activities, station activities, and full investigations.

Group activities were administered to intact classes. These consisted of open-ended paper and pencil tasks based on a variety of stimuli. In one case, the stimuli included a demonstration of an experiment by the exercise administrator. In the remaining cases, students were given written or tabular information. As part of the group administrations, students were also given a brief set of student background questions and either a mathematics or science block from the 1986 assessment.

Station activities consisted of hands-on tasks that required students to work with a set of materials and to answer questions based on them. These activities were divided into two sets of six tasks for each grade level. Groups of six students were given the tasks, with students rotating from activity to activity every eight minutes. One task in each of the sets was administered by computer. Students received directions for the activity via the computer and recorded their answers using the computer. The remaining station activities asked students to use apparatus to investigate relationships and asked them to record their findings using paper and pencil.

Full investigations required students to design and conduct experiments examining a question posed by an administrator. Students were given very elaborate equipment to conduct their experiments and asked to report their findings and discuss them with the administrator after the investigation.

The distribution of tasks across thinking skills and administration modes is shown in Table 2. The grade levels in which the tasks were carried out are shown in parentheses.

Table 2. NAEP pilot study: thinking and inferencing skills by administration mode

Thinking and inferencing skills	Group	Administration modes: Station	Administration modes: Individual
Sorting, classifying (distinguishing patterns within a single class of items)		Birds (3)[1] Birds (3) Seeds (3, 7, 11) Vertebrae (11) Seeds (7)	
Observing and inferencing; formulating hypotheses based on mathematical and scientific principals (inferring relationships between an independent and dependent variable)	Whirlybird (3, 7) Number relationship (7, 11)	Sand and tubes, (3, 7, 11) Rolling funnels (3, 7, 11) Circle game (3) Number game (7, 11) Wig-wag (3, 7) Water on brick (3) Balance scale (7, 11) Double staircase (3, 7, 11) Capillarity (7, 11) Conductivity (11)	
Interpreting provided data (inferring patterns in results)	Hair color (3) Triathlon (3, 7, 11)	Gumball game (3, 7, 11) Bubbles (3, 7, 11) Magnet and compass (11)	
Designing and conducting an experiment	Heart rate and exercise (11) (designing only)	Sugar cubes (7) Magnet (3)	Sugar cubes (3) Pegboards (3, 7, 11) Survival (7, 11) Density (7, 11)

[1]Grade level indicated in parentheses.

Twelve adventurous school districts agreed to participate in the pilot project, and third-, seventh-, and eleventh-grade students were assessed in all four regions of the country. Within each region, an attempt was made to select schools in middle-income urban, disadvantaged urban, and small city areas. Twenty-two administrators were trained during a one-week period to administer the tasks and code the observational checklists for the full investigations. The pilot-test was conducted during April 1986 by teams of three administrators, each burdened with over 100 pounds of equipment and apparatus. The teams spent a week in each district conducting the pilot study, using one class at each grade level in each of three schools. Almost 1,000 students were assessed in all, with approximately 100 to 300 responses obtained for each task.

Scoring guides were developed for all open-ended tasks, and the student responses were categorized, entered into the computer, and analyzed. The results of the pilot test were shared with a panel of six advisors. Overall, the tasks were well-received. The panelists suggested revisions to some tasks, refined the scoring guidelines, and commented on the many ways that the data from a national assessment of such tasks could be analyzed. For example, there was agreement that the results would provide information on how students approach such problem-solving tasks and how they think about scientific and mathematical relationships. The results would also provide student profiles across tasks and indicate differences in performance among various subpopulations of students.

SUMMARY

In an effort to provide more useful results, NAEP has incorporated many new complex changes in the 1986 science assessment (Messick, 1983; Messick, 1985). These changes include the following:

- ☐ more background information about students, teachers, and school administrators that can be linked to student achievement;
- ☐ BIB spiralling to improve the ability of conducting relational analysis both among aspects of subject area study and among background variables;
- ☐ IRT scaling to provide a common scale and set of subscales on which performance can be compared across age and grade levels and subpopulations within age and grade levels both at one point in time and across assessments; and
- ☐ an increased emphasis on measuring higher order skills, includ-

ing ambitious research in the area of hands-on performance assessment using scientific equipment and apparatus.

These changes are costly, technically demanding, and time consuming. However, NAEP has already demonstrated the potential of these techniques in its reports on the 1983–84 reading and writing assessments. It is hoped that in analyzing the results of the 1985–86 science assessment, NAEP will continue to refine and improve these efforts and provide even more useful information.

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Chapter 7

THE SECOND INTERNATIONAL MATHEMATICS STUDY*
Major Findings and Implications

Kenneth J. Travers

The Second International Mathematics Study (SIMS) was a comprehensive survey of the teaching and learning of mathematics in the secondary schools of twenty countries. It was conducted under the aegis of the International Association for the Evaluation of Educational Achievement (IEA) with substantial funding from several U.S. federal agencies, including the National Science Foundation, the National Center for Education Statistics, and the former National Institute of Education.

The IEA is an international, nonprofit, scientific association incorporated in Belgium for the principal purposes of (1) undertaking educational research on an international scale; (2) promoting research aimed at examining educational problems in order to prov' . facts that can help in the ultimate improvement of educational systems; and (3) providing the means whereby research centers in the various member countries of IEA can undertake cooperative projects. The Mathematics Project Council, responsible for the Second Mathematics Study, was chaired by Roy W. Phillipps of the New Zealand Department of Education (Appendix I, p. 153).

The countries participating in the IEA include the following: Australia, Flemish Belgium, French Belgium, Canada (British Columbia and Ontario), Chile, England and Wales, Finland, France, Hong Kong, Hungary, Ireland, Israel, Ivory Coast, Japan, Luxembourg, the Netherlands,

*Opinions, conclu'ons, or recomm ndations contained herein are those of the authors and do not necessarily reflect the views of the funding agencies.

New Zealand, Nigeria, Scotland, Swaziland, Sweden, Thailand, and the United States.

In each participating country, SIMS was carried out at a nationally recognized educational research institution under the direction of a national committee of specialists in mathematics education and educational research. International aspects of the study were directed by an international committee. Members of the U.S. National Mathematics Committee, the U.S. Technical Advisory Panel, and the International Mathematics Project Council are listed in Appendixes I and II, pp. 153–4.

The First International Mathematics Study took place in 1964 in twelve countries. Eleven of these countries, including the United States and Japan, participated in the second study in 1980–82. IEA studies are characterized by the use of national probability samples of students drawn under guidelines specified by an international sampling plan and reviewed by an international sampling referee. U.S. sampling for SIMS was directed by the Survey Research Laboratory at the University of Illinois. The total U.S. sample consisted of students and their teachers from about 500 classrooms in public and private schools nationwide. Garden (1984) reports technical aspects of the SIMS sampling.

STUDY MODEL AND TARGET

The Second International Mathematics Study was based on three aspects of the curriculum: the intended curriculum, the implemented curriculum, and the attained curriculum (see chart).

The *intended* curriculum is reflected in curriculum guides, course outlines, syllabi, and textbooks adopted by school systems. In most countries, national curricula emanate from a ministry of education or similar body. In the United States, of course, such statements of intended goals and curricular specifications come from state departments of education and from local districts. Thus, it was considerably more difficult to describe the intended curriculum for the United States than for almost any other country that took part in the study.

The *implemented* curriculum focuses on the classroom, where the teacher interprets and puts into practice the intended curriculum. Teachers exercise their own judgment in translating curriculum guides and adopted textbooks into programs for their classes. Hence, their selection of topics or patterns for emphasis may not be consistent with those intended.

To identify the implemented curriculum, a number of questionnaires were developed for classroom teachers to complete. For example, teachers were asked whether or not they had provided instruction for each of the items on the achievement tests. ney were questioned about such matters as the use of calculators in their classes. They were also asked to provide detailed information on the number of class periods that they devoted to specific topics and subtopics and on how they presented and interpreted this mathematical content to their classes.

The *attained* curriculum is what students have learned as measured by tests and questionnaires. Extensive achievement tests were designed to assess student knowledge and skills in areas of mathematics designated as important and appropriate for the students being tested. The fit between these tests and the actual curricula in individual countries varied considerably. The tests contained items that were less appropriate in some countries than in others. In addition, the tests could not possibly contain an adequate range of items to fully represent all curricula in all countries.

The student outcome measures also included a number of opinion surveys and attitude scales. These were devised to elicit student views on the nature, importance, ease, and appeal of mathematics in general and of selected mathematical processes.

Questionnaires on background information were designed for schools, teachers, and students for two target populations of students (Figures 1 & 2). Item sampling was utilized in order to provide for sufficient content coverage.

The two populations studied were (1) Population A—All students in the grade in which the majority of students have attained the age of 13 by the middle of the school year (this group was taken to be the eighth grade in the United States); and (2) Population B—All students who are in the normally accepted terminal grade of secondary school *and* who are studying mathematics as a substantial part (approximately five hours per week) of their academic programs.

In the United States, Population B was defined as those students who were in college preparatory mathematics courses that required as prerequisites at least two years of high school algebra and one year of high school geometry. Although such students were typically in the twelfth grade, the definition did allow inclusion in the target group of those in the eleventh grade (and lower) who had moved through the standard sequence of courses more quickly than usual.

EIGHTH GRADE FINDINGS

Intended Curriculum

From an international perspective, the eighth grade mathematics curriculum in the United States looks more like a program of studies for the end of elementary school than for the beginning of high school. The

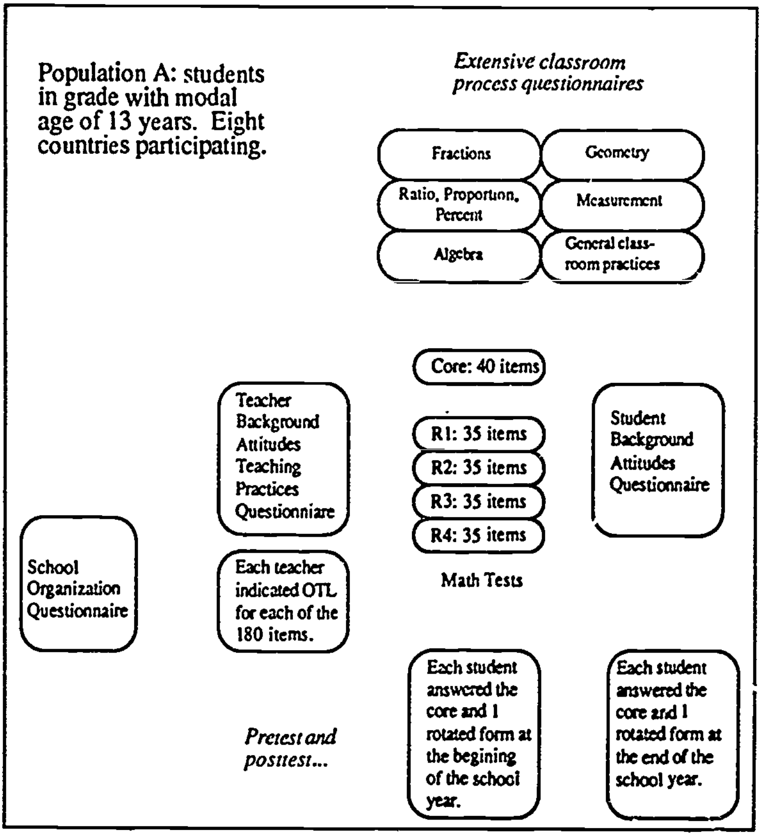

Figure 1 Survey instrumentation for the longitudinal, classroom process study in Population A

Note: Reprinted, by permission of the author, from R. G. Wolfe, *The IEA Second International Mathematics Study: Overview and Selected Findings,* 1986.

usual curriculum is dominated by arithmetic and measurement rather than devoted to such topics as algebra, geometry, and probability.

A supplementary measure of the intended curriculum was provided by the teachers, who indicated how much time during the school year they expected to allocate to various mathematics topics. Figure 3 reports these data for five countries. For example, in Japan algebra is emphasized in the curriculum for Population A. (It should be noted that in Japan, Population A consisted of twelve-year-olds, who were a year younger than the target population in most other countries.) In France and Belgium, the focus is on geometry and common fractions. In the United States, however, there is a less clear focus. While fractions and

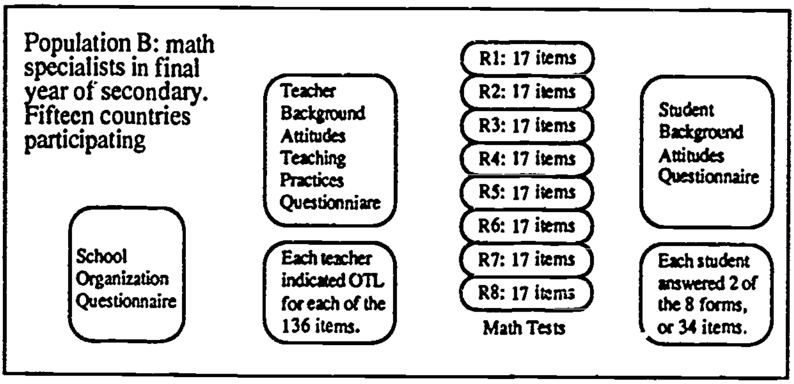

Figure 2 Survey instrumentation for cross-sectional study, Population B
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algebra receive some attention, so do ratio, proportion, and percent; measurement; and geometry. Furthermore, other data indicate that in the United States many of these topics are dealt with repeatedly over several grade levels. In sum, the U.S. curriculum can be characterized as being of "low intensity" in contrast to the focused, more demanding curricula of several other advanced, industrialized countries.

Implemented Curriculum

One dramatic finding of the study was that there is not *an* eighth grade mathematics curriculum in the United States. In a national sample of 236 classes, four distinct curricular patterns were identified based on textbooks used as well as teacher reports of the nature of the class. These curricular patterns were remedial (24 classes), typical (155 classes), enriched (26 classes), and algebra (31 classes).

For each of the 180 items on the achievement test, teachers were asked to indicate whether the content needed to correctly respond to the item was taught during the eighth grade, was taught in a previous year, or was not taught at all. Table 1 presents the content coverage during eighth grade for five topics and four class types.

Notice that typical and enriched classes covered a large portion of the content in most areas. Enriched classes covered more than did typical classes in algebra, geometry, and measurement. Remedial classes emphasized arithmetic and covered less algebra and geometry. The algebra classes covered a considerable amount of algebra (actually more than was on the test), but they covered little else. No class covered much of the geometry that was on the international test, which included transfor-

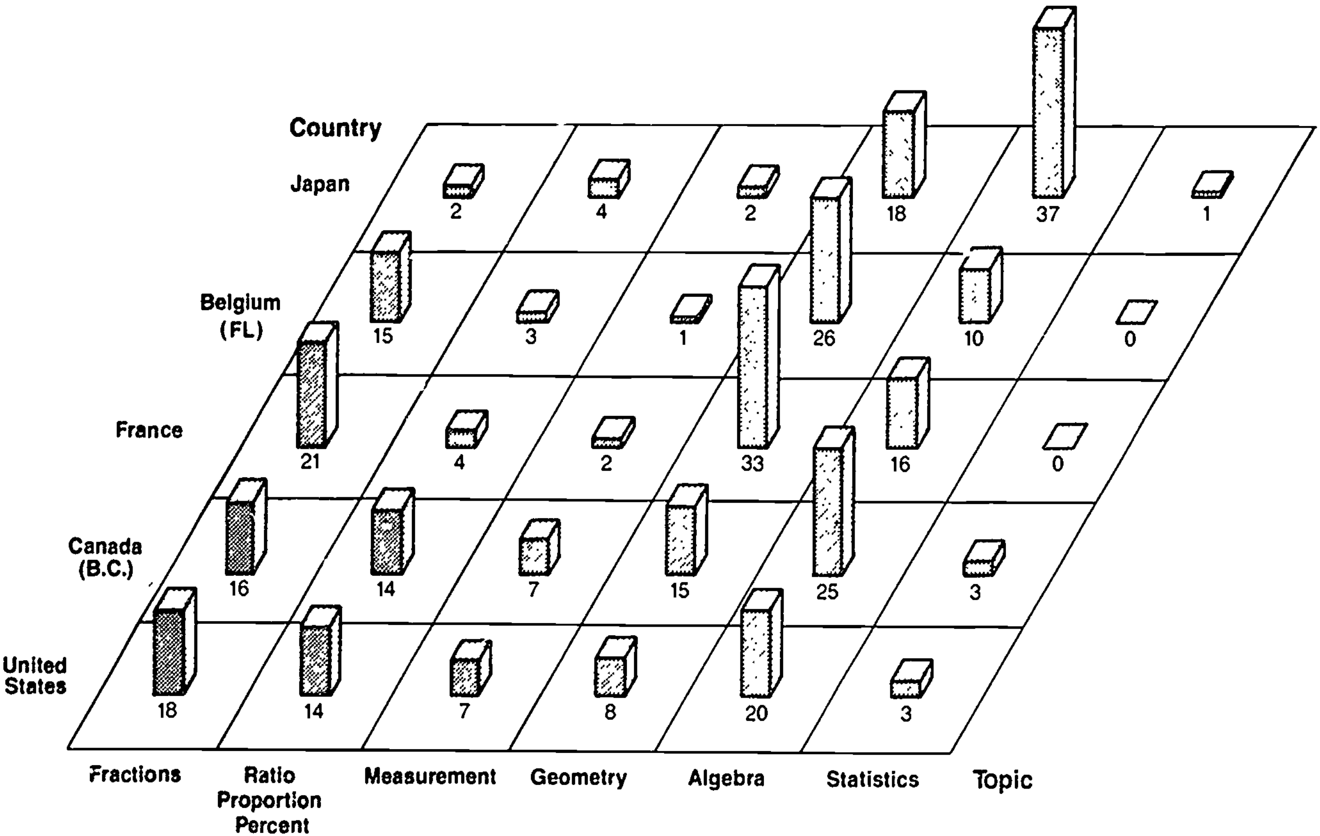


Figure 3 Intensity of instruction for five Population A countries

Table 1. Percent of items taught during eighth grade[1]

Content area	N[2]	Class type			
		Remedial	Typical	Enriched	Algebra
Arithmetic	62	76	80	84	42
Algebra	32	37	64	80	86
Geometry	42	25	41	54	24
Measurement	26	53	64	75	20
Statistics	18	48	58	59	15
Overall	180	51	64	72	40

[1]The data in this table represent the opportunity to learn these subjects during the eighth grade and do not include mathematics taught before the eighth grade.
[2]N = number of items in each content area

mational geometry (not usually taught in the United States) and spatial visualization.

An equally dramatic finding was the great variation in coverage of these topics. Figure 4 shows box-and-whisker plots of the opportunity to learn mathematics through eighth grade for each of the four class types

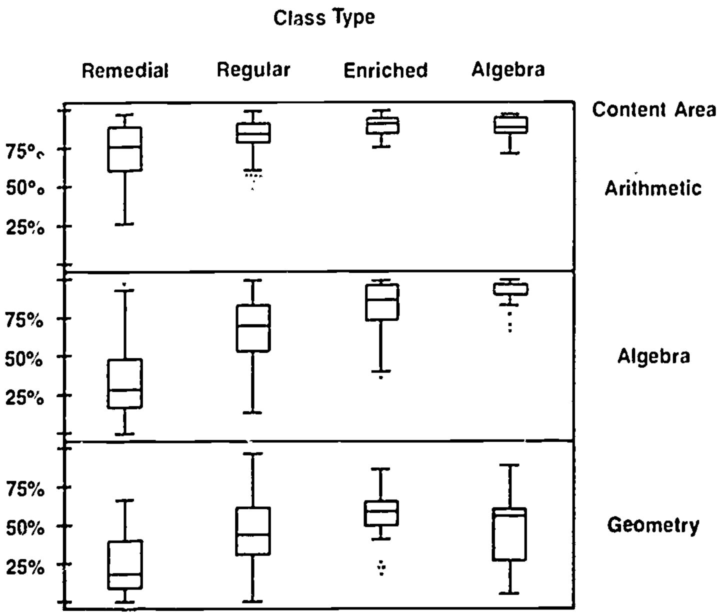


Figure 4 Opportunity to learn mathematics: Class type by content area (eighth grade, United States)[1]

[1]Includes mathematics taught up to and during the eighth grade

for arithmetic, algebra, and geometry. The box encompasses the middle 50 percent of the classes that were taught a given proportion of the items on the international test. For example, the remedial classes were reported to have been taught between 60 percent and 85 percent of the arithmetic on the test. The line across the middle of the box shows the median score. The whiskers encompass the middle 90 percent range of coverage.

Remedial classes received very little instruction in Algebra, with median coverage of about 25 percent. The range of coverage is from 0 percent to about 90 percent. Notice also that while the algebra classes received high coverage in algebra, they had been taught only about 50 percent of the geometry on the international test by the end of grade eight. A comparison of the curricular coverage of arithmetic and algebra through grade seven in Japan and through grade eight in the United States is shown in the box-and-whisker plots in Figure 5.

The opportunity-to-learn data reveal two aspects regarding the lack of intensity of the eighth grade mathematics curriculum in this country. There is an overall lack of topical emphasis, in arithmetic, algebra, and so on. In addition, within these topics there is enormous between-classroom variation of coverage that reflects marked inequalities of opportunities for students across the United States to learn substantial mathematical content.

Attained Curriculum

Table 2 presents a summary of mean U.S. eighth grade achievement scores for each of the five content areas—arithmetic, algebra, geometry, statistics, and measurement. Separate scores are given for the pretest and post-test.

The OTL (opportunity-to-learn) column lists the average rating by teachers of the percent of content that had been taught either before or

Table 2. National estimates of mean scores in eighth grade classes

		Mean scores			
Content area	N[1]	OTL[2] (%)	Pretest (%)	Post-test (%)	Gain (%)
Arithmetic	62	87	42	51	+ 9
Algebra	32	69	32	43	+11
Geometry	42	44	31	38	+ 7
Measurement	26	70	35	42	+ 7
Statistics	18	73	53	57	+ 4

[1]N = number of items in each content area

[2]OTL = opportunity to learn

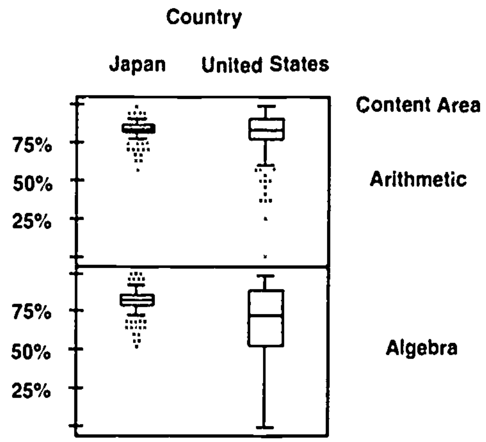


Figure 5 Opportunity to learn arithmetic and algebra in the United States (eighth grade) and Japan (seventh grade)

during the year. OTL data give some indication of how well the tests matched the U.S. curriculum and represent a sort of "ceiling" on how well U.S. students might be expected to do. Notice that geometry has the lowest OTL score.

Table 3 compares mean end-of-year achievement for the U.S. eighth grade sample with the 25th percentile, median, and 75th percentile scores of all participating countries combined. In algebra, arithmetic, and statistics, the U.S. students performed at about the international median. In geometry and measurement, the U.S. eighth graders performed at about the 25th percentile. In no case was the U.S. performance above the international median.

Figure 6 shows a plot of achievement in algebra versus an opportunity to learn algebra in all countries for which both measures were avail-

Table 3. International comparisons of eighth grade achievement

		U.S.	International		
Content area	N[1]	Mean (% correct)	25th %ile	Median (% correct)	75th %ile
Arithmetic	62	51	45	51	57
Algebra	32	43	39	43	50
Geometry	42	38	38	43	45
Measurement	26	42	47	51	58
Statistics	18	57	52	57	60

[1]N = number of items in each content area

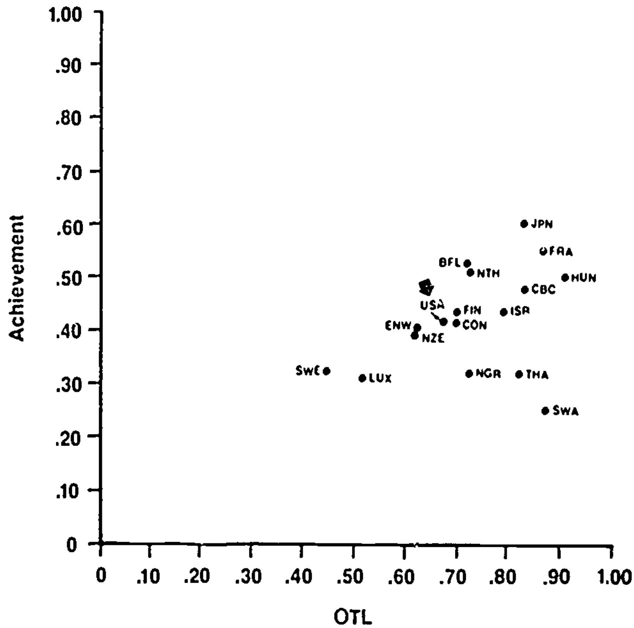


Figure 6 **Achievement vs. opportunity to learn (OTL) for algebra: Population A**

able. (Hong Kong, French Belgium, and Scotland did not collect opportunity-to-learn data.) Notice that the high algebra achievement for Japan is accompanied by an opportunity-to-learn score that is among the highest of all countries. This is characteristic of Japan for all topic areas and both populations. That is, Japan is always among the highest achieving countries (if not the highest) and is among the highest in terms of opportunity to learn each topic as well. At the other end of the spectrum, note that low achievement in algebra (for example, in Sweden or Luxembourg) is accompanied by low opportunity-to-learn ratings. For the United States, achievement in algebra, which is close to the international mean, is accompanied by an opportunity-to learn rating that is close to the international median.

Another portrayal of the relationship between opportunity to learn and achievement in the United States is shown in Figure 7. The existence of four dramatically different mathematics curricula in the eighth grade has already been noted. Now the corresponding achievement scores for these class types are shown, with the added information of pretest scores from the beginning of the eighth grade and end-of-year achievement

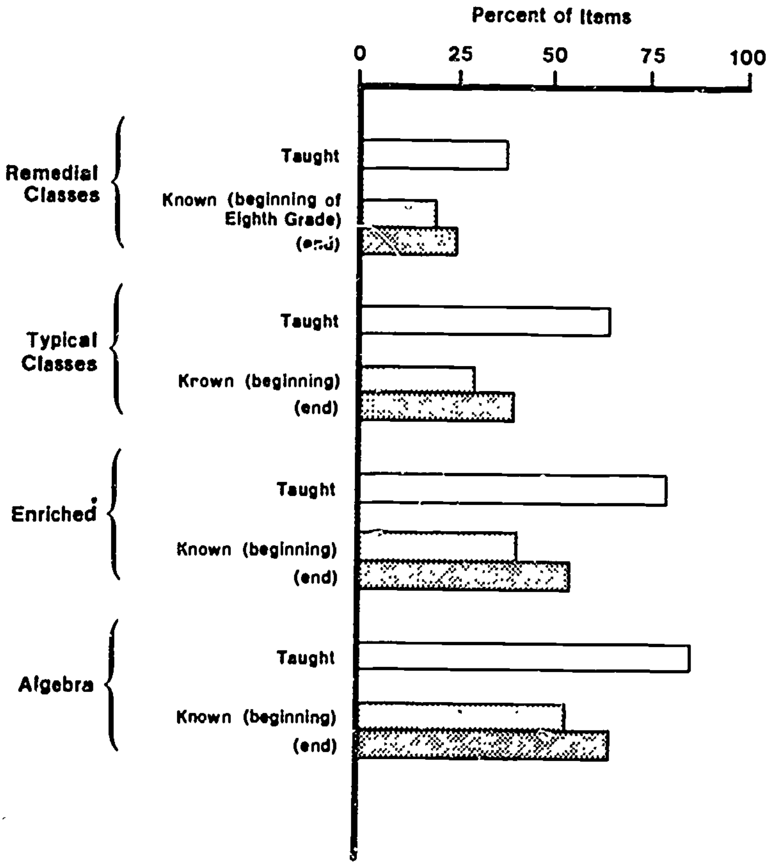


Figure 7 Algebra achievement of eighth grade students by class type (United States)

scores. Notice that for the remedial classes, beginning-of-the-year achievement in algebra is close to 20 percent. (Since a multiple choice test with five options was used, the students appear to be merely guessing!) Note also that by the end of the eighth grade, the remedial classes have not yet reached the level of achievement the typical classes had at the *beginning* of the eighth grade, and so on for the enriched and algebra classes. These vastly different achievement levels for incoming freshmen raise serious questions about the efficacy of pre-high school programs, not to mention the degree to which these differences are effectively accommodated by high schools once the students arrive.

Item-Level Data

Figures 8–10 show growth data on selected arithmetic and algebra items. The arithmetic item (Figure 8) deals with addition of common fractions and is noteworthy since this topic area receives intense coverage in France. Information on the French curriculum indicates that a consideration of common fractions is deferred until a thorough job is done of developing the number system from the point of view of whole numbers and decimal fractions. This contrasts to the U.S. curriculum, where common fractions are typically dealt with before decimal fractions.

In algebra, little work is done in Japan prior to the seventh grade. However, during that year, coverage is very intense. The corresponding growth on these items, as seen in Figures 9 and 10, reflects the contrast-

Item 003

2/5 + 3/8 is equal to

A 5/13

B 5/40

C 6/40

D 16/15

E 31/40

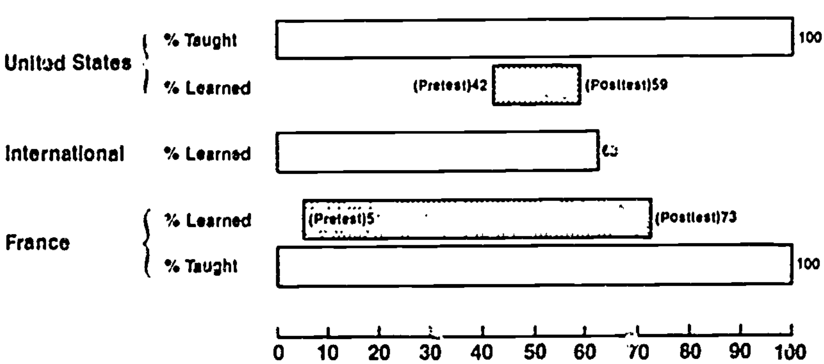


Figure 8 Opportunity to learn and achievement for a selected arithmetic item: Population A (eighth grade in United States and France)

Item 113

$(-6) - (-8)$ is equal to

A 14

B 2

C −2

D −10

E −14

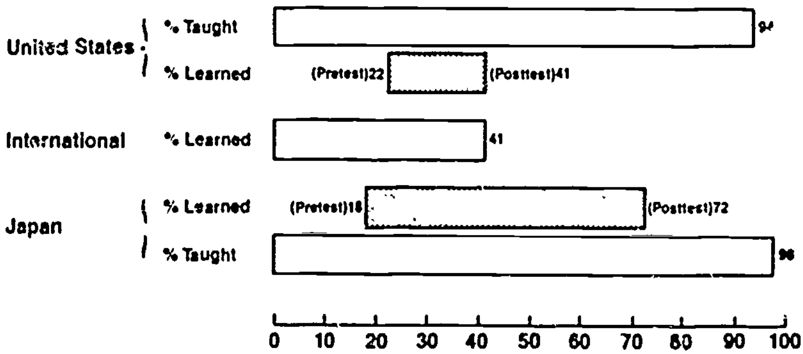


Figure 9 Opportunity to learn and achievement for a selected algebra item: Population A (seventh grade in Japan; eighth grade in United States)

ing curricular emphases. Similar patterns are found for other items and on overall growth in algebra achievement in the United States and Japan.

TWELFTH GRADE FINDINGS

Intended Curriculum

System Retentivity. It was clearly demonstrated in the First International Mathematics Study that the retentivity of a school system was an important factor in explaining school achievement. For example, more selective systems tend to have higher achieving mathematics students than less selective systems. Therefore, detailed information was obtained from each country concerning the proportions of students remaining in school through the final year and proportions of those students who are studying college preparatory mathematics. In the United States, it was found that 82 percent of seventeen-year-olds remain in school. Of this group, it was estimated that about 15 percent were enrolled in college

Item 015

Simplify: $5x + 3y + 2x - 4y$

A $7x + 7y$

B $8x - 2y$

C $6xy$

D $7x - y$

E $7x + y$

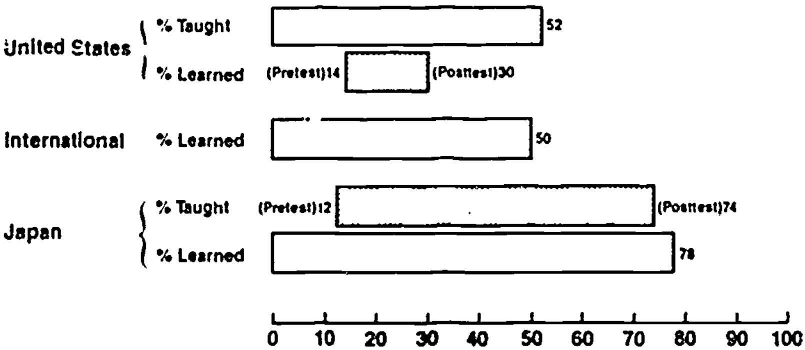


Figure 10 **Opportunity to learn and achievement for a selected algebra item: Population A (seventh grade in Japan; eighth grade in United States)**

preparatory mathematics classes. In some countries—for example, England and New Zealand—the system is very selective, retaining less than 20 percent of the age group in school. Japan, on the other hand, retains a large proportion of students, with a retentivity rate of over 90 percent. The United States is about average among the countries in terms of the proportion of students taking the most advanced college preparatory mathematics available in the school.

Types of Programs. The great diversity in the twelfth grade mathematics curricula in the United States was reflected in the Second International Mathematics Study. For example, there are Advanced Placement Calculus classes in which full-fledged, college-level calculus is taught. There are also "senior mathematics" courses classified as "precalculus" that include items in elementary functions, trigonometry, and probability and statistics. Certain of these precalculus courses do, in fact, deal with some calculus, but they fall short of university-level study in the subject.

Role of the Textbook. The textbook was found to define course boundaries for mathematics subjects taught by teachers. Limited use was made of resources beyond the textbook for either content or teaching methods. This finding points to the importance of the textbook (and of the textbook publishers) in determining the content of the curriculum, as well as methods to be used in teaching that content.

Implemented Curriculum

Table 4 shows the content that teachers reported had been covered either during the twelfth grade or earlier. Note that teachers estimate that the precalculus classes have covered about the same amount of content as the calculus classes in the first four content areas. In the remaining areas, the calculus classes were taught substantially more content, particularly functions and calculus.

The teachers noted that most of the emphasis in teaching analytic geometry was placed on developing students' two-dimensional skills, especially in conic sections and curve sketching. Very little, if any, work was done on solid analytic geometry. In teaching trigonometry, little time was devoted to inverse functions, their graphs, or the relationships involved. The same pattern of relative neglect holds for trigonometric relationships involving representations of complex numbers or the use of polar coordinates.

Table 4. Percent of items taught in twelfth grade classes

Content area	N[1]	Precalculus		Calculus	
		Taught before	Taught this year	Taught before	Taught this year
Sets and relations	7	31	50	50	40
Number systems	17	39	42	75	14
Algebra	26	34	52	53	41
Geometry	26	21	40	41	26
Elementary functions and calculus	46	8	37	9	83
Probability and statistics	7	29	14	50	6
Finite mathematics	4	29	21	62	8

[1]N = number of items in each content area

Attained Curriculum

Table 5 shows average achievement scores for U.S. students in precalculus and calculus classes. The table also gives international averages and quartiles for the fifteen countries that were in the study at the senior secondary level.

The scores for the precalculus classes were lower than expected by U.S. investigators and low by international standards as well. Notice, for example, that on algebra, the U.S. students scored 43 while the international median was 57. The international first quartile for algebra was 47. In other words, one-half of the international students in the study obtained a score of 57 or less and the lowest one-fourth of these students obtained a score of 47 or less. The U.S. score of 40 for the precalculus students is very low indeed. On the other hand, notice that U.S. students in the calculus classes obtained a score of 57 (the international average) on the algebra portion of the international test.

Figure 11 plots achievement and opportunity-to-learn data for the functions and calculus portion of the international test for Population B. The characteristic pattern noted for Population A is found here as

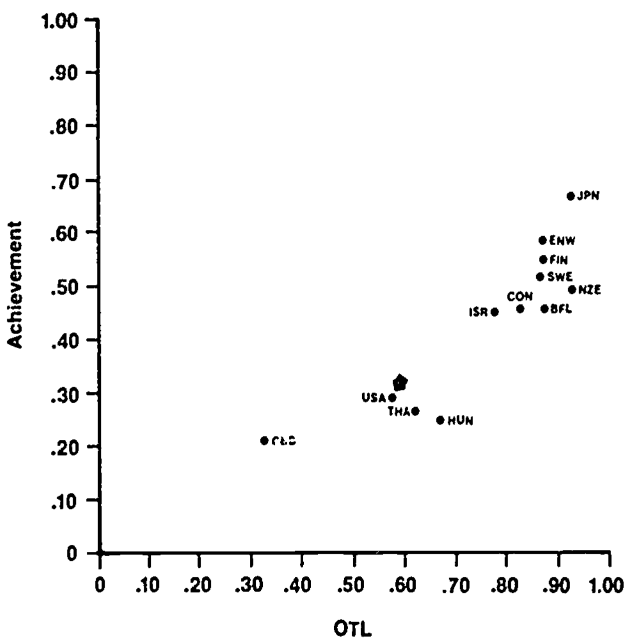


Figure 11 **Opportunity to learn vs. student achievement for functions and calculus: Population B**

Table 5. Average achievement for U.S. classes and for classes in fifteen countries,[1] twelfth grade, 1981–82

Content area	N[2]	United States: Precalculus (% correct)	United States: Calculus (% correct)	United States: Total (% correct)	International: 25th %ile	International: Median	International: 75th %ile
Sets and relations	7	54	64	56	51	61	72
Number systems	17	38	48	40	40	47	59
Algebra	26	40	57	43	47	57	66
Geometry	26	30	38	31	33	42	49
Elementary functions and calculus	46	25	49	29	28	46	55
Probability and statistics	7	39	48	40	38	46	64

[1]The countries included in addition to the United States are Flemish Belgium, French Belgium, Canada (British Columbia and Ontario), England and Wales, Finland, Hong Kong, Hungary, Israel, Japan, New Zealand, Scotland, Sweden, and Thailand.

[2]N = number of items in each content area

well. High achievement for Japan is accompanied by a high opportunity to learn. (In fact, Hong Kong had slightly higher achievement on this content area but did not collect opportunity-to-learn data.) The low achievement for British Columbia is explained by its low opportunity-to-learn score. (Calculus is not included in the province's twelfth grade program.) The United States' low international standing in achievement on this topic is also accompanied by a relatively low opportunity to learn. The fact that only a small fraction of Population B students in the United States take a full-fledged calculus course helps account for low teacher coverage of functions and calculus.

Item-Level Data

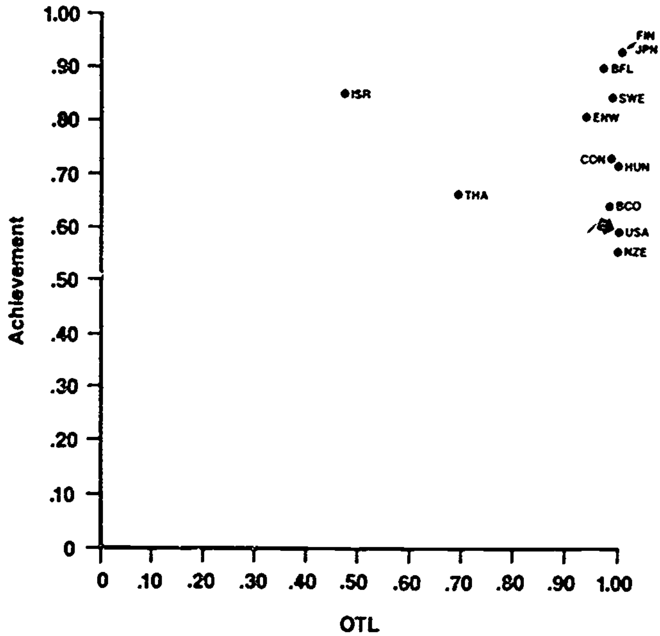
Figures 12 and 13 plot achievement and opportunity-to-learn data for a calculus item and a basic algebra item. For the calculus item, the low performance of U.S. students can again be accounted for by a low opportunity to learn. However. the nearly bottom-rung standing for the algebra item is *not* explained so readily. As expected, reported teacher coverage is very high for the United States, as it is for most countries. Unfortunately, the sort of performance shown here for the United States is the norm, rather than atypical.

Yield

Yield may be defined in the context of this study as what proportion of students has learned how much mathematics. From an international perspective, U.S. yield in mathematics is low. In Figures 14 and 15, data on the intended, implemented, and attained curriculum are presented for five countries: Canada (British Columbia), Japan, England and Wales, Sweden, and the United States. The height of each bar graph is an index of the content of the curriculum as intended, implemented, and attained. The width of the bar reflects the retentivity of the school system for the country. Therefore, the area of each bar may be thought of as a yield measure for the respective country.

Figures 14 and 15 first indicate a generally negative association of retentivity with achievement. That is, less retentive, more selective systems tend to have high achievement scores. The notable exception is Japan, which has high achievement even though retentivity in Population B mathematics is comparable to that for Sweden and the United States.

The portrait of twelfth grade mathematics students in the United States is one of diversity. The students in Advanced Placement Calculus classes are achieving at about the international average. However, these students represent only a small proportion (about two to three percent) of seventeen-year-olds. This select group of students, the "cream of the



002 For all rational numbers *a*, *b*, *c*, and *d*, $a - (b + (c - d))$ is equal to

A $a - b + c - d$

B $a - b - c + d$

C $a - b - c - d$

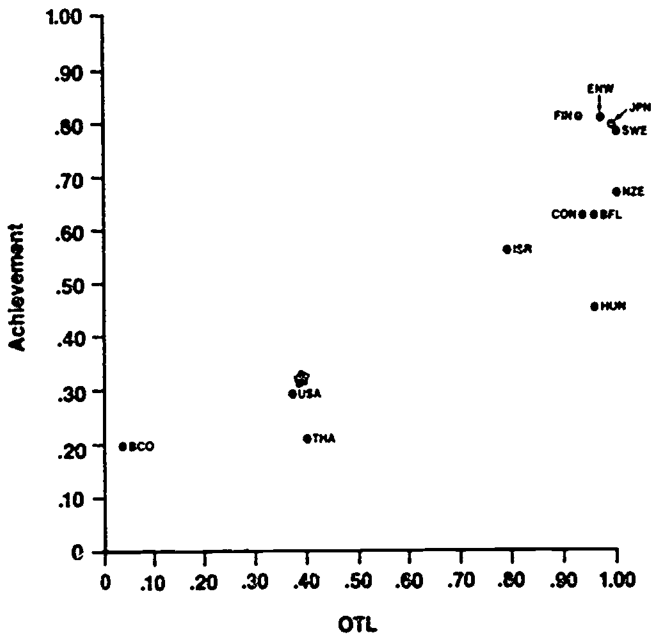
D $a - b + c + d$

E None of these

Figure 12 Opportunity to learn vs. student achievement for integration: Population B

crop," could reasonably be expected to do better on the items on the international test than they did, especially for those items that are clearly a part of their curriculum.

The precalculus classes are another story. This group, the majority of twelfth grade, college preparatory, mathematics students, looks very weak internationally, often scoring among the lowest one-fourth of the countries. These students, on average, know less mathematics at the *end* of twelfth grade than do students in the calculus classes at the *beginning*



103 $\int_1^2 (x^3 - x)\,dx$ is equal to

A 1-3/4

B 2

C 2-1/4

D 3

E 6

Figure 13 Opportunity to learn vs. student achievement for number systems: Population B

of twelfth grade. Clearly, the majority of our twelfth grade mathematics students achieving at a level that may not enable them to succeed in college-level mathematics courses.

POLICY IMPLICATIONS

Certain policy implications for U.S. mathematics education may be drawn from the Second International Mathematics Study.

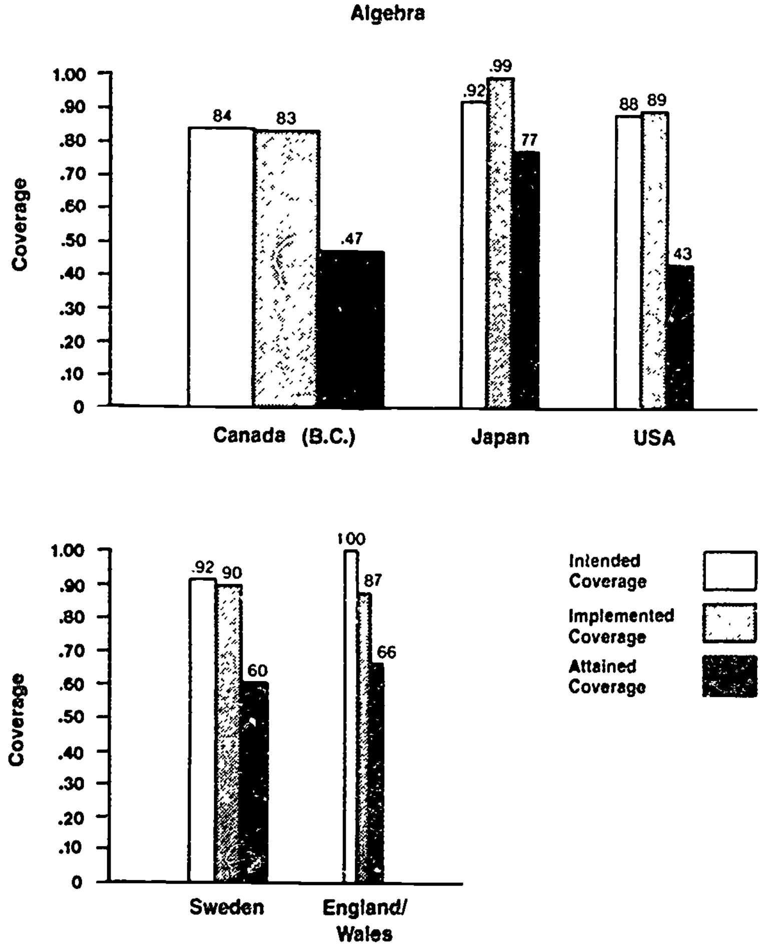


Figure 14 **Intended, implemented, and attained coverage in algebra for five countries: Population B**
Width of bar graph reflects Population B retentivity

Primacy of the Curriculum

SIMS has demonstrated that the content of the intended curriculum for a given target population to a large extent determines what it is that teachers teach. That is to say, teachers in the SIMS countries tended to teach what was in the stated curriculum and did not teach what was not in the curriculum.

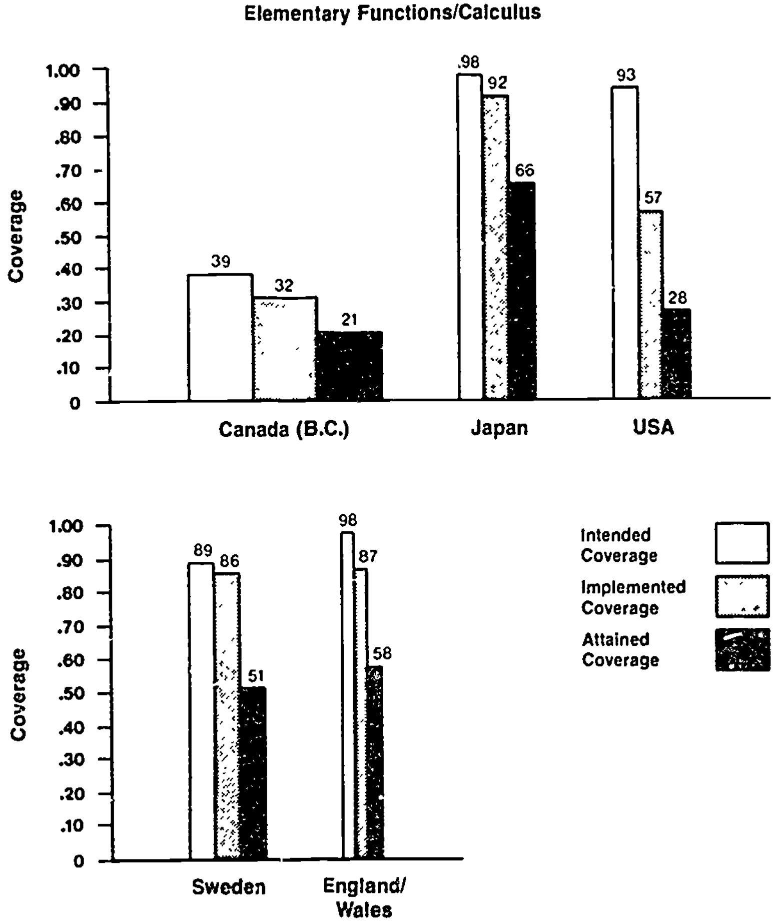


Figure 15 Intended, implemented, and attained coverage in elementary functions/calculus for five countries: Population B
Width of bar graph reflects Population B retentivity

For most IEA countries, determining the content of the intended curriculum was a rather routine matter, since such information is contained in ministry curriculum guides. For the United States, no such national guidelines exist. However, teacher dependency on published textbooks for both what to teach and how to teach it is well known. In SIMS, it was found that the textbook was the primary instructional resource for over 90 percent of teachers at both the eighth and twelfth grade levels.

A content analysis of textbooks revealed that they define boundaries for the content of instruction. That is, while not all content in the book is taught by the teacher, the teacher does not typically go beyond the textbook for content.

Implication: The role of textbooks as de facto curriculum guides deserves renewed attention. Textbook publishers are critically important agents in any consideration of curriculum reform.

While a national curriculum is not seen as viable, or necessarily desirable, the feasibility should be explored of establishing *national criteria* for attainment in mathematics at each grade level.

Curricular Intensity

Curricular intensity relates closely to the primacy of the curriculum. Cross-nationally, it has been shown that for the SIMS target populations, characteristic curricula can be identified for many nations. For Population A in France and Belgium, the emphasis is on geometry. In Japan, twelve-year-olds in Population A (seventh graders) receive intense coverage of algebra. Corresponding dramatic growth in student achievement during the school year is found in those countries where algebra is emphasized.

By contrast, no such emphasis or intensity is in evidence in the United States except for the algebra classes. Instead, the curriculum is characterized by a repetition of content from earlier grades. Consequently, for most students at the Population A level, the curriculum takes on much more the appearance of an elementary school program dominated by arithmetic than a program that prepares students for the study of high school topics such as geometry, algebra, and statistics. This propensity to prolong the study of arithmetic beyond the elementary grades reflects a perceived need to continue instruction in the subject until higher levels of mastery are obtained.

Implication: A restructuring of the curriculum in the United States is called for so that a clear focus is evident at each grade level. This restructuring will entail a reconsideration of the efficacy of spiralling topics (i.e., the continual revisiting of the same topics at each grade level), which tends to dominate the U.S. approach. The nature of the subject matter to be studied and when it is to be studied must take into account many factors, such as learning styles, the role played by mathematics in other parts of the curriculum, societal needs, expectations of post-secondary institutions, and so forth. The potential of computer technology for promoting instructional and curricular goals is also of critical importance.

Curricular Differentiation

In contrast with many other countries, the United States does not have *one* mathematics curriculum at the Population A level (eighth grade) but several, each with rather different curricular content. Four such class types were identified—algebra, enriched, typical, and remedial. Students in the algebra classes cover a regular first-year high school course in algebra. Typical and enriched classes deal with arithmetic, measurement, and some algebra and statistics. Little geometry is included. The enriched classes tend to cover more algebra than the typical classes. Remedial classes are offered a curriculum that is predominantly arithmetic.

Student achievement in the four class types reflects the differences in the curriculum that they are offered. The remedial classes know virtually no algebra at the beginning of the eighth grade and show little growth during the year. The typical classes begin the year with a slightly greater knowledge of algebra than that exhibited by the remedial classes at the *end* of eighth grade and show more growth than do the remedial classes. The enriched classes begin the year in achievement where the typical classes left off and again show growth. The algebra classes begin where the enriched classes left off and demonstrate considerable growth during the school year.

Implication: The practice of sorting eighth grade students into tracks that lead to vastly different goals in high school should be carefully examined. Significant proportions of students who are only twelve or thirteen years of age are being assigned to mathematics classes that offer relatively little opportunity to learn the content needed for success in high school mathematics.

Yield (Twelfth Grade)

The yield of an educational system may be described in terms of how many students are taken how far. With respect to *delivery of instruction,* yield may be thought of in terms of how many students have the opportunity to learn how much mathematics. On both of these indices of yield, the United States is low. Even though the U.S. system has relatively high retention (about 82 percent of students remain in school through the end of the twelfth grade), the proportion of students in advanced mathematics is only 15 percent. Only a small fraction (about 3 percent of the grade cohort) pursues a full course of calculus. By comparison, 92 percent of Japanese youth remain in school, and all students in the advanced mathematics classes (about 14 percent of the grade cohort) study calculus.

Implication: A study should be made of factors leading to low enrollments in advanced mathematics courses in the United States. A major contributor would be expected to be the dramatic curricular differentiation in earlier grades. A related factor to be examined would be student attitudes. National Assessment of Educational Progress data show that nine-year-olds list mathematics as their favorite subject. For thirteen-year-olds, it is the second most-liked subject. For seventeen-year-olds, mathematics is the least-liked subject.

The Co-primacy of Teaching (Opportunity to Learn)

As in previous IEA studies, opportunity to learn has proved to be a powerful variable for accounting for between-country variation in student achievement. In Japan, high teacher coverage of topics (high opportunity to learn) is accompanied by correspondingly high student achievement. In the United States, where teacher coverage is low, student achievement tends to be low.

Within-country variation of teacher coverage was also examined. As expected, the centralization that characterizes the Japanese education was accompanied by relatively low variation in opportunity to learn. That is, Japanese children have relatively equal opportunities to learn the considerable mathematics topics that are available to them at their grade level. Very high within country variation in opportunity to learn was found in the United States. That is to say, the decentralized nature of education in the United States appears to have resulted in missed opportunities for many eighth graders to learn a core content of mathematics.

Implication: SIMS data suggest that U.S. achievement can be enhanced by increasing the opportunity to learn. Such increments could be realized by upgrading the content of the curriculum and textbooks, specifying national standards for achievement at each grade level, and reducing or eliminating curricular differentiation, especially at the lower levels of secondary school.

REFLECTIONS ON SIMS

Importance of U.S. Participation

Taking part in an IEA study requires a significant commitment of time and financial resources. Historically, U.S. participation in such studies has been extremely important for two main reasons. First, U.S. researchers have played key roles in the planning and development of many IEA studies. Second, U.S. funding has often provided the critical support needed to carry out the international aspects of IEA studies. Hence, U.S. policy with respect to participation in IEA studies has significant implications not only for this country but for all participant nations. It is important that U.S. policy with respect to participation in IEA studies be clarified. To this end, a U.S. center should be established for coordinating international studies in education.

Funding

Funding for SIMS from 1976 to 1979 can be generously characterized as spotty. At several junctures, plans had to be reworked and staff laid off because of the uncertainty of sufficient funds to proceed with the study. Indeed, for several years, it was not at all clear whether the United States would even participate. It is strongly recommended that future studies not be undertaken until sufficient funds for the entire project are secured.

Sampling

The reponse rate for SIMS participation was low at the district and school levels. It is not at all clear how this low response affected the data. Examination of marker variable data has not produced evidence of marked bias in the sample.

Cooperation in an IEA study was a more serious problem in the United States than in any other country (Garden, 1987). This is due primarily to the decentralized system of education in the United States. With a recognized and authoritative national center for carrying out IEA studies and ample provision for planning and for field work (similar to that for the National Assessment of Educational Progress), it is likely that cooperation for future international studies could be greatly improved.

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Wolfe, R. G. (1986, April). *The IEA Second International Mathematics Study: Overview and selected findings.* Paper presented at the annual meeting of the American Educational Research Association, San Francisco.

Appendix I. IEA's Mathematics Project Council

Roy W. Phillipps, Chairman
New Zealand Department of Education
Robert Garden, International Project Coordinator
New Zealand Department of Education
Kenneth J. Travers
Chairman, International Mathematics Committee (IMC)
(The IMC designed the Second International Mathematics Study and developed the international instruments.)

Other members of the council include the following:
Sven Hilding, Sweden
Edward Kifer, United States
Gerard Pollock, Scotland
Tamas Varga, Hungary
James Wilson, United States
A. I. Weinzweig, United States,
Consulting Mathematician
Richard Wolfe, Canada
Consulting Psychometrician

Appendix II. SIMS Committees

National Mathematics Committee

James Fey, University of Maryland (Chairman)
Joe Crosswhite, The Ohio State University
John A. Dossey, Illinois State University
Floyd Downs, Hillsdale High School, San Mateo, California
Edward Kifer, University of Kentucky
Curtis C. McKnight, University of Oklahoma (National Research Coordinator)
Jane Swafford, Northern Michigan University
Kenneth J. Travers, University of Illinois at Urbana-Champaign
A. I. Weinzweig, University of Illinois at Chicago
James Wilson, University of Georgia
Richard Wolf, Teachers College, Columbia University

National Technical Advisory Panel

Edward Kifer, University of Kentucky (Chairman)
Leigh Burstein, University of California-Los Angeles
Robert Linn, University of Illinois at Urbana-Champaign
William Schmidt, Michigan State University
Jack Schwille, Michigan State University
Richard Wolf, Teachers College, Columbia University
Richard Wolfe, Ontario Institute for Studies in Education

Appendix III. United States Reports

United States Summary Report: Second International Mathematics Study. Champaign, IL: Stipes Publishing Company, 1985

Technical Report I, Item Level Achievement and OTL Data, May 1985

Technical Report II, Questionnaire Data for Schools, Teachers and Students, (November 1985)

Technical Report III, Classroom Processes Data (November 1985)

Technical Report IV, Instrument Book, Achievement Tests and Background Questionnaire (December 1985)

Technical Report V, Instrument Book, Classroom Process Questionnaires (December 1985)

Detailed National Report (August 1986)

The Underachieving Curriculum: Assessing U.S. School Mathematics from an International Perspective (January 1987).

Classroom Processes in School Mathematics:
Volume I: Eighth Grade
Volume II: Advanced Mathematics

(Monographs of the *Journal for Research in Mathematics Education,* National Council of Teachers of Mathematics, to appear Spring 1987)

(Note: The last two reports are funded by current grants from the National Science Foundation.)

Appendix IV. Articles

1. Travers, Kenneth J. and Curtis C. McKnight, "Mathematics Achievement in U.S. Schools: Preliminary Findings From the Second IEA Mathematics Study," *Phi Delta Kappan,* February 1985, pp. 407–413.
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Chapter 8

THE CURRENT STATUS OF SCIENCE CURRICULA
Insights From the Second International Science Study

Willard J. Jacobson

As an integral part of the Second International Science Study conducted by the International Association for the Evaluation of Educational Achievement (IEA), all of the countries engaged in the study undertook an investigation of science curricula in their countries. These science curriculum studies served as the base for the design of the instruments used in the study of science achievement. The curriculum studies focused on the intended curriculum. Later phases of the study dealt with the implemented curriculum and the achieved curriculum (Miller, 1986).

As a part of this international effort, an analytical and empirical study of science curricula was carried out in the United States (Miller, 1985). This study was of science curricula for kindergarten through the twelfth grade. Special attention was given to the science curricula for the following four populations of students: (1) Population 1—fifth graders, (2) Population 2—ninth graders; (3) Population 3P—twelfth graders taking physics; and (4) Population 3N—twelfth graders not studying science.

WHAT WAS STUDIED AND HOW

The science curriculum study in the United States was based on an international grid and an analysis of science curriculum materials. Rating forms were developed for determining how much a science subject was emphasized.

International Grid

An international grid—an overall outline of science programs on the science curriculum studies carried out for the IEA's First International Science Study (FISS) and additional studies—was provided to each of the countries by the IEA's international coordinator.

Analysis of Science Curriculum Materials

Most teachers rely on the textbook as a major instructional resource. Iris Weiss (1978) made an analysis of the most widely used science texts. The relative emphasis of topics studied was determined using the following formula:

$$\frac{\text{pages devoted to topic}}{\text{pages of subject matter in book}} \times 100 = \text{percentage emphasis}$$

Topics that had less than three percent relative emphasis or were mentioned in only twenty percent or fewer of the texts were dropped from the roster.

In addition, the contents of science instructional material developed by science curriculum development projects supported by the National Science Foundation were analyzed in the same way as textbooks. Also, all available courses of science study for states and large cities were analyzed.

Draft national curricula were developed and submitted to the IEA's U.S. National Committee for criticism and suggestions. This draft curriculum consisted of the following three objectives:

1. Obtaining traditional science knowledge through the study of biology, chemistry, earth science, and physics.
2. Obtaining knowledge in applied or integrated science topics such as environmental science and energy.
3. Learning science processes and attitudes by developing inquiry skills through the definition of science problems and application of science knowledge.

Empirical Survey

Seventeen rating forms were developed from the international grid and the analyses of science curriculum materials. Each of the items on the rating forms was rated using the system shown in Figure 1.

The ratings included both emphasis, or amount of time devoted to

Figure 1 Determining universality and emphasis of curricula topics (per school year)

Universality		Major emphasis	Minor emphasis	Nil emphasis
	Pop. 1	more than 1 hr	less than 1 hr	nil
	Pop. 2/3	more than 3 hrs	less than 3 hrs	nil
All or most students (75%–100%)		3	2	0
Some students (25%–75%)		2	1	0
Very few or no students (0–25%)		0	0	0

a topic, and universality, or percentage of students who studied a topic. It should be noted that the highest possible rating was 3 and the lowest 0.

Sixty-one packets containing seventeen rating forms were distributed; fifty-five were returned. All of the members of the IEA's U.S. National Committee took part as did school administrators, science program administrators, and practicing teachers from all over the country. Each of the participants was asked to respond in terms of the school science programs with which they were familiar. Some of them restricted themselves to the science programs for the grades for which they were most knowledgeable. Figure 2 is an example of the ratings in the content area of earth science. The ratings for the science topics in the grid were reported by June Miller in her monograph, *An Analysis of Science Curricula in the United States* (1986).

SOME FINDINGS

The comparative mean ratings of the traditional science content are shown in Figure 3. As expected, in the secondary science courses of earth science, biology, chemistry, and physics, their particular content is emphasized. For the nature of the topics in each specific course, it may be more interesting to look at the detailed content analysis found in the monograph by June Miller (1986, pp. 60–74). Of special interest are the ratings of the traditional sciences in elementary school science (Population 1) and ninth grade science (Population 2). These are shown in the left two bars of Figure 3 for each of the sciences. The respondents were

Figure 2 Example of mean and standard deviation scores of a traditional science content area

Content area	1	2	3N	3E	3B	3C	3P	
Earth Science								
1 Solar system	2.1	2.4	2.2	2.1	0.2	0.3	0.6	($\bar{X}$)
	1.0	0.8	1.1	1.3	0.8	0.8	1.1	(sd)
2 Stellar system	1.6	1.9	1.6	2.0	0.1	0.2	0.4	
	1.1	0.3	1.2	1.3	0.5	0.6	0.7	
2a Space exploration and recent discoveries in space[1]	1.5	2.1	1.9	1.7	0.3	0.3	0.6	
	1.1	0.8	1.1	1.3	0.8	0.8	1.1	
3 Meteorology	1.8	2.3	1.8	2.4	0.3	0.2	0.3	
	1.1	0.8	1.1	1.1	0.6	0.6	0.6	
3a The water cycle[1]	1.7	—	—	—	—	—	—	
	1.1	—	—	—	—	—	—	
4 Constitution of the earth	1.9	2.0	1.7	2.3	0.2	0.3	0.3	
	1.0	0.8	1.0	1.1	0.4	0.5	0.6	
5 Physical geography	1.2	2.0	2.0	2.3	0.2	0.3	0.3	
	0.9	0.9	1.1	1.1	0.5	0.6	0.6	
5a Causes of the ice ages[1]	—	1.7	1.5	1.9	0.2	0.2	0.1	
	—	0.9	1.2	1.2	0.5	0.6	0.5	
6 Soil science	0.5	1.0	1.1	1.5	0.3	0.3	0.1	
	0.7	0.9	1.1	1.1	0.4	0.5	0.3	
6a Soil formation and analysis[1]	0.5	1.0	—	—	—	—	—	
	0.7	0.9	—	—	—	—	—	

[1]Items are U.S. options

asked to make judgments about the emphasis and universality in science education that students had received in school from kindergarten through grade five for Population 1 and kindergarten through grade nine for Population 2.

Earth science was the most emphasized traditional science for Populations 1 and 2. It seemed to be the most important element of general science in both grades five and nine. The two most emphasized topics were the solar system and meteorology. From experience in developing the testing instruments, it appears that there was more emphasis on space exploration in the United States than in other countries.

Biology was the subject most likely to have been studied by twelfth graders who were not studying science. For many American young people, biology is the last science subject that they study in school. Among the biological topics that received high ratings for Population 2 were cell structures, life forms, metabolism, plant growth and regeneration, natural environment, and cycles in nature.

Chemistry is the least emphasized traditional science in programs for Populations 1 and 2. It has been hypothesized that chemistry is a comparatively abstract science and a difficult subject to interpret to children and young people. Only one rather inclusive topic, introductory

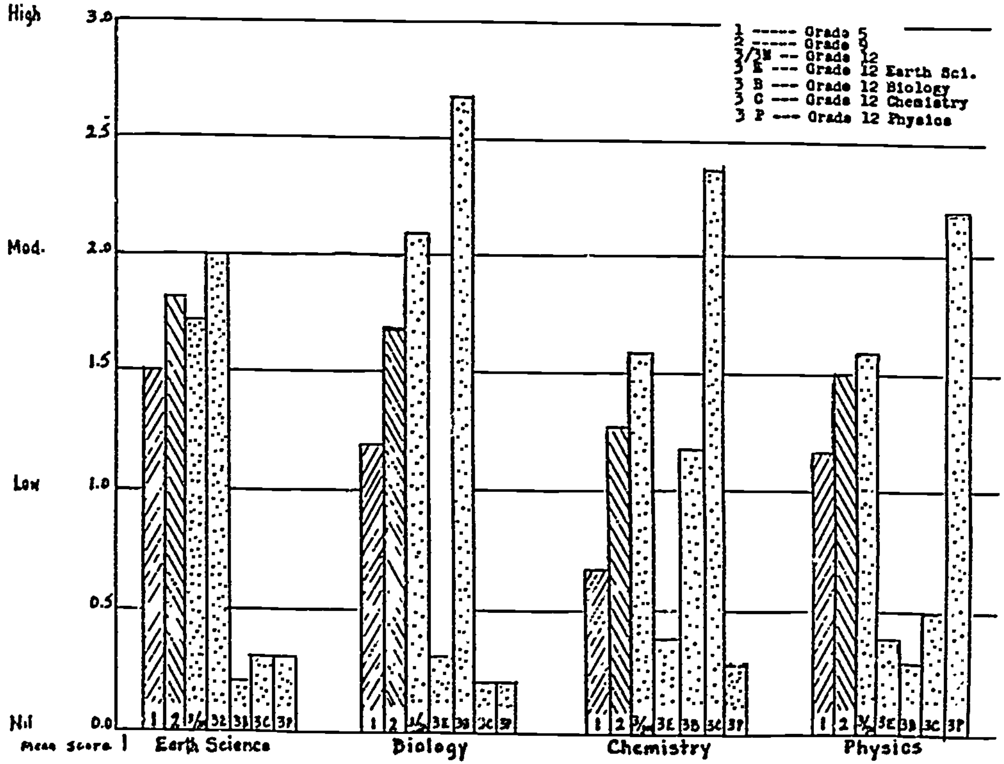

Figure 3 U.S. mean ratings of traditional science content

chemistry, received a high rating in terms of emphasis in general science courses.

There seems to be a greater agreement on the content of physics than other traditional sciences. Such traditional topics as dynamism, current electricity, measurement, energy, and changes of state received high ratings. Low ratings were given to electronics, theoretical physics, and nuclear weaponry.

The ratings of applied and integrated science are given in Figure 4. Environmental science has the highest rating. Environmental science content is more prominent in the general science curricula for Populations 1 and 2 than any of the traditional sciences except earth science. Health science also has both a high emphasis and universality rating. Since health is also taught in other contexts than science, it may be that its overall rating should be higher.

A parity seems to have emerged between learning subject matter content and developing science process skills. The total mean scores for Population 2 (ninth graders) and Population 3N (twelfth graders not studying science) showed an emphasis on process skills. There was almost equal emphasis on content and process in grade five, but for Population 3 (twelfth graders) there was greater emphasis on science content. The scores on the IEA's Second International Study achievement tests also indicate that there have been gains in science inquiry competencies.

There is relatively less attention to the higher order skills involved in thinking and science investigation. Some science curricula included such science process areas as recognizing, identifying, classifying, interpreting, and summarizing. Higher level skills involving science investigation and research are left to second year programs in biology, chemistry, and physics. However, most American students do not participate in these higher level courses.

Considerable attention is given to the history and philosophy of science, especially for twelfth graders. Topics such as the nature of science had considerable emphasis. Less emphasis was reported for ethical issues and controversies related to science and technology.

Some emphasis is given to technical and engineering science in secondary schools. The two items rated highest were "engines, motors, vehicles," and "relationship between technology and science."

Computers are commonplace in American schools. In response to the SISS Teacher Questionnaire, 34 percent of the teachers reporting for Population 1 schools, 53 percent from Population 2 schools, and 64 percent from Population 3 schools reported that students had access to computers in school. Further exploration is needed as to how best to use the microcomputers in schools.

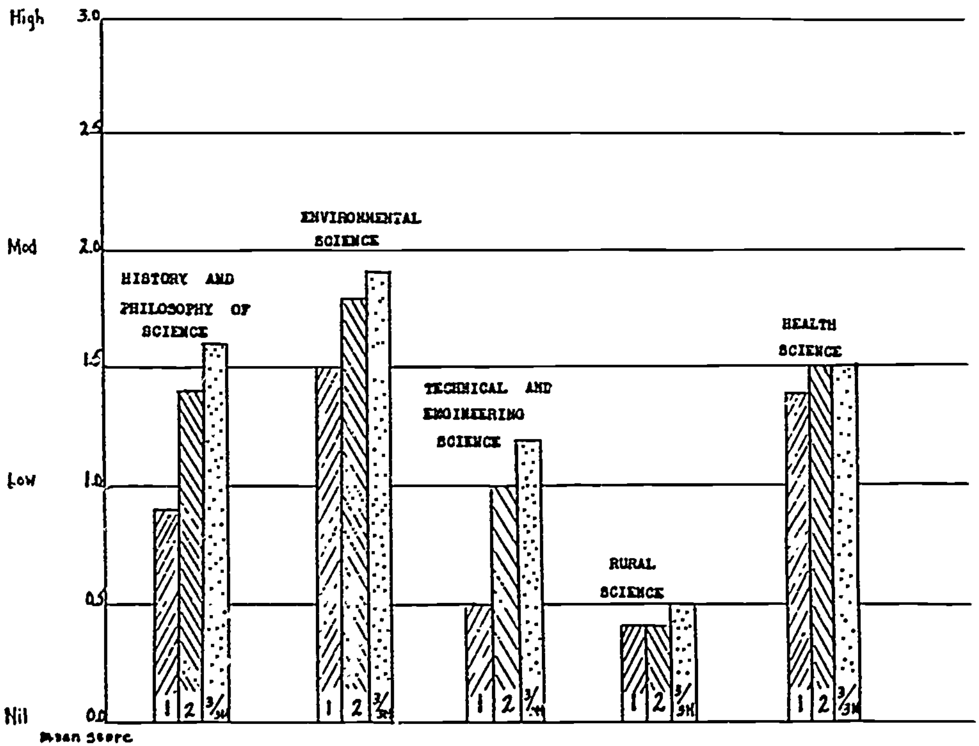

Figure 4 U.S. mean ratings of applied and integrated science content

USING THE FINDINGS

The findings from this study should be of value to everyone engaged in planning and developing science programs, preparing science textbooks and other science teaching materials, or wishing to compare their curricula with science curricula in use elsewhere in the United States. The results of this study are not designed to tell anyone what they should include in their science program. Instead, the results may indicate science areas that have been slighted or omitted. In general, the findings indicate the science topics that have been emphasized in science programs and courses.

THOUGHTS FOR THE FUTURE

There are problems and possibilities with regard to science curricula that should be considered.

Mobile Population

U.S. census data indicate that about one in six American families will move to a different home during the course of a year. The percentage of children in first grade who will complete their elementary and secondary education in the same school or school system is very small. A way needs to be found to make periodic appraisals of what students do or do not know and can or cannot do so that students will not be unduly handicapped because they have missed some important experiences in science or mathematics. Critical lacks can often be taken care of once they are diagnosed.

Problems in Secondary Schools

Secondary schools in the United States organize science curricula in ways that are quite different from the ways science curricula are organized in most other countries. Some of our European friends call the U.S. program a "layer cake approach," in reference to our practice of offering one science per year. In most other countries, students study a science such as physics for two, three, four, or even five years. Certainly, there is a need for reappraisal of our science programs in the secondary schools. In the second phase of the Second International Science Study, students who had more than one year of a science were tested. The achievement of these advanced science students may give us clues as to how science instruction should be organized.

Laboratory and Inquiry Skills

There is evidence from the Second International Science Study that American fifth and ninth graders have improved in process skills but still lag behind students in some other countries. In the second phase of the study, students in the fifth and ninth grades have been tested for laboratory process skills using science process kits. More should be found out about the science process skills of these U.S. students.

Lifelong Learning in Science

Sometimes it appears that schools and schooling are organized as if learning is to end as students pass through the schoolhouse door for the last time. Instead, ways should be found to lead students to learn throughout their lifetimes.

• • •

There is considerable evidence, including evidence from the Second International Science Study, that, if we plan carefully and devote the necessary energy and resources, students can achieve what we want them to achieve. Our studies and others indicate that students in 1983 had better command of science process skills than did students in 1970. Since we "can get what we want," we have a profound responsibility to plan carefully to determine what it is we really want.

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Chapter 9

SCIENCE CURRICULA
An International Comparison Between the United States and the USSR*

Catherine P. Ailes
and Francis W. Rushing

The project "Soviet Precollege Education in Science and Mathematics: A Comparison with the United States" is funded by a grant from the Studies and Analysis program within the Science and Engineering Education Directorate of the National Science Foundation. The objective of the project is to prepare a comprehensive review of precollege science, mathematics, and technical education in the USSR, and whenever possible, to provide relevant comparisons with precollege education in the United States. When completed, this research will evaluate the qualitative aspects of Soviet precollege education in science and mathematics, assess the relative strengths of the educational systems of the two countries, and discuss the implications of the comparative assessment for U.S. policy makers. This paper describes the process by which U.S. curriculum data were collected and how these materials were utilized in the comparative study focusing on precollege science and mathematics education in the Soviet Union.

It is difficult to generalize about science and mathematics education in the United States, because of the pluralistic, decentralized nature of the system. Although there have been a number of studies published on the status of science and mathematics education, they are not definitive in the sense of "norming" or defining the "typical case" in the United States. Therefore, although this research does not have as its main thrust a comprehensive survey of U.S. precollege science and mathematics education, some collection and compilation of information is required to

*This paper discusses a project that is in progress and should not be quoted or cited without permission of the authors.

supplement the existing information against which to contrast the Soviet Union.

METHODOLOGY

A number of relatively recent surveys[1] of state initiatives to respond to perceived problems in mathematics and science education have included state-by-state summaries of actions in areas such as teacher training and retraining, graduation requirements, and curricular reforms; however, the results of these surveys have not been consolidated to form a generalized picture at the national level. SRI has analyzed results of these state-by-state surveys to help arrive at a more general description of national averages for use in making comparisons with the USSR. National-level data, such as those compiled by the National Center for Education Statistics, the National Science Foundation, and the National Science Teachers Association also have been used.

In addition to these sources, nine states, representing various geographic regions of the U.S., were selected for more detailed analysis of U.S. mathematics and science education curricula. From these states, curriculum guides on mathematics and science objectives and concepts by grade levels were obtained.[2] In addition, two specific school system guides, one urban and one rural, were reviewed from each sample state to determine how individual systems and their teachers achieve statewide objectives with the assistance of published course outlines and teaching strategies. To obtain more in-depth information on how choice of textbooks and course plans related to existing curriculum guides, several local teachers were contacted. This sample information, along with existing published surveys, will help form a general framework or norm against which the Soviet system of mathematics and science education can be contrasted.

Once the detailed curricular materials and textbooks at the elementary and secondary level have been sorted through, narrowed to a manageable amount of material, and organized by level and subject matter, mathematics and science education specialists will be called upon to assist with the review and evaluation of their technical content. Panels of three specialists at each of the two levels and two disciplines (mathematics/elementary, mathematics/secondary, science/elementary, science/secondary) will be convened in SRI's Washington offices to examine and assess the materials that have been selected for review. The panel specialists will be selected from recommended names provided by the National Science Foundation, National Council of Teachers of Mathematics, National Science Teachers Association and from SRI's own staff of mathematics and science education specialists.

Subject content/grade matrices have been developed in order to organize the materials for the panels. As the curricular materials provided by the state departments of education and the local school districts often did not provide sufficient information to develop the grids, the local school systems were asked to identify the most frequently utilized textbooks. Textbooks were then examined to determine the range of concepts that might be covered at various grade levels. The concepts identified by the local curricular guides were matched to the list of concepts from the texts, and a content/grade matrix was developed for the elementary, middle, and secondary levels.

PROBLEMS ENCOUNTERED IN GATHERING U.S. NATIONAL LEVEL DATA

Statewide curriculum guides indicate that mathematics and science education in the United States varies considerably depending upon location. Statewide guides show divergence in scope and sequence. Even though local system guides seem to correlate generally with the state guides, there are many cases, nonetheless, of great variation in when a subject is taught and which topics are included in the course content.

One reason for such variation may be that although curriculum guides are designed to provide a framework within which classroom presentations can be made, many curriculum guides appear to be inadequate for teacher use. From the limited samples examined in this study, it would be difficult for all but the most knowledgeable of teachers to use the guides to design lesson plans. Therefore, textbooks, rather than curriculum guides, may provide a more accurate indication of actual curriculum.

There is considerable variation, however, in how textbooks are used, rendering them also imperfect guides to what is taught. Results of interviews with teachers indicate that due to a number of constraints, but most particularly time limitations, they often select individually which chapters of a text will be used in a given mathematics or science course. Therefore, even if the same text is being used, different subject content is often being taught.

Teaching methods are difficult to ascertain, from either existing curricula or textbooks, and must depend partially on individual teachers. For example, most curriculum guides emphasize both learning factual information and problem-solving, but determining the mix of these two approaches in any given state, or even within an individual school, is difficult. Whether a teacher relies primarily on fact retention or problem-solving depends on the training of the teacher involved and, to some extent, the subject matter more than either a curriculum guide or textbook.

CONCLUSION

Examination of U.S. curriculum materials suggests that, in the absence of national science curriculum guides and preselected texts, formal national data on mathematics and science curricula are only partially available, depending upon state and locality. Even when curricula are available, because of reasons such as level of difficulty, differing use of textbooks, decentralization, and school/teacher autonomy, there are great variations in what is being taught in mathematics and science in the United States. Therefore, comparison with other national education systems requires a combination of curricula and textbook analysis, as well as selected interviews, to ascertain common trends in mathematics and science education in the United States.

NOTES

1. See, for example, "A Survey of State Initiatives," *Education Week*, July 27, 1983, pp. 25–37; "A 50-State Survey of Initiatives in Science, Mathematics and Computer Education," Education Commission of the States, No. SM-83-1, September 1983: and "Meeting the National Challenge: Recent Efforts to Improve Education Across the Nation," Department of Education, November 15, 1983.
2. For example, Georgia Department of Education's *Basic Curriculum Content for Georgia's Public Schools*; *Science Guide for Secondary Schools*; *Mathematics Guide for Secondary Schools.*

Chapter 10

DEVELOPING A NATIONAL INDICATOR SYSTEM FOR MONITORING MATHEMATICS AND SCIENCE EDUCATION
The Thorny Curriculum Problem[1]

Richard J. Shavelson,
Jeannie Oakes and Neil Carey

Any national indicator[2] system designed to monitor the "health" of mathematics and science education must include a curriculum component for several reasons. First, curriculum is the medium of exchange, the substance of education, educational processes revolve around subject matter. Second, it is and has been in the past a central feature of educational reform movements. Third, the content covered in the curriculum predicts achievement.[3]

Given the centrality of curriculum to any national education indicator system, it is ironic how difficult it is to define curriculum indicators. Issues of federal and state control of education immediately emerge when consideration is given to monitoring the content of the mathematics and science curriculum. Even if the content area problem could be solved, there are a multitude of possibilities but little guidance regarding what can be measured to capture the "content and process" of mathematics and science education.[4]

The purpose of this paper is to set forth, tentatively, considerations for developing mathematics and science curriculum indicators. The following four points are made:

1. Curriculum indicators must index the curriculum that students experience in their classrooms.
2. A curriculum must be conceived more broadly than a bundle of

facts and skills and their interrelationship. It must also include the nature of the students taught, the method of teaching the subject matter, and the context in which educational transactions take place.

3. Curriculum indicators must capture the nature of the "process" of mathematics and science communicated to students.
4. Curriculum experts must define the key notions in mathematics and science that any literate student should know and be able to apply to everyday life experiences.

WHAT IS ACTUALLY TAUGHT

At each point in the educational system where decision makers determine what should be taught, a curriculum is generated. At one level, scholars and experts in the pedagogy of various subject areas conceptualize ideal curricula; these curricula often appear in conceptual papers and influence the content of textbooks and commercially produced curriculum materials. At a sociopolitical level, federal, state, and local policy makers create curricula when they adopt official regulations, standards, and guidelines regarding courses and subject area content; these generally appear in formal curriculum documents. Within local school systems, district office administrators and curriculum committees typically flesh out this mandated curriculum framework into curriculum guides that specify a scope and sequence of topics and skills in subjects, provide specific course outlines, and suggest lessons. At the level of instructional planning, individual teachers operationalize the curriculum with specific materials and lessons for particular groups of students. Finally, at the level of instruction, curriculum is implemented by teachers and experienced by students during classroom interaction, homework, and other outside-of-class activities. At this level, teachers create curriculum "on their feet" in response to the exigencies of the classroom. (See Goodlad, Klein, & Tye, 1979, for a discussion of curricular levels.)

That curriculum exists at several levels of the educational system is important for monitoring, primarily because the substance of curriculum can differ significantly from one level to the next. Measuring curriculum at one level will not necessarily provide accurate or complete information about the curriculum at other levels. For example, curriculum guides and adopted course outlines tell little about what actually is studied within particular courses. Even teachers using the same textbooks may teach considerably different content.[5]

Ideally, all of these curriculum levels should be monitored to adequately describe the curriculum. No one level provides the key to understanding what content is taught or how curriculum changes. Such a system would include parallel measures for state curriculum frameworks and standards, district curriculum guides, adopted textbooks, teacher instructional plans, and classroom instruction. This multilevel curriculum monitoring could document the effects of various curriculum sources on classroom practice and answer the following kinds of questions: What curriculum is found in the officially adopted policies of states and local districts? What curriculum is found in adopted texts and materials? What curriculum characterizes classroom practice? Where are there consistencies and inconsistencies among various curriculum levels? Where is the slippage most likely to occur? These data could lead to informed curriculum policymaking.

In a less-than-perfect monitoring system of the several curriculum levels, the implemented curriculum is of the most critical importance since that is the curriculum students actually experience. Whether state and district documents include highly valued sequences of concepts, processes, topics, and skills makes relatively little difference if students are not experiencing them in classrooms. The danger, of course, with only assessing the implemented curriculum is that it may lead the unsophisticated to assume that the teachers are the sole determinants of content quality and make decisions independent of other curriculum levels. Nevertheless, monitoring the curriculum that is implemented will provide the most useful information about what content students have an opportunity to learn. Therefore, the first priority for curriculum indicators is that they be measured at the point of instruction.[6]

CURRICULUM IS MORE THAN CONTENT

Further complicating the matter of assessing the curriculum is that curriculum includes far more than simply content. The context of classroom instruction, the characteristics of students, and the curriculum decisions of teachers all powerfully influence what is taught and learned. Attempts to understand the science and mathematics curriculum must consider all these dimensions.

Content

Content, as defined here, means the coverage of particular topics, processes, and skills. Indicators must determine just what science and mathematics students have an opportunity to learn. But asking simply whether particular content is covered is inadequate. To fully understand content coverage, it is important to know how much time and emphasis are devoted to various concepts, processes, and skills, and how content is sequenced.

Beyond these determinations of what content is taught, other considerations are important for assessing the quality of the content. At least the following two dimensions of content relate to its quality:

1. *Congruence of content with "expert" opinion.* How well does the content presented reflect the opinions of scientists, mathematicians, and science and mathematics curriculum scholars regarding the inclusion and emphasis given to various goals and objectives, concepts, processes, and skills?
2. *Scientific accuracy of content.* How well does the curriculum accurately reflect scientific and mathematical knowledge?

Context

As important as the content itself, how well it is learned by students is mediated by the classroom context in which it is taught. Several elements stand between science and mathematics content and students. For example, the following elements all affect classroom learning: what space, equipment, and other resources are available and how they are used; what time is available and how it is spent; what teaching strategies are employed; how learning activities and tasks are structured; what grouping strategies are fostered by school policy and what peer interaction patterns emerge; and what methods of evaluation are used.

The importance of the context is illustrated by research linking particular contexts with student learning. For example, activity-based science instruction appears to positively affect both cognitive and affective outcomes. In addition, peer interaction in small, heterogeneous, cooperatively structured learning groups seems to increase student understanding of mathematics concepts.

Cognitive Characteristics of Students

In addition to the content and context of the curriculum, attention must be given to the pedagogical appropriateness of both to the needs of students, be they cognitive, motivational, or cultural. Of particular importance is whether the mental models students hold regarding science and math concepts and processes are taken into account in the selection and presentation of content.

Science and mathematics knowledge must be actively constructed by students, not simply absorbed. The degree to which students are able to construct an understanding of scientific concepts is affected by their existing mental models, that is, their previous understanding of these concepts. If the prior conceptions of students are far removed from those being presented, students may learn to answer questions about concepts correctly or perform experiments accurately without altering their prior conceptions or constructing a correct understanding of the meaning of what they are learning.

Student misconceptions not only affect their understanding of scientific concepts but also affect their ability to grasp scientific procedures. In the course of mathematics instruction, for example, children often develop erroneous understandings of mathematics procedures (sometimes called "buggy algorithms").

Unless curriculum content and classroom contexts are developed in ways that explicitly confront the current conceptions of students, their faulty understanding of propositions and procedures is likely to persist. The implication for assessing the curriculum, then, is that the degree to which the content and context build bridges that lead the student from naive or erroneous conceptions to more mature ones is of paramount importance.

Teacher Curriculum Decisions

Finally, in assessing the curriculum as implemented, attention must be given to the characteristics of teachers. Teachers, after all, make the decisions about learning goals and about the inclusion and exclusion of topics, processes, and skills as appropriate content. Teachers decide when students have learned enough to progress to new content and what the methods of presenting content will be. Teachers also determine activity and task structures, grouping and interaction patterns, and standards for evaluating student progress.

Teachers report that their own background and experiences influence the curriculum decisions they make (Klein, 1980). But currently, empirical evidence is not available on the relation between teacher characteristics (usually measured in terms of background, training, and experiences) and their communication of subject matter to students. Given the importance of these decisions, teacher characteristics must be considered central to curriculum indicators. However, the most important characteristics may not be those now measured. Ways should be sought to measure how teachers conceive of science and mathematics and the degree to which these conceptions match those of scientists and mathematicians.

CURRICULUM AS SCIENTIFIC INQUIRY

Typical curriculum indicators include student access to curriculum strands, teacher goals, content covered, and materials and technology available. Unfortunately none of these indicators captures the *manner* in which mathematics and science is taught. Mathematics might be taught as context-bound rules to be applied to an ambiguous class of problems or as a genuinely human process of logical, deductive inquiry. Science might be taught as a list of facts and procedures to be memorized, or as an inductive process of observation, conceptualization, and empirical testing with probabilistic outcomes carried out by humans trying to arrive at knowledge. While students might learn the same concepts and procedures as measured by the typical achievement tests, only some would have learned what mathematicians and scientists mean by doing mathematics and science.

Curriculum indicators, then, must enable us to determine the manner in which mathematics and science is being taught in our schools. *Manner* refers to the way the teacher *models* doing mathematics or science,[7] that is, the way the teacher presents key notions in the subject matter, the attitudes the teacher demonstrates toward doing mathematics and science, and the criteria by which the teacher evaluates the processes and products of students doing mathematics or science.

An example of manner might be appropriate at this point. Science ("wet") labs are often transparent. The student knows the givens and knows what the outcome *ought to be*. The student's problem is to get the experiment to work—that is, to come up with the result he or she knows the teacher and lab manual are looking for. This context results in some extraordinarily creative but unintended unscientific behavior on the student's part. For the student knows that if the product is not exactly as specified by the teacher or manual, he or she will receive a bad grade. The teaching manner in which the curriculum is taught is clear: science is a set of steps. If executed correctly, only one correct answer is possible. Contrast this with the unique teacher who has taught his or her students that science deals in probabilities and not absolutes, that there is an entire distribution of outcomes for a correctly carried out procedure, and, therefore, a particular outcome is probabilistic. Scientists repeat experiments over and over again to guard against the unusual event. Consequently, the distribution of outcomes over all the students in the lab becomes an exciting finding in itself. Under these conditions, students are more likely to focus on the process of carrying out the experiment and not the outcome. They are more likely to learn what "doing science" is all about.

Although manner is an important curriculum indicator, there is, to date, no way to measure it. Until research is done on this topic, it is unlikely that it will be incorporated as an indicator.

DEFINING THE CURRICULUM

Up to this point, the fundamental issue of what constitutes the mathematics and science curriculum has not been discussed. In the end, curriculum indicators must address this issue either directly or indirectly. The indirect approach is to define the curriculum by achievement indicators. Schools teach what is tested for. This is clearly a case of the tail wagging the dog. Its virtue is that this covert definition is less liable to have the federal government seen as dictating the curriculum to states and local education agencies. Its vices are many and may include stressing computation and step-by-step procedures with one correct answer instead of problem solving, putting at a disadvantage schools and teachers who do not teach to the test, and testing for aptitude rather than achievement by making test items independent of specific content.

The other extreme, specifying a national curriculum, is highly unlikely. It is out of the question if its rationale is just to fit the needs of a national indicator system.

There is, however, a middle ground, and that middle ground uses the informed judgments of mathematicians and scientists, mathematics and science educators, and the various interest groups to reach a consensus on a set of key notions in mathematics and science that all students at various point in their education should know and be able to use. The National Science Board's Commission on Precollege Education provided one such list in their report, *Educating Americans for the 21st Century,* as have other organizations, so it is not an impossible task to perform. Getting an agreement on what is important may be, however.

The point is that if a national indicator system to monitor curriculum and achievement and other components of education is developed, a mathematics and science curriculum will, in part, have been defined. This fact should be recognized for what it is, and the best methods of social science should be used to extract informed judgment about the curriculum and arrive at a set of key mathematics and science notions. These key notions should serve as the basis for developing curriculum indicators and for developing achievement tests. In both cases, indicator systems should seek evidence of student ability to apply these mathematical and scientific notions to solve mathematical and scientific problems, and to apply them to everyday problems. In addition, the indicator system should have open curriculum slots that allow education agencies to define other important aspects of the curriculum emphasized locally so that the indicator system also reflects this fundamental concept of American education.

FOOTNOTES

1. This paper draws on the authors' experience in a Rand project funded by the National Science Foundation (Grant # SPA-8470440), "Monitoring National Progress in Mathematics, Science and Technology Education." The views expressed in this paper do not necessarily reflect those of the NSF or of the Rand Corporation. This draft is not to be cited or quoted without the authors' permission.
2. An indicator is an individual or composite statistic that relates to a basic construct in education (e.g., teacher quality) and is useful in a policy context. An indicator should consist of reliable and valid information related to an important part of the education system, provide a benchmark for measuring progress or lack thereof, relate to key policy issues, be readily understood by a broad audience, and be capable of being contrasted with some standard, with itself over time, in two different locations, or with another indicator (Shavelson, forthcoming).
3. A fourth reason, from the perspective of this project, is that one role of the Science and Engineering Education Directorate of the NSF is to provide model curricular materials and teacher training in mathematics and science to the nation's school systems.
4. These issues are discussed in greater depth in a background paper specifying the problems and possibilities of monitoring science and mathematics curriculum (Oakes, forthcoming).
5. Why these differences exist has been explained in ways that are relevant to policymaking. For example, Cuban argues that curricula at different levels vary in their permeability (Cuban, 1979); some levels are quite susceptible to change through policy initiatives, while others exhibit considerable stability. Since curricular policy is developed and adopted at the sociopolitical level, the formal curriculum level changes readily in response to new policy. State and local documents take on new content, approaches, and emphasize new curriculum initiatives. At the level of the school system, curriculum is also fairly responsive; courses are developed, new texts and materials are adopted, and guide-

lines for teachers are written in accordance with new policies and adopted priorities. Curriculum at the instructional level, on the other hand, appears to be quite stable; the curriculum teachers plan and implement persists over time and proves difficult to influence with policy or program implementation (See, for example, Berman and McLaughlin, 1978; Fullan, 1982; Goodlad and Klein, 1970). Behind the classroom door, curriculum resists change.

6. Operationally, this means that curriculum must be assessed at the classroom level. This presents some obvious problems, since the classroom curriculum cannot be found in a tidy package that parallels curriculum guides or even textbooks. Observation is likely to provide the most accurate data about the curriculum of the classroom, yet observation is not practically possible for measuring the curriculum in schools across the nation. Further, measures of what is actually taught are most accurate if they encompass the entire school year; the resources required to conduct observational data-collecting (and analyses of these data) in more than a very small sample of schools would be staggering. A more reasonable approach than classroom observation would be to ask teachers to report what actually occurs during the course of classroom instruction. Teachers are a better data source than students in this regard, since students can only report what they have already experienced and cannot project to the end of the school year. Even so, adequate measures will require considerable new research and development, since curriculum has not often been the focus of data collection efforts. (Two notable exceptions are the International Education Assessment [IEA] instruments that included items asking teachers about specific content coverage and depth; and the University of Michigan IRT study [Freeman et al., 1983] of the determinants of classroom curriculum content that had teachers keep journals of the topics and skills they covered.)
7. The term teacher refers to human teachers and other media for communicating the structure and process of mathematics and science.

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Chapter 11

ASSESSING THE QUALITY OF THE SCIENCE CURRICULUM*

Senta A. Raizen

The last several years have been characterized by many calls for reform of science education in the schools,[1] and these calls have been accompanied by a variety of policy interventions: requiring more science courses for high school graduation, increasing standards for certification of science teachers, developing state guidelines for science curricula, and increasing the assessment of student achievement (Goertz, 1986). The reform movement has brought with it as well the desire to understand the current state of science education, including the effects of the various improvement efforts. As a result, several groups are working on the development of appropriate indicators to monitor the progress of science education (National Science Board, 1985; Department of Education, 1986; Romberg & Smith, 1986; Shavelson, 1986), among them the National Research Council's Committee on Indicators of Precollege Science and Mathematics Education. This paper discusses the committee's effort to develop approaches for assessing the quality of the science curriculum and some of the considerations that influenced the committee's thinking.

Despite the self-evident role that curriculum plays in formal education, attempts to monitor its quality are conspicuous by their absence. The reason is not hard to find: It is extraordinarily difficult both conceptually and technically to create even minimally acceptable indicators of curriculum quality. Nevertheless, the committee has identified the

*This paper is based in part on the work of the National Research Council's Committee on Indicators of Precollege Science and Mathematics Education. The committee's conclusions and recommendations on assessing curriculum quality will be included in its forthcoming report, *Improved Indicators of Science and Mathematics Education in Grades 1-12,* edited by Richard J. Murnane and Senta A. Raizen, Washington, D.C.: National Academy Press (in press).

quality of the curriculum as a key factor in assessing the condition of science education, based on the presumption that giving students the opportunity to learn subject matter not part of their home or social environment is a primary reason for science instruction in school. This opportunity is dependent on two aspects of the curriculum: the time devoted to particular subject matter and the content of instruction. Not only are these common sense presumptions, but the importance of both time and curriculum content in student learning are by now also well documented through research evidence. Several of the international and nationwide assessments (Husen, 1967; Wolf, 1977; Jones, 1984; Crosswhite, Dossey, Swafford, McKnight, & Cooney, 1985) and research studies on the teaching of particular concepts and knowledge (Walker & Schaffarzick, 1974; Davis, 1984; Romberg & Carpenter, 1985) have presented pertinent findings.

Having taken the position that one cannot give an account of the progress of science education without attention to the quality of the curriculum, the National Research Council's committee faced several difficult issues: What constitutes the curriculum? How and by whom is content determined? How can the quality of the content be judged? How can the quality of science curricula be compared, say, over time, or between schools, among school systems or among states, or internationally? The following brief discussion of these issues faced by the committee—and by any others who would attempt to monitor the quality of the science curriculum (see, for example Oakes, 1986)—illustrates the difficulties.

DEFINING THE CURRICULUM

What constitutes the curriculum? There are nearly as many definitions of curriculum as there are people who write about it. At the most abstract level, researchers, using Marxist analysis (Bowles & Gintis, 1976) or sociological and historical investigation (e.g., Friedenberg, 1963; Dreeben, 1968; Katz, 1971) have written about the overt versus the hidden curriculum, that is, the proclaimed intent of teaching substantive knowledge as contrasted to the hidden social purpose of readying individuals to play acceptable social and economic roles. This sort of analysis may be useful in developing explanatory hypotheses for providing different courses and curriculum content in science to different population groups.

Another approach to analyzing differences among curricula focuses on philosophy and purpose: the development of the intellect through the study of the academic and humanistic disciplines; the development of the good citizen and productive worker through a utilitarian coupling of school instruction and the requirements of work, play, family responsibility, and citizenship; the development of the human potential of each child through paralleling in the curriculum the natural development of children and adolescents; and the improvement of society through education. Currents of these philosophies are very evident in today's debates on what the science curriculum ought to contain—the fundamental concepts and processes of, say, chemistry; emphasis on the relationship between science and self and science and society (e.g., the functioning of the human organism, the contribution of synthetic drugs to better health, the problems of toxic waste); the connections between the basic science and the technologies derived from it that are an integral part of modern life (e.g., biotechnology, information technology); or how better decisions could be made on issues involving science and technology (e.g., the siting of nuclear power plants).

At a mundane working level, curriculum has been defined as the number and kinds of courses or—in elementary school—minutes per day of science to which a student has been exposed (Weiss, 1978; National Center for Education Statistics, 1981a, 1981b, 1984; Welch, Anderson & Harris, 1984; West, Diodato, & Sandberg, 1984; Cawelti & Adkisson, 1985). (For a more detailed description of these data and their sources, see the paper by Gilford in this volume.) Thus, one of the most common policy initiatives for improving science education has been to increase the number of science courses required for high school graduation (Education Commission of the States, 1985). Yet, this addresses only the time dimension of curriculum and largely ignores content. At minimum, improved definitions of secondary school courses, based on their content, should be developed (cf. the classifications produced by Evaluation Technologies, Inc., 1982) so as to track the nature as well as the number of the courses in which students are enrolled.

A more substantively oriented approach holds that analysis of the various materials that are designed to convey the intended subject matter will lead to identification of the curriculum. First, local district (or state) guidelines on what is to be included in science instruction give information on the intended curriculum. Second, the content of the textbook is known to be a major determinant of what gets taught (Stake & Easley, 1978; Goodlad, 1983). It is estimated, for example, that 75 percent of the time that elementary and secondary school students are in classrooms and 90 percent of their time on homework is spent with text materials (Goldstein, 1978), despite evidence that students may not be learning much from these materials (EPIE, 1980). Third, many educators believe the tests used to assess student achievement exert considerable influence on what is taught (Romberg, 1986). It can be argued that they as well as other instructional materials should be analyzed for subject matter content. These three manifestations of the content of the intended curriculum, together with the time devoted to study, make up observable components of the curriculum that can be readily recorded and analyzed, even if at some cost.

These components, however, do not in themselves constitute the curriculum. A more adequate definition must take account of the mediating influence of teachers who construct the curriculum actually presented to the students from these various pieces, based on their perceptions of student needs and capacities. As but one example, Berliner (1978) found that teachers give quite different emphasis to different topics in mathematics. He observed several fifth grade classes and found variations as high as from 10 minutes to 2223 minutes of pupil time devoted to long division over an average of 90 days of instruction. Other topics exhibited similar variations in time devoted to their instruction. The freedom of the teacher to adapt the curriculum is considered crucial by many educators and researchers. In fact, one of the papers presented at the 1985 National Forum for School Science emphasized the centrality of the teacher's role in the education process by calling for "curriculum-proof" teachers (Graham & Fultz, 1986). In recognition of the transformation of curriculum in the classroom, one may characterize plans outlined by state or local authorities, textbooks (and, in the case of science education, accompanying laboratory manuals and exercises), computer software, test materials, and teacher-prepared lesson plans as the "intended" curriculum, whereas the teacher's presentation and adaptation of these various components in the teaching of a class may be considered the "actual" curriculum. Studies conducted by the International Association for the Evaluation of Educational Achievement (IEA) speak of yet a third aspect of curriculum, namely, the "achieved" curriculum, or what students have learned as a result of instruction. This, however, is mediated not only by the available materials and guidelines, the teacher's construction of the materials and guidelines, and the time given to study, but also by what the student brings to the classroom. Therefore, assessment of the achieved curriculum goes beyond the scope of this paper, which is concerned with the quality of the science curriculum presented to the student. In order to appraise this quality for a given class, school, district, state, or the country as a whole, it would appear to be necessary to assess each of the components of the intended and the actual curriculum presented by the teacher.

DECISIONS ABOUT CURRICULUM CONTENT

How and by whom is the content of the intended science curriculum determined? In the United States, local districts are charged with the responsibility for deciding curriculum content, usually within guidelines set by the states. The degree to which such guidelines are mandatory varies from state to state. Many states merely specify a minimum number of credit hours for high school graduation—including requirements in science—and provide voluntary curriculum guidelines, hence local authorities have considerable discretion as to the content to be covered. However, the recent reform movement has seen increasing emphasis on state guidance and state assistance. Statewide mandates for testing, now instituted in 42 states (Goertz, 1986), tend to generate a common core of curriculum content, particularly where a state offers assistance to localities in meeting the learning goals set for students (e.g., Connecticut, Michigan, Pennsylvania).

Input to decisions on curricular content comes from many other sources. Some populous states, including California, Florida, and Texas, have state textbook adoption boards, though the lists of texts approved for school use by such bodies are usually comprehensive enough to allow much room for local choice. Nevertheless, the influence of large markets on the content of textbooks may be decisive. Sales to California and Texas can account for more than twenty percent of a book's total sales (Apple, 1985). In the highly competitive textbook publishing industry, where costs have been rising and sales dropping (Compaine, 1978), obtaining approval from the adoption boards in these two states may well be a consideration in formulating textbook content. Hence, critics argue that the greatest amount of public acceptance will rule the science that is included in textbooks, often leading to the trivialization of content rather than to a coherent presentation of the constructs of science geared to the development of scientific thinking (American Chemical Society, 1984; Komoski, 1985).

For some disciplines, chemistry and geography, for example, professional societies have recently developed detailed guidelines for the content of the school curriculum (American Chemical Society, 1984; Joint Committee on Geographic Education, 1984). In these cases, it is the professional chemist or geographer who is attempting to exercise influence over the curriculum. As another example, the National Science Teachers Association (1983–84) has selected outstanding examples of science teaching at the elementary level and in each of the disciplines generally taught at the secondary level to provide guidance to teachers on good curriculum content. This association has also synthesized the criteria that ought to be applied to the construction of science content in precollege education (Harms & Yager, 1981). The American Association for the Advancement of Science (1985) has recently launched an effort to involve scientists in identifying the content of what graduating high school students ought to know in science, which presumably will provide guidance to educators as well as to textbook publishers.

Thus, there are many factors that shape the content of the curriculum: local authorities, state authorities, textbook writers and publishers, various interested groups including scientists and their professional societies, teacher associations, and even religious groups, when science instruction appears to conflict with their values and beliefs. Does this mean that local autonomy leads to local diversity? Perhaps, but there are at least three centralizing forces acting on the curriculum: the textbooks which, as noted, seek to satisfy the market and thus embody general consensus on what ought to be taught; standardized tests—until recently rare in science but coming to play a more important role as assessment and instruction in science receive greater emphasis in grades kindergarten through six; and, at the secondary school level, college entrance requirements and subject matter achievement tests administered for college placement (e.g., the College Board Admissions Testing Program).

With respect to the textbook, according to the 1977 National Survey of Science, Mathematics, and Social Studies Education (Weiss, 1978), one-half of all science classes and about two-thirds of all mathematics classes use a single published textbook or program, and many of these classes use one of four or five of the most popular texts. Yet there has been little content analysis of textbooks since the mid-1970s (Walker, 1981). Consequently, the concordance among textbooks covering the same subject matter is not well understood, nor is the concordance between textbooks and standardized tests. Some research on this topic has been done in mathematics by Freeman et al. (1983). In an analysis of fourth grade mathematics texts and tests, these researchers found that there was a common core of topics treated in the four most commonly used texts, but that the proportion of topics covered on commonly used standardized tests which had received more than cursory treatment in a textbook was never more than 50 percent (Freeman et al., 1983, p. 511). Hence, students might have learned more mathematics than they were able to demonstrate on the tests. As for science textbooks, they are known to resemble each other in the heavy emphasis on new vocabulary. One analysis (Yager, 1983) found that about 3,000 special or technical words were included in science books intended for grades four through six, and over 9,000 in one of the senior high school physics texts.

The centralizing influence of testing may well increase in the future as the states develop procedures for science assessments that make comparisons among states possible. A great concern here is the underdeveloped state of testing for science knowledge, particularly knowledge that goes beyond the recall of facts (Frederiksen, 1979, 1984). There is an inverse relationship at present between the ease and efficiency of test administration and the extent to which a test assesses student knowledge and performance in a science valued by experts in the field. Unless the content of tests can be improved to reflect the intended learning, and particularly the more complex reasoning and process skills, tests may serve to reduce the curriculum to covering a broad array of facts without depth or connections.

As to the influence of institutions of higher education, there is more similarity in the expectations of like institutions, say, of elite universities or, for that matter, of community colleges across the country than there is among all sorts of institutions of higher education within a particular state. Thus, curricular and instructional differences are more closely associated with future educational expectations of students (and their teachers) in particular high schools than they are with school systems, states, or regions. High schools serving an upper middle class population whose sons and daughters are expected to go to elite institutions are likely to offer different content in their science courses than will high schools serving a poor urban or rural student body. The variation in course content can be great indeed, even in different classes within the same school. For instance, the recent IEA assessment of the mathematics achievement of eighth graders in a number of countries documented that there are four different types of mathematics courses taught in the United States in grade eight: remedial, typical, enriched, and algebra (Crosswhite, Dossey, Swafford, McKnight, & Cooney, 1985). As Table 1 shows, students in the algebra sections are the only ones to learn anything about algebra. It should come as no surprise that the achievement of U.S. students compares unfavorably with that of Japanese students, who all start algebra in seventh grade. Thus, while there is clearly variation in the curriculum to which students are exposed, it is not so clear that the determinants of the differences in curricular offerings reside in the hallowed tradition of local choice. Rather, the differences may come about through judgments that are quite similar across school districts, states, and regions of the country on the capacity of different types of students and the suitability of various curricula for these students.

MEASURES OF CURRICULUM QUALITY

Given the different components of curricula and their determinants, the tradition of local choice, and the very real differentiations in curriculum offerings, how should the quality of a curriculum be assessed? In its first

Table 1. Median anticipated number of periods for selected topics for eighth grade classes by class type: United States, 1981–82

	Median number of periods				
Topic	All classes	Reme-dial	Typical	Enriched	Algebra
Common fractions	15	20	20	10	2
Decimal fractions	15	20	15	10	1
Ratio and proportion	10	10	10	6	4
Percentage	15	15	15	10	2
Measurement	10	10	12	10	1
Geometry	15	10	15	15	1
Formulae/equations	20	2	20	26	50
Integers	10	10	15	10	8
Probability and statistics	4	0	5	5	0
Number of classes	236	24	155	26	31

Note: Reprinted, by permission, from Crosswhite, Dossey, Swafford, McKnight, & Cooney, *Second International Mathematics Study Summary Report for the United States,* 1985.

report (Raizen & Jones, 1985), the Committee on Indicators of Precollege Science and Mathematics Education called for a more systematic approach to the analysis of the content of textbooks (and also tests) than the current scattered research efforts analyzing such specific aspects of texts as concordance of emphasis on topics (Freeman et al., 1983) and the vocabulary demands in science texts (Yager, 1983). The reviews performed under the auspices of the American Association for the Advancement of Science (Science Books and Films, May–June 1985; May–June 1986) are a helpful step, but they are largely judgmental without systematic analysis of content. The committee therefore recommended that

> . . . at a minimum, periodic surveys should be conducted to determine the relative frequency of use of various mathematics and science textbooks at each grade level in elementary school and for science and mathematics courses in secondary school . . . followed by content analysis of the more commonly used texts. Analyses should proceed along several different lines: balance between the learning of the recorded knowledge (concepts, facts) and its application (process), emphasis given to specific topics, adherence to the logic of a discipline, opportunity and guidance for student discovery of knowledge [usually through hands-on or laboratory exercises], and incorporation of learning theory. (Raizen & Jones, 1985, p. 81)

Similar sorts of analyses could be performed on other recorded components of the curriculum—tests, state and local guidelines, and recommendations by professional bodies.

Getting information on the content of the curriculum as it is actually presented by various teachers has been approached in several different ways. Since this is a critically important issue, it seems useful to detail some of the approaches. The design for the international studies of science and mathematics achievement conducted by IEA specifies an analysis of curriculum at three points: the intended curriculum, the implemented (or actual) curriculum, and the attained curriculum, as indicated by student achievement. The implemented or actual curriculum is measured through questions to teachers on the classroom processes used in teaching a specific subject and grade level. For the second study of mathematics achievement, information on three types of variables was collected relevant to analyzing the implemented curriculum. First, teachers were asked whether or not they had provided instruction to the target class being tested by IEA for each of the items on the achievement test. For example, Table 2 reports teacher estimates of the percent of items on the test that they covered in their instruction during the year, or student "opportunity to learn" a topic. Second, teachers were asked to indicate which interpretations of selected concepts and processes they utilized. Figure 1 is an example of the analysis of interpretations used in teaching one eighth grade mathematics concept. Third, opportunity to learn selected mathematics topics was compared with achievement in these topics, as shown in Figure 2. Finally, the correlation between student test scores and opportunity-to-learn reports were used to determine how much mathematics is taught and learned (see Table 3).

A second example of relating student achievement to measures of the implemented curriculum is provided by the work of the Ontario Institute for Studies in Education (McLean, 1985). The opportunity-to-learn variable was correlated with student test results on items assessing performance in chemistry. In this analysis, shown in Table 4, the number of hours spent in teaching each topic were also reported, representing a second measure of the implemented curriculum.

Another type of measure of implemented or actual curriculum is used by the National Assessment of Educational Progress (NAEP). The design of the instrument does not allow for systematic analyses of the implemented curriculum at each grade level tested. For example, in the teacher questionnaire for the 1985–86 mathematics assessment (NAEP, 1985), seventh grade teachers were asked what topics were included in the school curriculum for grades six through eight (see Table 5). These items did not ask whether the teacher actually covered the topics or

Table 2. Teacher estimates of mathematics content taught during eighth grade needed to answer cognitive test items: United States, 1981–82 (average percent across items)

Content area Number of items	All classes	Class type Remedial	Typical	Enriched	Algebra
Arithmetic (62 items)	75	76	80	84	42
Algebra (32 items)	66	37	64	80	86
Geometry (42 items)	39	25	41	54	24
Measurement (26 items)	58	53	64	75	20
Statistics (18 items)	51	48	58	59	15
Overall (180 items)	60	51	64	72	40
Number of classes	287	29	189	31	38

Note:
1. Data include ratings from 51 teachers in the sample from whom complete data were not collected.
2. This table refers to content taught only during the eighth grade, not up to and including eighth grade.

Note: Reprinted, by permission, from Crosswhite, Dossey, Swafford, McKnight, & Cooney, *Second International Mathematics Study Summary Report for the United States,* 1985.

how much time was spent on each topic. The NAEP teacher questionnaires asked additional questions about teaching strategies and techniques in general (see, for example, question 108 on Table 5), but the questions were not tied to specific curriculum content. The third grade and eleventh grade teacher questionnaires for the same assessment did not include curriculum content questions.

Still another type of measure of the actual curriculum is direct observation of the amount of coverage of curriculum topics by teachers. Researchers at the University of Chicago have been observing first and fourth grade reading and mathematics in a small number of classrooms to determine the effect of various class conditions on the curriculum actually presented to students (Barr, 1985). Figures 3–5 show the average coverage of mathematics text lessons and problems by nine fourth grade teachers and the variation among teachers. The goal of this approach is

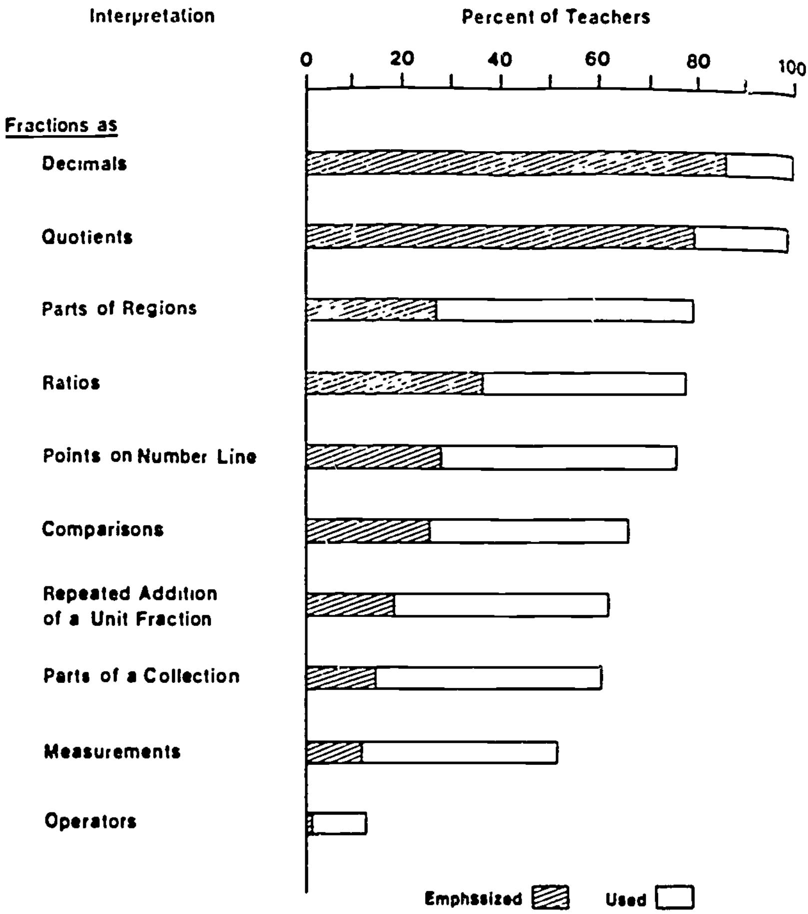

Figure 1 Interpretations of fractions from the classroom process questionnaires used by eighth grade teachers in arithmetic instruction

Note: Reprinted, by permission, from Crosswhite, Dossey, Swafford, McKnight, & Cooney, *Second International Mathematics Study Summary Report for the United States,* 1985.

to determine the variation in implemented curriculum by teacher and to analyze the effects of various conditions such as average class aptitude, textbook difficulty, and amount of instructional time spent on curriculum coverage.

Although these approaches to capturing the content of the actual curriculum are quite creative and useful, there are some problems. Teachers may not be able or willing to answer accurately survey ques-

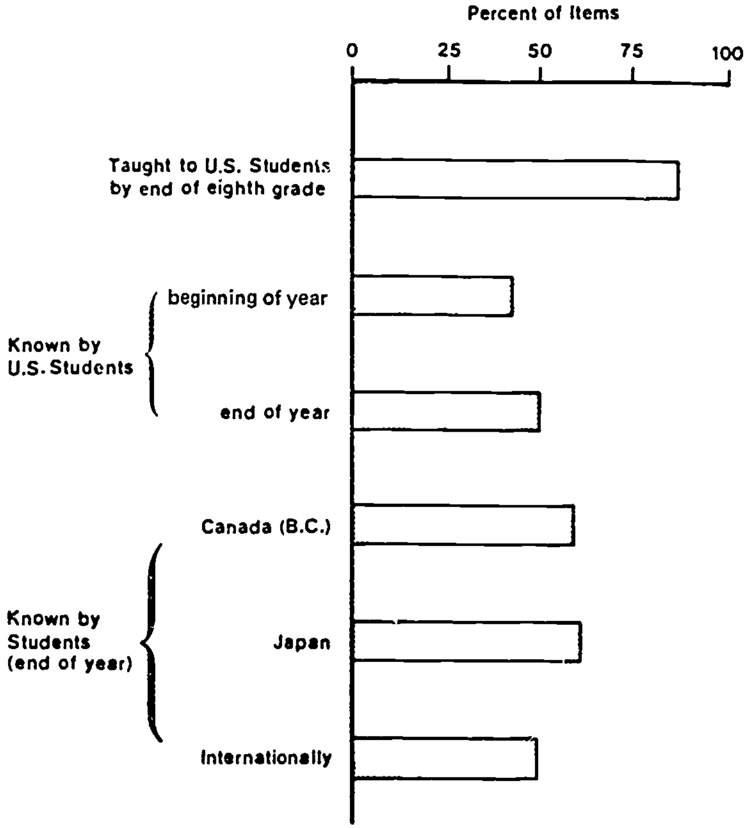

Figure 2 **Average percent of arithmetic items on international test taught and learned (eighth grade)**
Note: Reprinted by permission, from Crosswhite, Dossey, Swafford, McKnight, & Cooney, *Second International Mathematics Study Summary Report for the United States,* 1985.

tions on topic coverage, particularly if their answers are used to evaluate their own performance. Classroom observation is very costly and therefore feasible for only a small number of classrooms; hence the ability to generalize any findings will be limited. Nevertheless, classroom observation, if done by trained observers, can document the content of instruction more accurately than any other method. If sufficient funding were available for an adequate sample, results from classroom observation could help in forming curriculum decision by local districts. Classroom observation could also possibly be used as a check on what teachers re-

Table 3. Average percent of items on the international test reported taught and learned in eighth grade mathematics: United States and nineteen other countries, 1981–82

	United States			
Topic (number of items)	Opportunity to learn[1]	Mean pretest score	Mean post-test score[2]	Mean post-test score for 20 countries[3]
Arithmetic (62 items)	87	42	51	51
Algebra (32 items)	69	32	43	43
Geometry (42 items)	44	31	38	41
Measurement (26 items)	70	35	42	51
Statistics (18 items)	73	53	57	55

Note: Reprinted, by permission, from Crosswhite, Dossey, Swafford, McKnight, & Cooney, *Second International Mathematics Study Summary Report for the United States,* 1985.

[1]Opportunity-to-learn by the end of eighth grade—that is, up to and including eighth grade.

[2]Post-test data are based on 280 classes in the United States.

[3]The international means are based on a restricted set of 157 items in common between the international test and the U.S. national version of the test. The number of items by topic on the 157 item international test were: arithmetic, 46; algebra, 30; geometry, 39; measurement, 24; and statistics, 18. In all cases the U.S. results differ less than one percent from those in the table above when restricted to the set of 157 items. The countries included, in addition to the United States, were: Belgium (Flemish); Belgium (French); Canada (British Columbia); Canada (Ontario); England and Wales; Finland; France; Hong Kong; Hungary; Israel; Japan; Luxembourg; Netherlands, New Zealand; Nigeria; Scotland; Swaziland; Sweden; Thailand.

port about content coverage and instructional strategies on survey questionnaires.

CREATING INDICATORS

Information on curriculum quality, even if better measures were to be developed, is not useful unless it can be compared to something: some implicit or explicit norms, curriculum quality at some other time (three

Table 4. Grade twelve chemistry topics and associated statistics for correlation between achievement and opportunity to learn (OTL), median number of hours devoted to the topic, average and standard deviation of classroom achievement means. OTL scale: 1 = not taught, 2 = taught before, 3 = taught this year

Topic	Ach/ OTL	OTL	No. hours	Mean ach.	s.d. ach.
Structure of atoms [Unit 2]	.37	2.6	6	0.53	0.13
Structure of aggregate atoms [Unit 3]	.33	2.5	5	.45	.11
States of matter and gas laws [Unit 4]	.47	2.3	9	.48	.11
Oxygen and hydrogen [Unit 5]	.29	2.3	3	.51	.11
The mole, atomic weight, molecular weights [Unit 6]	.60	2.6	10	.55	.12
Formulas, nomenclature and equations [Unit 7]	.38	2.6	10	.52	.11
Water and solutions [Unit 8]	.31	2.2	4	.45	.11
Ions in aqueous solution [Unit 9]	.37	2.2	3	.41	.11
Elements of group 2 [Unit 10]					
Elements of group 7 [Unit 11]					
Periodic classification of elements [Unit 12]	.50	2.4	4	.46	.09

Note: Reprinted, by permission, from L. McLean, *Drawing Implications for Instruction from Item, Topic, and Classroom-Level Scores in Large-Scale Science Assessment,* 1985.

or ten years ago), or curriculum quality in some other place (another school system, another state, another country). Moreover, once change has been documented, it needs to be assigned a positive or negative value. How is the question as to whether the quality of the science curriculum is improving or deteriorating to be answered? The first report of the National Research Council's Committee on Indicators of Precollege Science and Mathematics Education concluded that

> there are no established standards for content derived either from past practice, practice elsewhere, anticipated need, or from theoretical constructs de-

Table 5. Questions 97–107. What is included in the mathematics curriculum in your school in grades 6 through 8? Circle all that apply on each line.

	Not taught	Grade 6	Grade 7	Grade 8
97. Common fractions	A	B	C	D
98. Decimal fractions	A	B	C	D
99. Ratio and proportion	A	B	C	D
100. Percent	A	B	C	D
101. Measurement	A	B	C	D
102. Geometry	A	B	C	D
103. Algebra (formulas and equations)	A	B	C	D
104. Integers	A	B	C	D
105. Probability and statistics	A	B	C	D
106. Problem solving	A	B	C	D
107. Other (specify)	A	B	C	D

108. On the average, how often do you give your students writing assignments (word problems, short-answer questions) in mathematics?

A Almost every day
B Several times a week
C About once a week
D Less than once a week
E Never

Note. Reprinted from National Assessment of Educational Progress, *NAEP Field Test Teacher Questionnaire,* 1985.

veloped, say, from the nature of the discipline being taught or from learning theory. Until some consensus can be reached on instructional content that represented desirable alternatives for given learning goals, it is premature to suggest indicators for [curriculum quality]. (Raizen & Jones, 1985, p. 81)

Assuming that analysis of textbook and test content and of opportunity-to-learn measures would proceed. the committee recommended assessment of quality through norms implicit in the judgment of the qualified experts, stating that "When information on what is taught has been collected and analyzed, reviews should be done by scientists, mathematicians, and other experts in the disciplines as well as teachers and educators" (p. 81).

To help improve the monitoring of curriculum quality, the committee currently envisages an approach based on developing four types of indicators: (1) an indicator of the extent of content covered in the

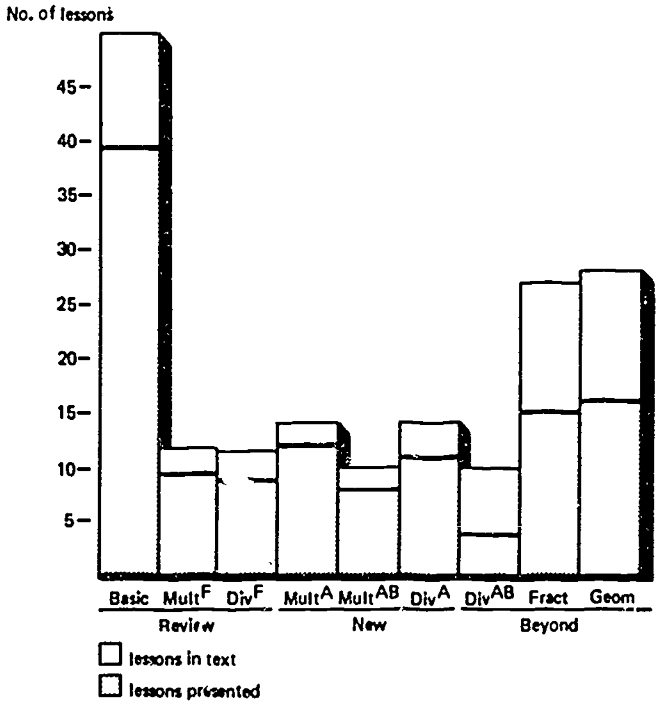

Figure 3 Average number of lessons in the text in the nine math areas and the average number presented to students

Note: Reprinted, by permission, from R. Barr, *A Sociological Analysis of the Influence of Class Conditions on Mathematics Instruction,* 1985.

curriculum, (2) an indicator of the depth of coverage of the content in the curriculum, (3) an indicator of the scientific accuracy of the content in the curriculum, and (4) an indicator of the pedagogic quality of the curriculum. Curricular frameworks would provide references for the indicators. The review below summarizes the committee's deliberations and proposals for indicators of curriculum quality as discussed in its forthcoming report (Murnane & Raizen, in press).

Content Coverage

As noted earlier, a crude way of assessing content coverage in secondary schools is to measure the number of mathematics or science courses taken by a student. A more refined measure would be to use the information provided by course titles; for example, Algebra 1 as contrasted to General Mathematics. In elementary school, the analogous measure is time devoted to a subject; for example, seventeen minutes per

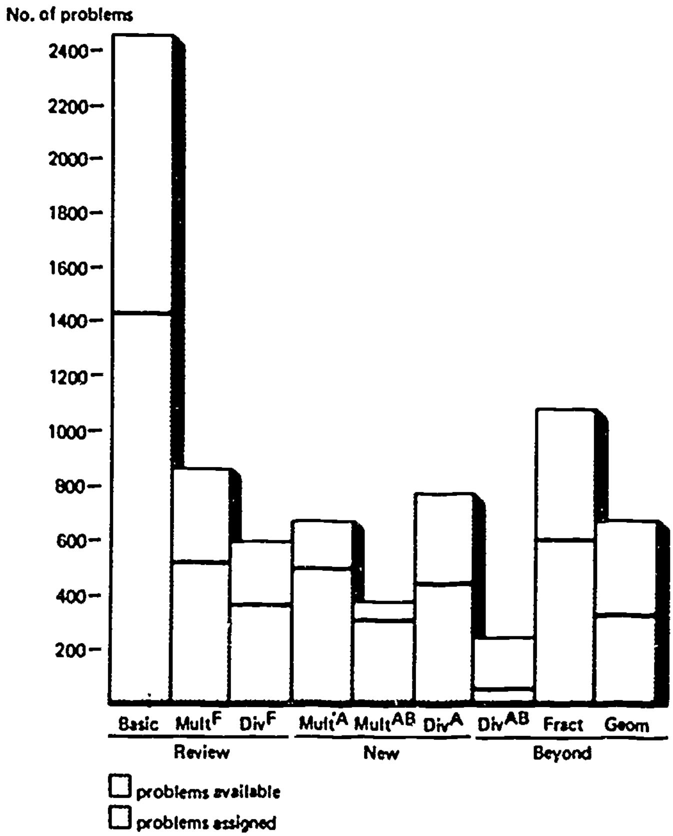

Figure 4 Average number of problems available in the text in the nine math areas and the average number assigned to students

Note: Reprinted, by permission, from R. Barr, *A Sociological Analysis of the Influence of Class Conditions on Mathematics Instruction,* 1985.

day are spent on average on science in grades kindergarten through three (Weiss, 1978). For these sorts of measures, it is assumed that more time or enrollment in more science courses represents a positive direction, although clearly there has to be an upper limit, considering other needs for the school curriculum. No advocate of science education would agree that the limit has as yet been reached in this country. A possible norm could be found in the time devoted to science instruction and in science course enrollments in other industrialized countries.

In order to develop references for assessing content coverage of local and state curriculum guidelines, textbooks, tests, and the like, the

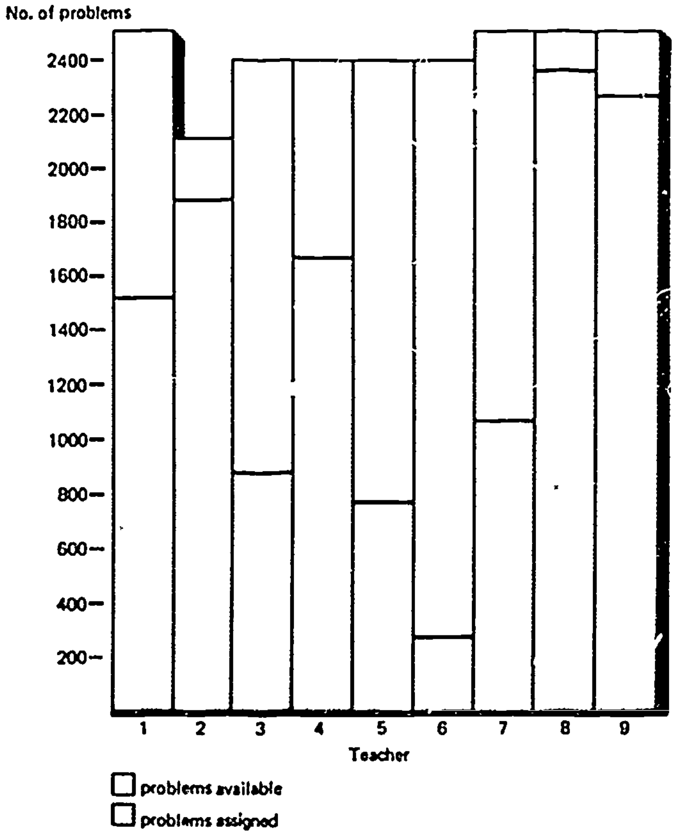

Figure 5 Number of basic math problems available in the text and the number assigned by the nine teachers
Note: Reprinted, by permission, from R. Barr, *A Sociological Analysis of the Influence of Class Conditions on Mathematics Instruction,* 1985.

approach being suggested by the committee starts with the development of exemplary curriculum frameworks designed to act as templates against which the content of existing and planned curricula could be matched. The degree of match between the content of a framework and the content of the analyzed textbook or other component of the intended curriculum would be expressed in a measure which would represent the comprehensiveness of coverage. The question arises as to what a suitable chunk of curriculum might be for the construction of a framework, since year-long blocks are not necessarily appropriate, particularly for the elementary science curriculum. One might think in terms of the following blocks: grades kindergarten through five, grades six through eight, and separate frameworks for individual high school science courses, perhaps separated into sequences for precollegiate preparation and for general scientific literacy to be expected of all graduating high school students. The frameworks could be used by a local school system interested in buying a new textbook series in science for grades kindergarten through five, or to decide on the kinds of tests to be used. Similarly, state or local curriculum guidelines could be mapped against such frameworks. At the same time, analyses could be carried out as to the suitability of given textbooks with respect to the wishes of the state policy makers, thus helping to inform decisions on textbook adoption.

In many cases, existing frameworks might be used as a starting point, such as the ones constructed for science by California (California State Department of Education, 1984) and South Carolina (South Carolina Department of Education, 1986). It may also be useful to look at curriculum frameworks from other countries (Klein & Rutherford, 1985). The committee believes that, in order to be useful to state and local education agencies, each exemplary curriculum framework needs to include several alternatives among desirable learning goals while at the same time presenting a common core that adequately represents the structure of the subject matter. For each of the major scientific principles to be included in a framework, alternative content topics should be listed as well as associated process skills so as to allow flexibility to states, localities, schools, and classrooms. The frameworks should represent the best thinking of scientists and curriculum specialists in each pertinent field. Periodic review and revision would be crucial to keep the frameworks current.

In principle, it would be possible to match the actual curriculum (as well as the intended or planned curriculum) to the frameworks. The kinds of opportunity-to-learn measures described above obtained through surveys of teachers and perhaps of older students might be used, given appropriate checks through actual observation on reliability of the information thus collected. Alternatively, as noted, classroom observation itself may be feasible for assessments of limited scope, particularly at the local district level. The information on the actual curriculum could be compared to the frameworks in the same manner as the information on the intended curriculum.

Depth of Treatment

The goal of science instruction is not just the learning of facts, but a basic understanding and appreciation of the structure of a scientific discipline, the process of doing it, and some of the complex problems solved and created by its application. Therefore, the curriculum needs to concentrate on a limited number of carefully chosen topics that form a coherent body of knowledge to be studied in depth—quite the opposite direction of the usual practice in textbook revisions that results in tacking on additional topics to an already over-abundant menu. The literature also suggests that the use of laboratory or hands-on experiences and the in-depth study of particular topics are related to the engagement of students and to their interest in a course (Harms & Yager, 1981). Therefore, in the committee's view, the proposed frameworks need to accommodate judgments on depth of coverage as well as breadth of coverage by making depth of coverage an explicit evaluation criterion.

Once a framework is in hand, it can be used as a template to make judgments on the depth of coverage in text and other materials, and in classroom instruction. The judgments will depend on the weights assigned by the judges to the importance of various topics, concepts, and processes. It is quite possible that different weights might be assigned by different judges to particular topics and even to the need for broad coverage as contrasted to the depth of coverage of key topics and concepts. For example, scientists and disciplinary specialists may place greater emphasis on depth versus breadth than do state and local curriculum authorities. Therefore, in the judgment process, the weights assigned to various topics, concepts, and process skills by different expert groups should be clearly noted.

Scientific Accuracy

The committee also recommends that the quality of the science as presented in the curriculum be evaluated. It suggests that the assessment of the scientific accuracy of the intended curriculum's content—for example, the materials intended to guide instruction, including state and local guidelines, textbooks, computer software, laboratory materials, and tests—could be carried out periodically by panels of scientists convened for this purpose. It would be desirable to carry out such reviews in conjunction with the ratings of materials for content coverage and depth, so that information on all three factors regarding a particular textbook or test would become available at the same time.

Assessing the scientific accuracy of content as it is actually presented by teachers in the classroom is much more difficult, for the reasons already stated. The committee views classroom observation as an appropriate tool, but at best it could provide information on only a limited number of classrooms. Another approach considered by the committee may be to establish some sort of threshold through teacher tests of subject matter competence—a necessary, if not sufficient, condition for scientifically accurate instruction. Like the tests for students, the tests for teachers should be based on the content of the relevant framework.

Pedagogic Quality

The problems of assessing pedagogic quality are analogous to those of assessing scientific accuracy, except that the aspects of the curriculum to be judged are instructional strategies, design and sequencing, and consonance with what is known about learning various scientific constructs, processes, skills, and the like. Panels of relevant experts could judge the pedagogic strengths and weaknesses of the components that constitute the intended curriculum, but in the committee's view indicators of the pedagogic quality of actual classroom practice would be difficult and expensive to obtain. Not only do the limitations of teacher surveys and classroom observation already discussed apply to this area as well, but there are additional obstacles in the relative lack of consensus on the best pedagogic practice, despite years of research on teaching effectiveness (see, for example, Darling-Hammond & Hudson, 1986).

Effective teaching strategies appear to be closely linked to context, that is, to the teaching of specific subject matter, at specific grade levels, to student populations with specific competencies. Since research on teaching effectiveness is just beginning to take account of these contextual factors, one would hesitate at this time even to suggest some sort of test of pedagogic competence. Perhaps the follow-up work to the report by the Carnegie Forum on Education and the Economy (1986), which will aim to create a national board for teaching standards and teacher certification, will help build the needed understanding and consensus on what pedagogic knowledge teachers need to have in given settings.

Creation of Standards

A parallel strategy considered by the committee for assessing the overall quality of the science curriculum is the development of standards of excellence through selecting and profiling high quality programs, somewhat in the fashion of the *Focus on Excellence* series published by the National Science Teachers Association (1983-84), but in a more systematic manner to cover adequately the several curriculum blocks from grades kindergarten to five through high school. Selected high quality programs could then be analyzed by scientists, science educators, teachers, and cognitive researchers to provide a synthesis of a high quality model or several models. The notion would be to capture in a holistic manner the several dimensions of quality—breadth, depth, scientific accuracy, pedagogic quality—rather than analyzing for them separately.

These two modes are not necessarily independent, in that the holistic strategy might use the separate analyses of the different quality dimensions as a starting point or the results of the holistic syntheses might be used to construct the exemplary frameworks and elucidate pedagogic quality. The two strategies could be developed in parallel to make possible an improved understanding of the quality of the science curriculum in the country's schools.

FOOTNOTES

1. See, for example, Adler, 1982; Boyer, 1983; Education Commission of the States Task Force on Education for Economic Growth, 1983; National Commission on Excellence in Education, 1983; National Science Board Commission on Precollege Education in Mathematics, Science and Technology, 1983; Sizer, 1984; and Twentieth Century Fund Task Force on Federal Elementary and Secondary Education Policy, 1983.

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Chapter 12

WHAT'S BEING TAUGHT AND WHO'S TEACHING IT

Bill G. Aldridge

A survey of U.S. public and private high schools was conducted during August and September of 1985. The data collected included science course offerings of the schools and specific teaching assignments of the teachers for the 1985–86 school year. For the first time, accurate information is available on the number of science teachers in U.S. high schools, what they are teaching, at what levels, how much the computer is being used, and assignment differences between men and women.

U.S. REGISTRY

For more than fifteen years, the National Science Teachers Association (NSTA) has been collecting the names of science teachers and their teaching assignments for grades seven through twelve in U.S. secondary schools. This effort was originally supported by the National Science Foundation as part of its undertaking to maintain an official registry of scientific personnel. When funding for the project ended many years ago, NSTA decided to continue maintaining the registry, and it is still called the Official U.S. Registry of Teachers.

The registry is maintained through annual mailings to secondary school principals who fill out a form indicating the names of their science, math, and social science teachers; the subjects, grade level, and number of sections they teach; and whether or not they use the computer to teach a subject. These forms are sent out every August, a time when school principals know their enrollments and have made teaching assignments for the impending school year. Even though the usual response is only about 50 percent, the response rate appears to be nearly random from year to year; thus the average school is updated in the registry about every two years. The registry now contains names and teaching information on about 350,000 science, social science, and mathematics teachers in U.S. secondary schools.

NSTA has been able to maintain the registry over the years by marketing its mailing labels. In addition to being used by NSTA and various government agencies like the National Science Foundation, the mailing labels are sold to publishing and supply companies and equipment manufacturers. Because NSTA could not afford the expense of detailed analyses of survey results, the National Science Foundation supported an analysis component of the 1985-86 survey.

SURVEY SAMPLE SELECTION

The U.S. registry forms for the 1985-86 school year were mailed in August of 1985. Of the 48,427 forms mailed, about 26,000 were returned by the end of October. Others continued to arrive throughout the school year. The final return, however, was not greater than 28,000. The sample for this study was assembled from the 26,000 responses. It was created as a stratified random sample of 2,211 high schools containing 8,539 teachers who taught one or more sections of science. For the purposes of this study, a high school was defined as a school that contained grade twelve. The sample was stratified by seven ranges of school size, three grade ranges (grades kindergarten to twelve, grades seven to twelve, and either grades nine to twelve or ten to twelve), and whether the school was public or non-public. Therefore, the strata contained 42 cells. Table 1 shows the total number of high schools in the United States for each cell. These numbers were derived from the 1985-86 catalog of Quality Education Data, Inc. (1986, p. 21), which compiles school lists.

Table 1 also shows the number of schools included in the sample. The last section of the table, the scaling factor, shows the ratio of the total schools in the United States to the number of schools in the sample for each cell. This ratio is used as a weighting factor for each cell in computing an average per school statistic and then extrapolating to the total population. If means and standard errors are calculated for each cell, then totals for the population and their standard errors can also be calculated. The correct estimate of the extrapolated variance is the cell variance multiplied by the factor, $N\,[(N - n)/n]$. The square root of the sum of the variances over a group of cells gives the sampling standard error for that extrapolated group.

METHODOLOGY

Survey forms for the study were hand selected from the 26,000 responses but, except for the variables of concern, were randomly picked. The forms were then sent to the University of Maryland, where, under the direction of Dr. Jeri Benson, the data were screened for completeness and entered into a computer file. Although some attempts were made to analyze these data using a statistical package, the results were not consistent or useful. Thus, a data tape was made and the data files loaded onto a microcomptuer system (MS/DOS) at NSTA headquarters. The data were carefully examined and reloaded into a database management system (Revelation). Programs were then written to answer various questions. The resulting reports, all extrapolated to the population, are good estimates for the high schools of the United States. Individual cell results are, of course, less reliable, and for cases of small numbers of schools per cell, may be of little value.

RESULTS

Initial results are all that are available at the time of preparation of this paper. These results are mainly from two types of computer printouts. The first of these gives the number of teachers in the sample for that particular category, the total number of teachers in that population (the extrapolated value), the total number of class sections taught, and then a listing of those class sections, as they break down by subject taught. Finally, this report shows the average teaching load of teachers in this category. The second report is much more detailed. It gives results by gender and grade level, and shows which teachers are using computers and in which classes. Because these are preliminary results, the figures have not been rounded and in some cases suggest a precision that is not warranted by the method of calculation. Caution should be used in interpreting the number of significant digits.

Science Teachers

Table 2 gives results of the survey for all high school teachers who teach one or more sections of science. The sample contains 8,539 teachers. There are 94,480 persons teaching one or more sections of science in schools in the United States that contain grade twelve. There are 424,518 sections of science, math, and non-science being taught by these teachers.

Table 1. Total high schools in the United States and in the survey sample based on size, grade level, and public or non-public status

Grade level	School size 1-99	100-299	300-499	500-749	750-999	1000-1499	1500+
Total high schools in the United States							
Public schools							
7-12	247	1051	815	631	266	208	79
9,10-12	461	1404	1435	1560	1354	2190	2004
K-12	339	1141	724	441	197	105	23
Non-public schools							
7-12	195	243	112	54	14	11	0
9,10-12	317	535	387	296	202	136	48
K-12	2327	1583	614	326	111	70	0
Survey sample							
Public schools							
7-12	48	179	143	82	38	17	3
9,10-12	63	191	195	206	136	173	90
K-12	11	66	35	28	25	15	6
Non-public schools							
7-12	22	40	13	3	1	2	0
9,10-12	20	73	67	38	29	14	8
K-12	11	50	40	19	9	2	0

	School size						
Grade level	1-99	100-299	300-499	500-749	750-999	1000-1499	1500+
Scaling factor							
Public schools							
7-12	5.15	5.87	5.70	7.70	7.00	12.24	26.33
9,10-12	7.32	7.36	7.35	7.57	9.96	12.66	22.27
K-12	30.82	17.29	20.69	15.75	7.88	7.00	3.83
Non-public schools							
7-12	8.86	6.08	8.62	18.00	14.09	5.50	0
9,10-12	15.85	7.35	5.78	7.79	6.97	9.71	6.00
K-12	211.55	31.66	15.35	17.16	12.33	35.00	0

Table 2. Science teachers in the United States by discipline, number of sections taught, and percent of teaching load (extrapolated from survey sample of n = 8,539)

Total individuals teaching = 94,480
Total sections taught = 424,518

Discipline	Sections	Percent of teaching load
Biology	129,282	30.45
Chemistry	62,130	14.63
Physics	32,217	7.58
Environmental sciences	[illegible],464	2.46
Earth-space sciences	25,644	6.04
Advanced physical sciences	20,177	4.75
Physical sciences, grades 7–9	28,346	6.67
Advanced life sciences	21,331	5.02
Life sciences, grades 7–9	15,284	3.60
General applied sciences	23,749	5.59
Mathematics	33,258	7.83
Non-science courses	22,630	5.33
Total	424,518	100.00

Average number of sections taught = 4.49

Table 3 indicates the sex of science teachers (if given in the survey) and how many science teachers use computers to teach their sections. If a teacher is shown to teach three sections and checks the column that he or she uses a computer, it is not known whether the computer is used in all three sections or only in one. Thus, the maximum possible use of the computer is indicated with the word, "potential." Table 4 gives information on the teaching load of individual science teachers. For example, most science teachers teach four, five, or six sections.

Biology Teachers

Tables 5–8 provide results for high school teachers who teach one or more sections of biology. Table 5 shows how the average teacher's load is distributed. Tables 6 and 7 contain the same kinds of basic data as shown for science teachers in Table 3 and 4. However, for the specific disciplines, some of the results require a different interpretation than for the general case. The distribution of sections (Table 7) and grade levels (Table 8) give important information on how many teachers are teaching only one section, two sections, and so forth, and the level at which the course is taught.

Physics and Chemistry Teachers

Tables 9–16 provide similar results for chemistry and physics teachers. Thus, this paper conveys basic survey results for the core high school

Table 3. Science teachers, sections taught and computer use by sex (extrapolated from survey sample of $n = 8{,}539$)

Total individuals teaching = 94,480
Total sections taught = 424,518

	Number	Percent
Sex of teacher		
Male	63,544	67.25
Female	29,949	31.69
No sex given	986	1.04
Total	94,480	
Sections taught, by sex of teacher		
Male	283,868	66.86
Female	136,825	32.23
No sex given	3,823	.90
Total	424,518	
Computer use, by sex of teacher		
Male	18,041	71.08
Female	6,889	27.14
No sex given	450	1.77
Total	25,381	100.00
Sections potentially using computers, by sex of teacher		
Male	65,016	69.56
Female	27,325	29.23
No sex given	1,115	1.19
Total	93,457	100.00

Table 4. Distribution of sections taught by one science teacher

No. of sections	No. of teachers	Percent	Total sections	Percent
1	5,498	5.81	5,498	1.29
2	6,557	6.94	13,115	3.08
3	7,435	7.86	22,305	5.25
4	15,259	16.15	61,037	14.37
5	42,127	44.58	210,638	49.61
6	11,359	12.02	68,157	16.05
7	1,810	1.91	12,671	2.98
8	1,163	1.23	9,307	2.19
9	314	.33	2,826	.66
No number	2,954	3.12	18,958	4.46
Total	94,480	100.00	424,518	100.00

Table 5. Disciplines taught by biology teachers, by number of sections taught and percent of teaching load (extrapolated from survey sample of $n = 3,762$)

Total individuals teaching biology = 42,823
Total sections taught = 129,283

Discipline	Sections	Percent of teaching load
Biology	129,282	63.21
Chemistry	13,165	6.43
Physics	5,423	2.65
Environmental sciences	4,392	2.14
Earth-space sciences	5,106	2.49
Advanced physical sciences	5,576	2.72
Physical sciences, grades 7–9	6,041	2.95
Advanced life sciences	10,519	5.14
Life sciences, grades 7–9	6,066	2.96
General applied sciences	7,160	3.50
Mathematics	5,935	2.90
Non-science courses	5,842	2.85
Total	204,513	100.00

Average number of sections taught = 4.77

science courses of biology, chemistry, and physics. Figure 1 shows a breakdown of teaching assignments for the average biology, physics, and chemistry teacher. The study examined several other subjects in the physical, earth, and life sciences, and those results will be available from NSTA through its general publications in the form of a monograph.

DISCUSSION

There are several important results from this survey that should be noted. There are 94,500 teachers teaching one or more sections in the nation's high schools. These teachers are teaching 369,000 sections of science, 22,600 sections of non-science, and 33,300 sections of mathematics. There are 14,628,000 students enrolled in these high schools. From a 1982–83 NSTA study, class size can be used to determine the total number of students enrolled in 1985–86, assuming class size has remained the same. By this method, there were 8,292,000 students (56.7 percent of total) enrolled in science courses in U.S. high schools in 1985–86. This appears to be a somewhat smaller number than would be expected, especially since many students may be enrolled in more than one science class. Still, on the average, this would imply that the typical high school student takes two courses in science during grades nine through twelve.

Table 6. **Biology teachers, sections taught and computer use by sex (extrapolated from survey sample of n = 3,762)**

Total individuals teaching biology = 42,822
Total sections = 129,282

	Number	Percent
Sex of teacher		
Male	27,104	63.29
Female	15,215	35.53
No sex given	502	1.17
Total	42,822	
Sections taught, by sex of teacher		
Male	81,453	63.00
Female	46,587	36.03
No sex given	1,242	.96
Total	129,282	
Computer used, by sex of teacher		
Male	6,126	63.40
Female	3,209	33.21
No sex given	326	3.37
Total	9,662	100.00
Sections potentially using computers, by sex of teacher		
Male	17,329	64.94
Female	8,737	32.74
No sex given	615	2.30
Total	26,682	100.00

Table 7. **Distribution of sections taught by one biology teacher**

No. of sections	No. of teachers	Percent	Total sections	Percent
1	10,276	23.99	10,276	7.94
2	8,179	19.10	16,359	12.65
3	7,193	16.79	21,581	16.69
4	6,640	15.50	26,562	20.54
5	8,983	20.97	44,918	34.74
6	1,407	3.28	8,442	6.53
7	58	.13	412	.31
8	13	.03	111	.08
9	68	.16	617	.47
No number	0	.00	0	.00
Total	42,822	100.00	'29,282	100.00

Table 8. Distribution of grade levels taught by one biology teacher

Grades taught	No. of teachers	Percent	Total sections	Percent
9	4,072	9.50	10,679	8.26
10	23,718	55.38	68,789	53.20
11	559	1.30	1,731	1.33
12	469	1.09	841	.65
9&10	2,651	6.19	8,069	6.24
9&11	69	.16	260	.20
9&12	150	.35	638	.49
10&11	764	1.78	2,975	2.30
10&12	761	1.77	3,046	2.35
11&12	465	1.08	1,281	.99
9-11	461	1.07	1,825	1.41
9-12	3,877	9.05	13,027	10.07
10-12	4,444	10.37	14,844	11.48
Other	153	.35	552	.42
Error	202	.47	717	.55
Total	42,822	100.00	129,282	100.00

Table 9. Disciplines taught by chemistry teachers, by number of sections taught and percent of teaching load (extrapolated from survey sample of $n = 2{,}390$)

Total individuals teaching chemistry = 26,308
Total sections taught = 62,131

Discipline	Sections	Percent of teaching load
Biology	15,642	12.17
Chemistry	62,130	48.36
Physics	12,509	9.73
Environmental sciences	1,269	.98
Earth-space sciences	3,143	2.44
Advanced physical sciences	5,280	4.11
Physical sciences, grades 7-9	6,926	5.39
Advanced life sciences	2,562	1.99
Life sciences, grades 7-9	3,538	2.75
General applied sciences	4,700	3.65
Mathematics	7,524	5.85
Non-science courses	3,224	2.51
Total	128,453	100.00

Average number of sections taught = 4.88

Table 10. Chemistry teachers, sections taught and computer use by sex (extrapolated from survey sample of $n = 2,390$)

Total individuals teaching chemistry = 26,308
Total sections taught = 62,130

	Number	Percent
Sex of teacher		
Male	17,179	65.29
Female	9,017	34.27
No sex given	111	.42
Total	26,308	
Sections taught, by sex of teacher		
Male	40,531	65.23
Female	21,243	34.19
No sex given	356	.57
Total	62,130	
Computer used, by sex of teacher		
Male	6,125	67.84
Female	2,877	31.86
No sex given	25	.28
Total	9,027	100.00
Sections potentially using computers, by sex of teacher		
Male	14,620	68.55
Female	6,665	31.25
No sex given	41	.19
Total	21,327	100.00

Table 11. Distribution of sections taught by one chemistry teacher

No. of sections	No. of teachers	Percent	Total sections	Percent
1	10,617	40.35	10,617	17.08
2	5,564	21.15	11,129	17.91
3	4,031	15.32	12,093	19.46
4	2,808	10.67	11,232	18.07
5	2,828	10.75	14,140	22.75
6	393	1.49	2,360	3.79
7	9	.03	69	.11
8	7	.02	58	.09
9	47	.18	427	.68
No number	0	.00	0	.00
Total	26,308	100.00	62,130	100.00

Table 12. Distribution of grade levels taught by one chemistry teacher

Grades taught	No. of teachers	Percent	Total sections	Percent
9	78	.29	188	.30
10	1,079	4.10	2,709	4.36
11	10,683	40.60	24,085	38.76
12	1,443	5.48	2,550	4.10
9&10	77	.29	174	.28
9&11	0	.00	0	.00
9&12	14	.05	56	.09
10&11	909	3.45	2,596	4.17
10&12	359	1.36	1,334	2.14
11&12	7,677	29.18	15,973	25.70
9–11	39	.14	68	.11
9–12	869	3.30	2,304	3.70
10–12	2,912	11.07	9,560	15.38
Other	47	.18	116	.18
Error	116	.44	409	.65
Total	26,308	100.00	62,130	100.00

Table 13. Disciplines taught by physics teachers, by number of sections taught and percent of teaching load (extrapolated from survey sample of $n = 1,774$)

Total individuals teaching physics = 19,029
Total sections taught = 32,217

Discipline	Sections	Percent of teaching load
Biology	7,471	8.03
Chemistry	17,115	18.40
Physics	32,217	34.63
Environmental sciences	838	.90
Earth-space sciences	2,544	2.73
Advanced physical sciences	3,900	4.19
Physical sciences, grades 7–9	5,538	5.95
Advanced life sciences	2,173	2.33
Life sciences, grades 7–9	2,412	2.59
General applied sciences	3,824	4.11
Mathematics	11,172	12.01
Non-science courses	3,809	4.09
Total	93,018	100.00

Average number of sections taught = 4.88

Table 14. Physics teachers, sections taught and computer use by sex (extrapolated from survey sample of $n = 1,774$)

Total individuals teaching physics = 19,028
Total sections taught = 32,217

	Number	Percent
Sex of teacher		
Male	14,453	75.95
Female	4,422	23.24
No sex given	152	.80
Total	19,028	
Sections taught, by sex of teacher		
Male	24,930	77.38
Female	6,827	21.19
No sex given	459	1.42
Total	32,217	
Computer use, by sex of teacher		
Male	6,123	77.23
Female	1,739	21.94
No sex given	64	.81
Total	7,928	100.00
Sections potentially using computers, by sex of teacher		
Male	10,368	79.03
Female	2,534	19.31
No sex given	215	1.64
Total	13,118	100.00

Table 15. Distribution of sections taught by one physics teacher

No. of sections	No. of teachers	Percent	Total sections	Percent
1	12,063	63.39	12,063	37.44
2	3,668	19.27	7,337	22.77
3	1,404	7.37	4,212	13.07
4	1,009	5.30	4,036	12.52
5	767	4.03	3,837	11.91
6	100	.52	601	1.86
7	0	.00	0	.00
8	6	.03	48	.14
9	8	.40	79	.24
No number	0	.00	0	.00
Total	19,028	100.00	32,217	100.00

Table 16. Distribution of grade levels taught by one physics teacher

Grades taught	No. of teachers	Percent	Total sections	Percent
9	625	3.28	1,659	5.15
10	160	.84	376	1.16
11	1,294	6.80	2,501	7.76
12	9,626	50.59	14,671	45.53
9&10	131	.69	443	1.37
9&11	31	.16	63	.19
9&12	14	.07	28	.08
10&11	284	1.49	337	1.04
10&12	66	.34	129	.40
11&12	5,217	27.41	8,850	27.47
9–11	221	1.16	221	.68
9–12	554	2.91	1,243	3.85
10–12	709	3.72	1,445	4.48
Other	7	.03	22	.07
Error	81	.42	222	.68
Total	19,028	100.00	32,217	100.00

If, however, as might be expected, all ninth grade students are enrolled in science, then the other course in science, taken during grades ten to twelve, would reflect an average enrollment of about one-third of the students per year. Since this study applies to the 1985–86 school year, when most states had already increased their science requirements, the fact that only one-third of the students in grades ten to twelve are taking science shows that there is still a participation problem.

Among some of the most dramatic results of this study were the following:

- ☐ 7,100 high schools offered no physics courses in 1985–86;
- ☐ 4,200 high schools offered no chemistry courses in 1985–86; and
- ☐ 1,900 high schools offered no biology courses in 1985–86.

Of the schools offering physics, 63.3 percent offered only one section, and 89.3 percent offered two or fewer sections. For chemistry, 37.4 percent of those offering it had only one section, and 67.6 percent offered two or fewer sections. Of the schools offering biology, 17.9 percent offered only one section, and 43.5 percent offered two or fewer sections.

The other, most striking result of this survey is the huge variety of teaching assignments given to science teachers. Science teachers are given multiple assignments in far greater numbers than previously believed. Also, very few science teachers have the opportunity to teach in a single

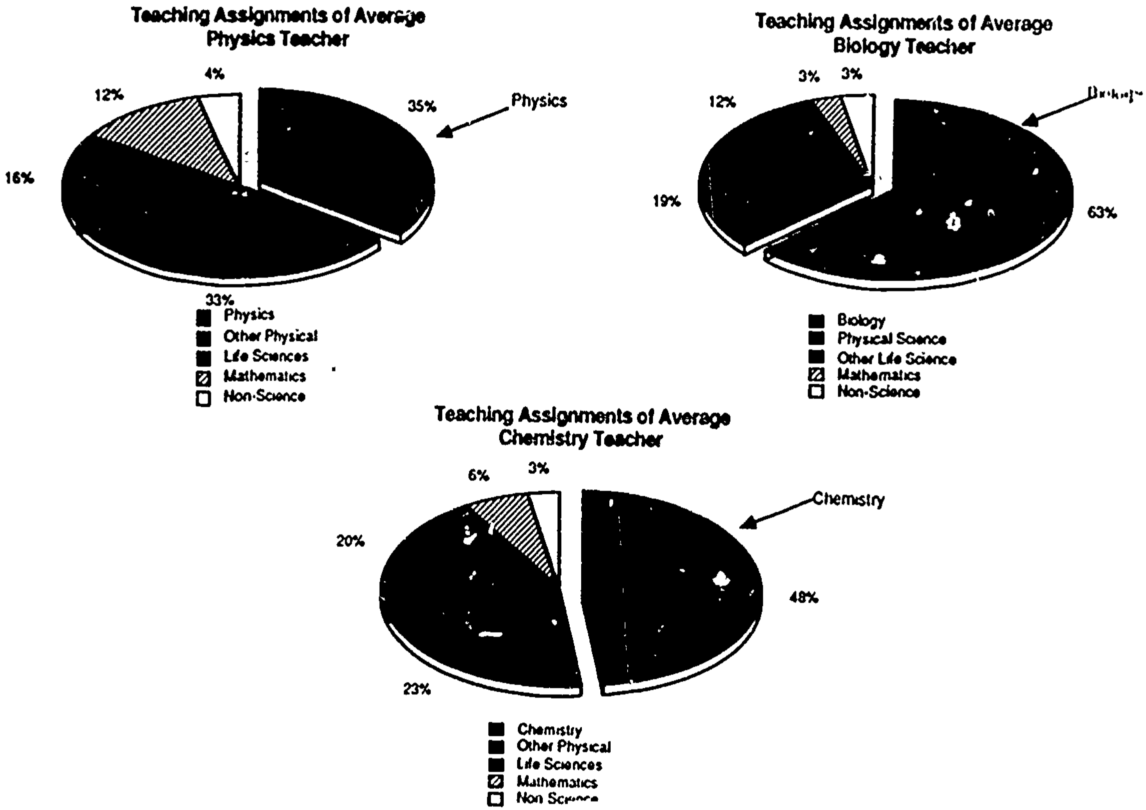

Figure 1 NSTA survey: 1985-86 school year

discipline. Physics, for example, is taught as a single section by 12,100 of the 19,000 teachers who teach one or more sections. Furthermore, 82.7 percent of all physics teachers teach either one section or two sections. Similar, but less dramatic results are apparent for both chemistry and biology.

Another important result of the survey is the fact that far fewer science courses are taught by non-science faculty than previously believed. If there were large numbers of non-science teachers teaching science as part of their load, one would expect to see a large number of teachers who teach one or more sections of science teaching three or more sections of non-science. Yet 59 percent of the non-science courses taught by teachers who teach one or more science courses constitute either one or two sections. This would imply that it is science teachers who pick up a non-science course to teach rather than non-science teachers who teach science. In any case, only 5.3 percent of the course load of teachers who teach one or more science courses is in non-science subjects. Also, only 7.8 percent is in mathematics, where one might reasonably expect to have in-field assignments for physics teachers, whose preparation is strongly mathematical.

There are several other results of some interest in this study. Some interesting comparisons can be made between public and non-public schools. For example, non-public schools offer more hard subjects like physics than do public schools, whereas public schools offer more "soft" sciences like biology and environmental science. However, in the hard subjects like physics and chemistry, there is greater use of the computer in the public schools than in the non-public schools.

Gender comparisons can also be made through the results of this survey. About 67 percent of science teachers are male and 33 percent female; however, in physics, 76 percent are male and about 23 percent female. Small differences appear in the use of the computer. For the most part, however, there appear to be negligible relative differences between the sexes in number of sections taught and in use of the computer.

The reader can examine a wide range of questions by computations among the results printed in the tables. Additional tables will soon be available from NSTA. These will cover all of the courses assigned to teachers who teach one or more science courses.

CONCLUSIONS

The major conclusion of this survey is that science teachers do not fit the stereotype of teaching in a single discipline. The idea that one prepares to be a physics teacher, biology teacher, or chemistry teacher for high school in the same way as for a college position is seen to be inaccurate. High school science teachers are more nearly that, *science* teachers, not single discipline teachers. The implications of this fact for preservice preparation and for licensing and certification are obvious. What is clearly needed is preparation for multiassignments, preferably in related disciplines. For example, persons trained in physics, chemistry, and mathematics are needed in one undergraduate program. These persons also need to be licensed and certified for all three fields. Then under no circumstances should they be assigned to other fields, as is now being done routinely. Similarly, a multiple preparation might include biology and chemistry, or it might include physics, astronomy, and geology.

An important conclusion of this survey is that the retraining task for teachers out-of-field is not nearly so formidable as previously believed. Since most out-of-field science teaching is being done by science teachers prepared in another field of science, the retraining time is greatly shortened. A person trained in one field of science can more easily learn another science field than a non-science teacher. This means that National Science Foundation institutes or workshops have a far greater potential for improving the situation than if non-science personnel were involved. The implication, however, is that the National Science Foundation and other organizations need to provide support for training a teacher in a second or third science field rather than in his or her major field of study. For example, even if a physics teacher has only 20 or 30 credits in physics, it is far more important to provide needed training in chemistry or biology, where the teacher may be teaching on a misassigned basis and for which he or she has no course work.

There are undoubtedly other important conclusions and recommendations implied by the results of this survey. When data analysis is complete, and additional results available, a full report will appear through NSTA's regular publication offerings.

Chapter 13

THE 1985-86 NATIONAL SURVEY OF SCIENCE AND MATHEMATICS EDUCATION*

Iris R. Weiss

The 1985–86 National Survey of Science and Mathematics Education was designed for two purposes. (1) to collect information on the current status of science and mathematics education; and (2) to identify trends that have emerged since the last major survey on these subject areas in 1977. Topics covered in the 1985–86 study included science and mathematics course offerings and enrollments, availability of facilities and equipment, instructional techniques, textbook usage, teacher background, and in-service education.

METHODOLOGY

The survey utilized a national probability sample of 425 schools at each of three grade ranges: kindergarten to sixth, seventh to ninth, tenth to twelfth. In each case, all public and private schools in the United States containing one or more of the target grades were included in the sampling frame. Thus, for example, a middle school with grades five to eight was eligible for selection in either the kindergarten to sixth grade or seventh to ninth grade sample or both. A total of approximately 6,000 science and mathematics teachers were randomly selected from teacher lists provided by the schools, and they and the principals were asked to complete appropriate questionnaries. Data were collected primarily by mail with mail and telephone follow-ups as needed. Planning for the

*This paper is based on work conducted by the author at Research Triangle Institute under a grant from The National Science Foundation.

study included two major components—(1) designing survey instruments that would provide the necessary information and (2) developing a data collection plan that would ensure high quality data. The accuracy and utility of the survey results depended on the successful accomplishment of both of these tasks.

INSTRUMENT DEVELOPMENT

Questionnaire development was carried out with the assistance of an advisory panel of experts in science and mathematics education, several of whom had also been involved in the 1977 study. All of the experts were acutely aware of the difficulty and expense of conducting school surveys; there was a constant tension between a desire for information and a recognition of the many constraints involved. Ideally one wants to collect information about those teacher and curriculum variables that are causally related to the primary outcomes of interest, for example, student achievement and attitudes. The problem is that current understanding of the educational process is very incomplete. It is simply not always known what makes a difference, and why. Consequently, Research Triangle Institute (RTI) staff and consultants had lengthy debates about the relative importance of collecting various bits of information. An overriding concern was to avoid having the questionnaires look imposing, require a lengthy completion time, or both.

One particularly thorny issue in the instrument development process was the need for trend data. The 1977 survey had demonstrated a way to improve some items, but any modifications would weaken the ability to detect changes since 1977. Again, lengthy debates were held about those cases where trend data would be so important that it was worth keeping the item identical even if it meant perpetuating inefficiencies. Sometimes items were changed; sometimes they were not.

At other times, RTI staff and consultants wrestled with the question of whether a survey was the best, or even an adequate, source of a particular type of information. For example, teacher self-report data on the amount of time spent on elementary school science are considerably more suspect than observational data. But rarely can a study afford to observe a nationally representative sample of schools. The RTI staff and consultants decided to go ahead and collect self-report data, as had been done in the 1977 survey, advising the user to "exercise caution in interpreting these results since they are based on teacher estimates of time spent rather than on precise measurements."

At the secondary level, the problem faced was trying to collect detailed information on the curriculum from teachers who typically teach several different courses each day; one would expect considerable differences depending on such factors as the type of course and the ability level of the students. As in the 1977 survey, the decision was made to randomly select a single class for questions about textbook usage, curriculum content, instructional objectives, and the like. In fact, one section of the questionnaire focused on a single lesson, the most recent one, in order to get the most accurate estimates possible of how class time was apportioned among particular activities.

DATA COLLECTION PLAN

Early in the instrument development process, one of the most difficult parts of any school survey was initiated—the approval process. Before a survey can be conducted in the schools, permission must be obtained from a lot of different people; failure to do so will jeopardize a study's response rate, sometimes even undermining the entire effort. Federally funded surveys must usually obtain clearance from the Office of Management and Budget (OMB), often a time-consuming process. And while OMB clearance may be necessary, it is unfortunately not sufficient. Protocol dictates that the chief education officer in each state be contacted prior to a school survey, and most of these officers will not approve a study unless it has been endorsed by the Council of Chief State School Officers' Committee on Evaluation and Information Systems (CEIS), a committee that meets only twice a year. And even CEIS endorsement is no guarantee that every state will approve a survey. For some time it looked as though the 1985 National Survey of Science and Mathematics Education would be carried out in only 49 states and the District of Columbia.

Once states approve a survey, the approval process moves from dealing with fifty or so agencies to the hundreds, or sometimes thousands, of districts in the sample. Again, protocol dictates that the district superintendent be informed which schools have been selected, the number of teachers that will be contacted, and how they will be chosen. Some districts, especially the larger ones, have their own OMB-like procedures for approval of research efforts, and sometimes these can take weeks or even months. Throughout the data collection process, persistence usually pays off, but often at considerable cost to both a survey's budget and schedule.

All of the "right things" were done to carry out this survey—CEIS approval was obtained, approval of each chief state school officer was obtained, the ever-growing number of district approval procedures were complied with, and special confidentiality procedures were agreed to when schools were reluctant to provide teacher names for sampling purposes. The endorsement of more than twenty professional organizations was obtained, including the American Association for the Advancement of Science, the National Science Teachers Association, the National Education Association, the American Federation of Teachers, and the National Associations of Elementary and Secondary School Principals. The questionnaires were carefully designed for ease of completion, were field tested and revised, and were then typeset and printed in two colors to add to their appeal. Each school was sent a set of scientist posters as an incentive; they were also promised copies of the Highlights Report at the completion of the study. Despite these efforts, the teacher response rate after repeated mail follow-ups was a very disappointing 50 percent or so. (The principal response rate was about 85 percent). It made little sense to proceed with analysis at that point. Eventually, after extensive (and expensive) telephone follow-up, the teacher response rate reached approximately 75 percent.

SELECTED PRELIMINARY FINDINGS

High school biology is offered in nearly every high school in the United States; about nine out of every ten high schools also offer a course in chemistry, and eight out of ten offer a course in physics (Table 1). Not surprisingly, students who attend small high schools are less likely to have the opportunity to take chemistry and physics than are their counterparts in larger schools. Course offerings also differ by type of community, with suburban schools more likely to offer chemistry and physics than those in rural and urban areas. Half of all science classes in grades ten to twelve are biology and life science classes, with most of the rest chemistry and physics. Only 3 percent focus on the earth and space sciences, and only 1 percent are considered "general science." In contrast, junior high school science classes are distributed fairly evenly across content areas, with about 30 percent biology and life science and

Table 1. Percent of high schools offering selected science courses

	1977	1985-86
Biology	95	99
Chemistry	89	91
Physics	78	81

Table 2. Percent of science classes with particular content emphases

	Grades 7-9	Grades 10-12
General science	22	1
Biology, life sciences, environmental science	31	50
Chemistry, physics, physical science	21	42
Earth, space sciences	22	3
Other	3	4
Missing	3	1

the remainder about equally divided among physical science, earth science, and general science (Table 2).

What do these courses attempt to accomplish? Teachers were given a list of objectives and asked how much emphasis each would receive in a particular course. Results showed that secondary science teachers consider the learning of basic science concepts to be the most important objective; approximately 85 percent reported a heavy emphasis on this objective compared to only about 50 percent for having students become more interested in science. The least emphasized objective on the list was learning about the history of science, with only about 12 percent of the teachers reporting heavy emphasis on this objective (Table 3).

Table 3. Percent of science teachers giving heavy emphasis to particular objectives

	Grades 7-9	Grades 10-12
a. Become interested in science	52	47
b. Learn basic science concepts	85	85
c. Prepare for futher study in science	52	56
d. Develop inquiry skills	63	57
e. Develop a systematic approach to solving problems	62	67
f. Learn to effectively communicate ideas in science	42	49
g. Become aware of the importance of science in daily life	67	60
h. Learn about applications of science in technology	40	40
i. Learn about the career relevance of science	28	32
j. Learn about the history of science	12	11
k. Develop awareness of safety issues in the laboratory	50	53
l. Develop skill in laboratory techniques	46	57

Table 4. Percent of textbook covered in science courses

	Percent of science classes	
	Grades 7–9	Grades 10–12
Less than 25 percent	2	1
25–49 percent	10	11
50–74 percent	27	37
75–90 percent	39	33
More than 90 percent	20	15

How do secondary science teachers go about achieving their objectives? More than 95 percent of secondary science classes use published textbooks and programs, although fewer than one in five reported they cover the entire book (Table 4). It is interesting to note that only two textbook publishers—Merrill, and Holt, Rinehart and Winston—account for more than half of the textbook usage in secondary science.

While textbooks were frequently chosen by persons other than the individual classroom teacher—for example, by a group of teachers from the school or by a district-wide textbook adoption committee—most science teachers are fairly satisfied with their textbooks (Table 5). More than 80 percent consider the textbooks to be clear and well organized and at an appropriate reading level for most of their students. However, more than 40 percent of the teachers think their textbooks need to provide more examples to reinforce concepts and nearly that many find their textbooks lacking in examples of the use of science in daily life (Table 6).

What activities are taking place in science classes? The 1977 survey found that lectures and discussions were considerably more common

Table 5. Persons responsible for textbook selection

	Percent of science classes[1]	
	Grades 7–9	Grades 10–12
Teacher	36	49
Principal	14	9
Group of teachers from school	39	35
District-wide textbook committee	42	30
State-wide textbook committee	12	10
Other	2	1

[1]Respondents were asked to circle all that apply.

Table 6. Teacher opinions of science textbooks

	Percent of teachers agreeing	
	Grades 7-9	Grades 10-12
This textbook		
a. is at an appropriate reading level for most of my students.	81	85
b. is not very interesting to my students.	31	30
c. is unclear and disorganized.	9	8
d. helps develop problem-solving skills.	52	59
e. needs more examples to reinforce concepts.	47	42
f. explains concepts clearly.	68	73
g. provides good suggestions for activities and assignments.	56	57
h. lacks examples of the use of science in daily life.	38	35
i. shows the applications of science in careers.	62	49
j. has high quality supplementary materials.	48	44

than laboratory activities. The same is true today, and the difference is even greater. In describing their most recent science lesson in a randomly selected class, three out of four teachers in 1977 indicated that it included lecture and discussion, and slightly more than half said it included hands-on activities. In the 1985-86 survey, more than 80 percent reported lecturing in their most recent lesson and only about 40 percent indicated using hands-on activities (Table 7).

While more than two-thirds of secondary science classes have computers "available," fewer than one in five teachers reported that computers were readily available and even fewer used them to any great extent (Table 8). For example, while teachers reported using computers in

Table 7. Percent of science classes participating in various activities in most recent lesson

	1977		1985-86	
	Grades 7-9	Grades 10-12	Grades 7-9	Grades 10-12
Lecture	76	68	82	84
Discussion	77	85	80	79
Student use of hands-on	53	59	42	39

Table 8. Availability of computers for use with science classes

	Percent of science classes	
	Grades 7-9	Grades 10-12
Not available	34	25
Available but quite difficult to access	25	27
Available but somewhat difficult to access	26	26
Readily available	14	20

a wide variety of ways—for drill and practice, for simulations, to teach science content, and as a laboratory tool—most classes that use computers do so only minimally. Only about 7 percent of the teachers reported using computers in the previous week's instruction in the randomly selected class, and the majority of these indicated that a typical student spent less than fifteen minutes working with computers (Table 9).

USES OF THE DATA

The 1977 survey results have been used by a wide variety of people, and similar use of the 1985-86 survey data is anticipated. At the federal level, data from the 1985-86 survey will appear in a National Science Foundation report on science indicators. Information is also being provided to several studies being conducted for the Department of Education's Center for Statistics. At least one state is planning to replicate this survey on a statewide basis, as they did following the 1977 survey, so they can compare their results to those in the nation as a whole. There have also been numerous requests for copies of the 1985-86 report and requests for presentations at professional meetings.

Table 9. Time typical student spent working with computers in science class during the previous week

	Percent of science classes	
	Grades 7-9	Grades 10-12
None	94	91
1-14 minutes	3	6
15-29 minutes	0	1
30-44 minutes	1	1
45-60 minutes	1	1
More than 60 minutes	1	0

The analyses completed and the additional analyses planned will only scratch the surface of what is a very rich and extremely interesting database. Therefore, it is particularly exciting to see another type of data usage emerging—having other researchers conduct additional analyses to answer questions of particular interest to them. Researchers at a number of universities and contract research organizations have already indicated their plans to do additional analyses on the public release data tape being prepared. In addition, the National Association for Research in Science Teaching is exploring the possibility of having a workshop for graduate students who may be interested in doing further analyses of our survey data as part of their doctoral programs.

It is clear that collecting high quality survey data is a very difficult, time-consuming, and expensive process but one that is an essential component of informed policy making. Identification of important information needs, careful collection of high quality data, full analysis of the data that have been collected, and widespread dissemination of the results will help ensure that the most benefit is received from the limited resources available for data collection.

Chapter 14

UPDATING THE SCIENCE CURRICULUM
Who, What and How?

Joanne Capper

A number of states and districts throughout the nation have recognized and attended to the need to update the science curriculum of elementary and secondary schools. Educators have begun to acknowledge the importance of some degree of scientific and technological literacy for all students, not just those that plan to specialize in science in college. But there are serious drawbacks to the current approach to curriculum development—factors that undermine the possibility of providing students with an intellectually satisfying science education.

Theoretically, the science curriculum in the United States is determined at the local level—by states, by districts, and in classrooms. The implemented curriculum, however, resembles a national curriculum, one that skims lightly over many topics but covers few to the level of depth that would allow students to think about science in a meaningful way. This is due primarily to two factors: the way textbook content is determined, and the profound reliance that teachers have on textbooks.

Curriculum development is strongly influenced by the textbook adoption process. States and districts adopt frameworks—science frameworks, mathematics frameworks, and so forth—which specify curriculum expectations. Publishers know that if they are to sell textbooks, their books must address the curricula of the buyers. But since publishers are unable to address all the goals specified in every district and state in the country, they must choose from among the frameworks.

LARGE STATES DETERMINE SCIENCE CURRICULUM

Twenty-two state education agencies assume direct control over the selection and purchase of textbooks for all the local districts in their respective states. And among those 22 states are the large and populous states of Texas, California, and Florida. Winning or losing an adoption in those three states can make or break a textbook company (Tyson, 1986). Because publishers cannot afford to produce a separate edition of a text for each state or district, they produce one textbook designed to please as many states or districts as possible. Since California, Texas, and Florida account for such a large part of textbook sales in the nation, these states wield an immense amount of influence over the content of textbooks. If publishers could afford to develop a separate text for each state or district, the implemented curriculum at the local level would be much more likely to reflect each district or state's curriculum. Since this is not economically feasible, the result is that many districts go through the process of developing their own science curricula, but use textbooks that more closely reflect the curricula of California, Florida, or Texas.

When the topics contained in the frameworks are not the same across states, publishers try to cover as many states as possible or risk the loss of adoption in a key state. The result is textbooks that cover many topics superficially and few topics with any real intellectual integrity. Since studies have shown that teachers rely on textbooks for as much as 98 percent of instructional time (Harms, 1981), the result is that many teachers across the nation are trying to cover too many complex topics in too limited an amount of time. When a teacher tries to cover too many science topics, the quality of learning suffers.

LOW LEVEL OF SCIENCE LEARNING

One commission after another has lamented the low level of learning in science. For example, the National Science Board's Commission on Precollege Education in Mathematics, Science and Technology (1983) stated that "students in our Nation's schools are learning less mathematics, science and technology, particularly in the areas of abstract thinking and problem solving" (p. 1).

Recent research findings in cognitive science help to explain this poor performance. Repeated studies have shown that many students aren't understanding the science they are taught and that even students who have successfully completed high school and college level science courses are not accurately understanding the concepts conveyed in these courses. Researchers are beginning to provide the evidence needed to explain why students aren't learning what they're taught. This research is revealing the highly complex intellectual activities needed to understand many scientific concepts.

RESEARCH TO IMPROVE SCIENCE LEARNING

Moreover, researchers are beginning to find ways to counteract some of the misconceptions students harbor, and quite recent developments in computer applications to science instruction appear quite promising. The new view of learning afforded by this research in cognition needs to be reflected in a revised science curriculum as well as the instructional materials and teacher training needed to support a new curriculum. While the more recent curriculum development efforts in science reflect the concern for an increased attention to the interaction of science, technology, and society, and a need for all students to become scientifically literate, very little of the research in how students learn science has been incorporated into reform efforts.

Scientists, science educators, cognitive scientists, and curriculum and technology experts attempted to address this state of affairs at a recent conference in California (Linn, 1986). Several recommendations were put forth. The participants suggested that the science courses offered to train scientists are inappropriate for training citizens. Courses in traditional scientific disciplines do not readily translate into skills or reasoning abilities that assist citizens in making intelligent decisions about a broad range of scientific issues. In addition, this group recommended that fewer topics be covered in depth rather than many in a fleeting fashion. Linn summarizes the rationale for this recommendation as follows:

> Study in depth is consistent with the new consensus about how learners change ideas. Such coverage is more likely to modify students' belief systems by providing integrated understanding of a science topic. Integrated understanding is more likely to compete successfully with well-established but inaccurate intuitive beliefs.
>
> Our understanding of the link between reasoning and subject matter implies that topics selected for in-depth coverage in science classes should reflect the fundamental problems of the discipline. The discipline-specific information imparted must have wide applicability. Those topics selected

> must serve as models that learners can use to master new topics after leaving school. (p. 15)

This complex and diverse set of factors suggests an unintended, seminational curriculum; topic-laden texts; contributions from cognitive science; an emphasis on technology; and the growing need for a scientifically and technologically literate citizenry. All lead to the need for a large-scale, national effort to reconsider what core concepts and skills are important for all students to know and to understand. The issues of core competencies are essential in order to avoid repeating the current error of overburdening the science curriculum with more topics than can be addressed in a meaningful way.

WHO SHOULD DETERMINE THE SCIENCE CURRICULUM?

The question, then, is who should decide what this new curriculum should be. The Council of Chief State School Officers recently submitted a proposal to the National Science Foundation to engage in a consensus-building approach to revising science goals. The primary rationale for a consensus approach lay in the belief that school practitioners—teachers, principals, state education agencies, and so forth—would not "buy in" to goals that they had no hand in developing. In addition, the project was designed with intensive implementation and dissemination components to ensure that the goals actually made their way into curricular frameworks, textbooks, and teacher training efforts. This project was not funded. Although some reviewers acknowledged the importance of "buy-in," many expressed a concern that the resulting goals would be watered down by a consensus process. Others were uncomfortable with the thought that this might lead to a national curriculum.

Other organizations are addressing the revision of the science curriculum—the American Association for the Advancement of Science, the National Science Teachers Association, and the National Council of Teachers of Mathematics for mathematics goals. While the goals that may result from the activities of these professional groups may be intellectually and scientifically sophisticated, they run the risk of being construed as a "top-down" approach to curriculum development. They may lack the needed support and commitment of the education populace that would implement the goals.

Few would deny the critical need for revising the science curriculum, but determining what the new goals should be, portraying the goals in an instructionally meaningful way, and ensuring that the goals reach classrooms are enormously difficult, complex, and expensive tasks. They are tasks that call for the cooperation and commitment of many groups—scientists, science educators, general educators, publishers, teacher training institutions, and funding agencies, among others. Science is no longer solely in the realm of the scientist but intimately affects us all.

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Chapter 15

REFORM IN SCHOOL MATHEMATICS

Thomas A. Romberg

This paper is based on "a belief that today, in most classrooms at all school levels, mathematics instruction is neither suitable nor sufficient to adequately equip our children with the mathematical concepts and skills needed for the 21st century. Furthermore, unless something is done to alter current schooling trends, conditions are likely to get worse in the coming decade" (Romberg, 1984, p. 1). Assuming that the schools of America will respond to the current perceived crisis in school mathematics, the nature of those anticipated changes needs to be identified. The School Mathematics Monitoring Center is being designed to document those changes and how they affect schooling practices.

The principal changes in school mathematics during the next decade should be related to new and different goals currently being proposed for our students. At present, the school mathematics program has been geared to preparing a minority of students to take calculus. Topics have been include (or excluded) based on assumptions of their importance toward that goal. For college-bound students who were disinclined toward calculus or deemed incapable of achieving competence, some basic knowledge of algebra and geometry has been considered sufficient. Finally, for non-college bound students, only arithmetic competence has been deemed essential.

Today these goals for all students are being challenged. Calculus, while still of major importance in most fields, no longer holds its preeminent position in mathematics (Ralston & Young, 1983). The calculator and, in particular, the computer have expanded the utility of other mathematical ideas, including mathematical modeling, algorithmic analysis, discrete mathematics, matrix algebra, coordinate geometry, statistics, and applications in various fields. The new technology has freed us from the cumbersome calculation routines of arithmetic, algebra, statistics, and even calculus. In so doing, this technology has expanded our ability to carry out even more complex computations.

A variety of recommendations have recently been made (Conference Board of the Mathematical Sciences, 1982, 1984; Romberg, 1984). The expected changes are in the following eight areas:

1. changes in content and structure of courses;
2. changes in course requirements;
3. changes in the sequencing and segmenting of mathematical topics;
4. changes in the use of technology;
5. changes in methods of assessment;
6. changes in the knowledge and professional responsibility of teachers;
7. changes in the way mathematics is taught; and
8. changes in the policy environment within communities.

The assumption underlying these prospective changes is that if they are implemented, students will know more mathematics, be able to use mathematics more effectively, and in turn be productive citizens in tomorrow's world.

A major task of the Monitoring Center has been to commission a series of papers that document and summarize the rationale behind these anticipated changes. In this paper, a preliminary summary of what has been found is reported. To organize this summary, current practice is described in terms of three constructs: knowledge, work of students, and work of teachers. Proposed practices are then described from the same perspectives.

CURRENT PRACTICES

The typical course offerings in mathematics in American schools start with a common curriculum that is followed by most students for eight years. The content of that curriculum is primarily the arithmetic for whole numbers and for positive rational numbers. Other topics such as measurement, integers, and geometry vary from school to school and, in general, receive little attention. The emphasis is on getting students to become proficient at a set of procedural pencil-and-paper skills.

The arithmetic curriculum is followed by several options. The most common is a college preparatory, two-year curriculum consisting of a year of algebra, in which the emphasis is on procedures for manipulating algebraic expressions and solving linear equations, and a year of Euclidean geometry, in which the emphasis is on constructing deductive proofs. For college-bound students who are planning to study mathematics, science, or engineering, a two-year precalculus sequence follows geometry. Calculus, too, is offered at many schools for students who were accelerated into algebra in grade eight. Finally, for the non-college bound student, another year of arithmetic (general math, shop math, technical math, etc.) is required, with some of those students then taking college prep courses or other math offerings later in high school.

By the time an age group of students reaches high school graduation, it is estimated that about 67 percent have taken an algebra course, 50 percent a geometry course, 30 percent an advanced algebra course, and 6 percent a calculus course. Another way of summarizing enrollment is that, for an age group, 10 percent are in an accelerated mathematics track, 20 percent in the science track, 20 percent in the college-prep track, and 50 percent in the general track. The general conclusion drawn in recent reports has been that current course offerings and enrollments in mathematics are inadequate.

Knowledge

Mathematics to most students is a static collection of concepts and skills to be mastered one by one. Furthermore, the student's task is to get correct answers to well-defined problems or exercises. The difficulties with this perception have arisen for several reasons.

First, mathematics has been over-fragmented. To develop a curriculum, one needs to segment and sequence the mathematical ideas for instruction. However, in many recent efforts, this has been taken to an extreme. The use of behavioral objectives and learning hierarchies has separated mathematics into literally thousands of pieces, each taught independent of the others. The difficulty with this approach is that while an individual objective might be reasonable, it is only part of a larger network. It is the network (the connections between objectives) that is important. The view of mathematics that students get is of isolated pieces rather than relationships.

Second, this fragmentation (and emphasis on low-level objectives) is reinforced by the testing procedures often associated with such curricula. Multiple-choice questions on concepts and skills emphasize the independence rather than the interdependence of ideas and getting right answers rather than using reasonable procedures.

Third, most teachers have not been exposed to a broader view of mathematics. Few teachers are familiar with the history or philosophy of mathematics or have ever worked as mathematicians. Their knowledge of mathematics is what is done in schools. Therefore, it is not surprising that they see little reason to view mathematics differently. They have little sense of mathematics as a craft, as a language, or as a set of procedures to solve problems.

Fourth, the segmenting and sequencing of mathematics has led to an assumption that there is a strict, partial ordering to mathematics. In American schools, this has been translated to mean you can't study geometry unless you can do arithmetic; you can't study algebra unless you can do decimals; you can't study calculus unless you have had trigonometry; and so forth. A student who is having difficulty adding fractions with unlike denominators should not be denied the opportunity to study geometric relationships.

Work of Students

Most current mathematics programs have conceived of the learner as a passive absorber of information who stores facts in his or her memory in little pieces that are easily retrievable. This concept of learning is based on the tenets of "behaviorism," a theory that evolved during the early part of this century. Actually the theory focuses on the outcomes of learning (behaviors) rather than how learning occurs. It assumes learning occurs by passively, but rationally, reflecting on stimuli from the environment. Learning is viewed as a change in behavior (or performance) and a change in scores (pretest and post-test differences) on some measure of performance. This theory, in its many forms, has strongly influenced all education in the United States and school mathematics in particular. Its strength lies in what Schrag (1981) has called its "generative" characteristics; that is, it is a theory that has generated a number of practical procedures which can be used in schools.

Probably the most dramatic research findings of the past quarter century center on the fact that learning does not occur via passive reflection. Instead, individuals approach each new task with prior knowledge. They assimilate new information and construct their own meanings. For example, before young children are taught addition and subtraction, they can already solve most addition and subtraction problems using routines such as counting on and counting back (Romberg & Carpenter, 1985). As instruction proceeds, they continue to use these routines to solve problems in spite of being taught more formal procedures. They will only accept new ideas when it is no longer feasible for them to use prior routines.

Work of Teachers

There has been a growing tendency to overspecify instructions for teachers. Taken to the extreme, the teacher becomes only a conduit in a system, covering the pages of a program without thought or consideration. The emphasis of teaching is shifted from curricular content and learning to management of individual progress. The teacher becomes a manager of resources and personnel (Berliner, 1982). For students, mathematics becomes completing pages or doing sets of exercises with little relationship between ideas, and teachers reinforce this perspective.

PROPOSED MATHEMATICS PROGRAMS

The ideas being considered in contemporary mathematics programs can also be described in terms of knowledge, work of students, and work of teachers.

Knowledge

The distinction between knowledge and the record of knowledge, knowing and knowing about (Romberg, 1983), is at the root of several of the dilemmas of mathematical education. As a record of knowledge, mathematics has a vast content. Furthermore, the accepted content of mathematics changes. Davis and Hersh (1981), observing that the world is in a Golden Age of mathematical production, raise the possibility of internal saturation and exhaustion and the notion that there is a limit to the amount of mathematics that humanity can sustain at any one time. Hence, some parts must inevitably be abandoned as new parts are added.

Students must see and experience the role of mathematics as a language and a science that orders the universe and as a tool for representing situations, defining relationships, solving problems, and thinking. They need to experience the powers of its language and notational system in the solution of problems in a wide variety of domains. The connectedness of ideas is critical, and so is the connectedness of process and concept. Students must experience mathematics as part of both larger content and larger process. They need to see it as a process of abstracting quantitative relations and spatial forms from the real world of practical problems and as a process of inventing through conjecture and the demonstration of logical validity. The emphasis in instruction must now be on experiences which help students to *know* mathematics (Romberg, 1983).

When mathematical knowledge means knowing and doing mathematics rather than knowing about mathematics, other things follow. Knowledge is both personal and communal in the sense that, while it may originate in an individual, it is validated by the community. Thus, the process of adding to mathematical knowledge through communicating is an integral part of knowing mathematics. Furthermore, the criterion for knowledge is not necessarily that it be true but that it be incorporated into the general system of knowledge (Rescher, 1979). In a sense, adding to the structure of mathematical knowledge *is* mathematics. This view means that mathematics is, by definition, dynamic and constantly changing and *not,* as has been the case in schools, a static, bound cumulation. The implications of these views for the whole culture of schools are extensive, suggesting radical changes in the work of students and teachers and in the professionalism of all educators.

Work of Students

The work roles of students and teachers are complementary (Skemp, 1979); one group teaches, the other learns. However, since schools are ostensibly places where students gather to learn, the role of the teacher should complement that of the student, rather than vice versa. Unfortunately, when knowledge is regarded as knowing about rather than knowing, the vocabulary reflects a reversal of emphasis. The work of the teacher is then to "transmit" knowledge. Logically, this means that the job of the student is to receive it, regurgitating on demand. In fact, the real work of the student is often a matter of negative goals, or meeting expectations sufficiently to pass through the system (Skemp, 1979). Clarke (1985) gives the following description of a student's work in a mathematics classroom is:

> " . . . she tells us what we're gonna do. And she'll probably write up a few examples and notes on the board. Then we'll either get sheets handed out or she'll write up questions on the board. Not very often. We mainly get a textbook. We'll get pages. She'll write up what work to do, page number and exercise. And that's about what happens." (p. 22)

The traditional situation described is organized, routine, controlled, predictable, and an unlikely environment for the creation of knowledge.

Briefly then, the work of students is to constantly extend the structure of the mathematics that they know by making, testing, and validating conjectures, which may originate as postulates of conscious thought or be derived intuitively. As long as it is the student making the conjecture, his or her mathematical knowledge will always be structured, consciously or unconsciously, because conjecture cannot be created from nothing. This amounts to the process of reflective intelligence in which the structure of knowledge is constantly revised by reflecting on events, seeking ways to fit them into the existing structure, and testing its predictive powers (Skemp, 1979).

Verbal and written communication is a crucial part of the process for several reasons. First, communication in the form of logical argument is central to mathematical proof. Second, communication of that proof is the means whereby personal knowledge is submitted for systematizing into the domain and thus accepted as new knowledge (Rescher, 1979). Third, developing competence in the categories and structures of the language system both structures the child's understanding and advances it towards a public mode of consciousness (Russell, 1978). Clearly, the work of students should no longer be a matter of acting within somebody else's structures, answering somebody else's questions, and waiting for the teacher to check the response. Nor is it a matter of evaluating knowledge according to right or wrong answers. In the creation of knowledge, there is only that which fits the structure of mathematical knowledge already created by the student and that which does not, and therefore should prompt conjecture.

Work of Teachers

There is an inexorably logical sequence when the acknowledged work of teachers is to transmit the record of knowledge. The most cost-effective way to transmit the record of knowledge is through exposition to a captive audience. Theoretically, the child could read and cover the same ground, but that would require a voluntary act, which is unlikely as long as children are not setting their own goals. Consequently, that exposition cannot happen unless there is control, which is easier if children talk as little as possible and stay in one place.

In contrast, if one regards the roles and work of student and teacher as complementary, when the emphasis is on creating knowledge rather than absorbing the history of other people's knowledge, the work of the teacher is to support, promote, encourage, and in every way facilitate the creation of knowledge by students.

NEW WORLD VIEW

The current structure of teaching and learning was a product of its times. It grew out of the machine-age thinking of the industrial revolution of the past century. The intellectual contents of the machine age rested on three fundamental ideas. The first was reductionism. The machine age was preoccupied with taking things apart. The idea was that in order to deal with anything you had to take it apart until you reached ultimate parts. The second fundamental idea was that the most powerful mode in thinking was a process called analysis. Analysis is based in reductionism. It argues that, if you have something that you want to explain or a problem that you want to solve, you start by taking it apart. You break it into its components, you get down to simple components, then you build up again. The third basic idea of the machine age has been called mechanism. Mechanism is based on the theory that all phenomena in the world can be explained by stating cause and effect relationships. The primary effort of science was to break the world up into parts that could be studied to determine cause and effect relationships. The world was conceived as a machine operating in accordance with unchanging laws.

These ideas gave rise to what has been called the first industrial revolution. In this world, work was conceived of in physical terms, and mechanization was about the use of machines to perform physical work. People were supplemented by machines as a source of energy. Human-machine systems were developed for doing physical work in such a way as to facilitate mechanization.

This whole process is clearly reflected in what has happened in school mathematics during the last half century. Mathematics was segmented into subjects and topics, eventually down to its smallest parts, called behavioral objectives. At this point, a hierarchy was created to show how these components were related to produce a finished product eventually. Next, the steps by which one traveled that hierarchy was mechanized via textbooks, worksheets, and tests. Furthermore, teaching was dehumanized to the point that the teacher had little to do but manage the production line. Businesses, industry, and, in particular, schools have been conceived and modified based on this mechanial view of the world.

Like the Model T Ford assembly line, current models of schooling were considered an example of the application of modern scientific techniques. Today better school mathematics programs ought to be able to be developed.

We are now in a new economic age—the Information Age. Labeling the new age as the Information Age is based on the fact that our industrial economy has changed so drastically that a new description was needed. Information is the new economic capital and the new raw material. The ability to communicate is the new means of production, and the communications network provides the relations of production. Industrial raw materials only have value if they can be put together to form a desirable product; the same is true of information.

The works of several authors (Naisbitt, 1982; Shane & Tabler, 1981; Toffler, 1985; Yevennes, 1985) point toward some of the attributes of the shift from an industrial society to an information society. First, it is an economic reality, not merely an intellectual abstraction. Second, the pace of change will be accelerated by continued innovation in communications and computer technology. Third, new technologies will first be applied to old industrial tasks but will then generate new processes and products. Fourth, basic communication skills are more important than ever before, necessitating a literacy-intensive society.

Zarinnia and Romberg (in press) have recently aruged that

> the most important single attribute of the Information Age economy is that it represents a profound switch from physical energy to brain power as the driving force, and from concrete products to abstractions as the primary products. Instead of training all but a few children to function smoothly in the mechanical systems of factories, adults who can think are needed . . . This is significantly different from the concept of an intellectual elite having the responsibility for innovation while workers take care of production. (p. 12)

If this is the case, then thinking skills must be the focus of instruction in mathematics in the near future, and assessment procedures need to be developed that portray not only the number of correct answers students can produce but the thinking that produced those answers.

Unfortunately, as Lauren Resnick (in press) has pointed out,

> American schools, like public schools in other industrialized countries, are the inheritors of two quite distinct educational traditions—one aimed at the education of an elite, the other concerned with mass education. These traditions conceived of schooling in different terms, had different clienteles, and held different goals for their students. Only in the last sixty years or so have the two traditions merged, so much so that in American schools it is now difficult to detect the separate threads. Yet a case can be made that it is a continuing and as yet unresolved tension between the goals and methods of elite and mass education that is producing our current concern for the teaching of [thinking] skills. (pp. 4–5)

The School Mathematics Monitoring Center has started the task of designing a system to document changes in the teaching and learning of mathematics by trying to understand the basic differences between what reforms are being proposed and current practice. Our review clearly indicates that the suggested reforms have their roots in a new world view which are reflected in the proposed changes in what mathematics should be taught and in what the work of both students and teachers should be.

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APPENDIX A
FORUM 86 PROGRAM

NFSS

NATIONAL FORUM FOR SCHOOL SCIENCE

FORUM 86: The Science Curriculum

November 14 and 15, 1986
The Hyatt Regency Crystal City
Arlington, Virginia

Sponsored by the
Office of Science and Technology Education
of the
American Association for the Advancement of Science
with the support of
The Carnegie Corporation of New York

Program

Friday, November 14

8:00 am Regency Foyer	Registration
9:00 am Regency E & F	Welcome and Overview of the Forum Lawrence Bogorad, *Harvard University and AAAS President* Audrey Champagne, *National Forum for School Science*
9:15 am	Keynote Address Paul Black, *Kings College London*
10:00 am Regency E & F	The School Science Curriculum: What We Know, What We'd Like To Know Provocateur: A. Graham Down, *Council for Basic Education* • Data producers F. Joe Crosswhite, *Northern Arizona University* Senta Raizen, *National Academy of Sciences* Neil Carcy, *Rand Corporation* Iris Weiss, *Research Triangle Institute* • Data users Pascal Forgione, Jr., *Connecticut Board of Education* Daniel Koretz, *U.S. Congressional Budget Office* Floraline Stevens, *Los Angeles Unified School District* Audience discussion will follow
12:15 pm Regency A-D	Luncheon Address: "Guess Who's Coming to School?" Harold Hodgkinson, *American Council on Education*
2:30 pm Regency E & F	The Future School Science Curriculum Presider: F. James Rutherford, *AAAS* • Goals and Structure of AAAS's Project 2061: Education for a Changing Future Margaret MacVicar, *Massachusetts Institute of Technology* Michael O'Keefe, *Consortium for the Advancement of Private Higher Education*

	• Common themes evolving from Project 2061: What science, math, and technology every high school graduate should know Mortimer Appley, *Harvard University* George Bugliarello, *Polytechnic University* Mary E. Clark, *San Diego State University* James R. Johnson, *3M Company (retired) and University of Minnesota* Ingram Olkin, *Stanford University*
3:45 pm	Break
4:00 pm	Discussion Groups Group A: Potomac I Group B: Potomac II Group C: Potomac III Group D: Potomac IV Group E: Potomac V Group F: Potomac VI Group G: Washington A Group H: Washington B Group I: Kennedy Group J: Jefferson Group K: Lincoln Group L: Roosevelt Group M: Arlington Group N: Fairfax Group O: Prince William Group P: Board
5:30 pm Regency A-D	Reception

Saturday, November 15

8:00 am Regency Foyer	Registration
9:00 am Regency E & F	Factors That Shape The Curriculum: Teachers, Texts, Technology, And Tests Provocateur: Sally Kilgore, *U.S. Department of Education* Joseph Bordogna, *University of Pennsylvania* Rosalie Cohen, *Temple University* Robert Hampel, *University of Delaware* Mary Budd Rowe, *University of Florida*
10:15 am	Break
10:30 am	Discussion Groups Same rooms as Friday's discussions
12:15 pm Regency A-D	Luncheon and Summary Discussion
2:15 pm	Conclusion of Forum '86

Breakout Discussion Leaders

Richard Berry, *National Science Foundation*
Patricia Butler, *U.S. Department of Education*
Jeremiah Floyd, *National School Board Association*
Lloyd M. Cooke, *National Action Council for Minorities in Education (emeritus)*
Dorothy Gilford, *National Academy of Sciences*
Johnnie Hamilton, *Fairfax (Virginia) County Schools*
Willard Jacobson, *Teachers College, Columbia University*
Douglas Lapp, *National Academy of Sciences*
Shirley Malcom, *American Association for the Advancement of Science*
Ina Mullis, *Educational Testing Service*
E. Joseph Piel, *SUNY at Stony Brook*
Robert Pollack, *Columbia University*
Thomas Romberg, *Wisconsin Center for Education Research and University of Wisconsin*
Francis W. Rushing, *Georgia State University and SRI International*
Maxine Singer, *National Cancer Institute*
Susan Snyder, *National Science Foundation*

The **National Forum for School Science** is an ongoing project of AAAS. The Forum sponsors programs to focus the nation's attention on the problems and potential of science education in the primary and secondary schools. In 1987, the Forum will focus on students and learning.

APPENDIX B
FORUM 86 PARTICIPANTS

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Gloria Aponte-Del Toro, *University of Puerto Rico*
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William Armistead, *U.S. Department of Education*
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J. Myron Atkin, *Stanford University*
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Gordon J. Aubrecht, II, *American Association of Physics Teachers*
Benji Austin, *Student Pugwash*
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Elizabeth Badger, *Massachusetts Department of Education*
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Kathleen Beauchat, *Rio Vista Elementary*
Wynne Beebe, *Media Speak*
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William J. Bennetta, *National Center for Science Education*
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Kenneth Brecher, *Boston University*
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Ted Britton, *University of Florida*
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Diane Bunce, *AAAS*
Joan R. Burchenal, *Darien High School*
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Joyce A. Clarke, *Virginia Polytechnic Institute and State University*
Ronald W. Cleminson, *Memphis State University*
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Michael R. Cohen, *Indiana University*
Rosalie Cohen, *Temple University*
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George Collier, *Hunterdon Central High School*
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J. Edmund White, *Southern Illinois University*
Judith White, *National Zoological Park*
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