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AUTHOR	Weiss, Iris
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ABSTRACT

In recent years, the need to improve education has received considerable attention. The development of educational indicators is necessary to help policymakers determine whether educational conditions have improved and what additional actions are indicated. The Council of Chief State School Officers State Education Assessment Center initiated a project in 1986 to develop state indicators of the condition of science and mathematics education. This paper describes how this project was developed including a conceptual model of the educational system and state-by-state indicators. The rest of the paper looks at ways that indicators could be used in policymaking and programmatic decision making. Areas discussed include: (1) "Curriculum and Instruction"; (2) "Educational Equity": (3) "Pre-Service Teacher Preparation"; and (4) "In-Service Education." (CW)

Council of Chief State School Officers
State Education Assessment Center

INDICATORS OF SCIENCE AND MATHEMATICS EDUCATION: PROVIDING TOOLS FOR STATE POLICYMAKERS *

Iris Weiss

Horizon Research, Inc.
Chapel Hill, North Carolina

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Science/Mathematics Indicators Project
Council of Chief State School Officers
400 North Capitol Street
Washington, D.C. 20001
(202) 624-7700

INDICATORS OF SCIENCE AND MATHEMATICS EDUCATION: PROVIDING TOOLS FOR STATE POLICYMAKERS

INTRODUCTION

The need to improve K-12 education in general, and science and mathematics education in particular, has received considerable attention in recent years. Response to these concerns has been particularly evident at the state level, where many states have instituted changes in course offerings, requirements for high school graduation, teacher certification, and in-service education policies.

Are conditions better or worse than they were before these reforms? Anecdotal evidence, while interesting, provides a very limited picture. As noted by the National Science Board Commission on Precollege Education in Mathematics, Science and Technology [1983], "periodic objective measurement of achievement and participation is essential to determine progress." The development of educational indicators is aimed at helping policymakers determine whether the conditions prompting the various educational reforms have improved, and what additional actions might be warranted.

The Council of Chief State School Officers State Education Assessment Center initiated the Science/Mathematics Indicators Project in 1986 to develop state indicators of the condition of science and mathematics education in elementary and secondary schools. The project has two goals:

(1) to improve the quality and usefulness of data on science and mathematics education for state policymakers and program managers

(2) to develop a system of indicators that provides the capacity for state-by-state comparisons and a national database to assess the condition of science and mathematics education.

During the first year of the project, information about existing science and mathematics education indicators was collected from each of the 50 states, the District of Columbia, and 3 territories (Guam, Puerto Rico, and the Virgin Islands). Using this information, a Task Force comprised of state science and mathematics specialists, state data managers, and national experts on science and mathematics education indicators developed a prioritized list of indicators. High priority indicators fell into two categories: indicators that this project should develop with the states, and indicators that could be obtained through other projects such as the Department of Education's National Assessment of Educational Progress (NAEP) and the Schools and Staffing Survey. The project's year-one report includes recommendations on those indicators that should be developed as part of this project [Blank and Espenshade, 1987a].

Second year project activities have focused on working with data managers and science and mathematics specialists in each state to develop a plan for collecting data on three priority indicators. As part of a series of five Regional Meetings held in February and March 1988, professional staff representatives from state departments of education shared ideas and strategies on the use of state data at both the state and local levels. This paper elaborates on those discussions; it focuses on indicators of science and mathematics education and how these types of data can be used in making policy decisions at the state level.

THE IMPORTANCE OF A CONCEPTUAL MODEL OF THE EDUCATION SYSTEM

If one is attempting to describe the status of science and mathematics education, there is almost no limit to the amount of relevant data that could be collected. Should we determine the average square footage of science classrooms? The number of water faucets? The amount of time spent on hands-on activities? The amount of homework assigned? The number of windows facing south? Clearly the answers depend on one's view of the educational process: it is important to collect data on key aspects of the education system, especially on those variables that are believed to be causally related to the primary outcomes of interest, e.g. student achievement. We would usually not want to spend resources collecting data on variables that are unlikely to be related to outcomes of interest.

Oakes [1986] noted that since the purposes of indicator systems are (1) to measure the health and effectiveness of the education system and (2) to help policymakers make better decisions, it is implicit that a set of indicators be selected

> based on an understanding of which components of the educational system are critical to its health and which features signal important changes in its condition. We should also know how the various components of the system are related to one another. .. Put another way, to properly specify which indicators should be part of a system, we need a model of how the education system works.

Unfortunately, while education research is making progress in understanding various components of the education system, the system is exceedingly complex, and there is not yet a single, widely accepted model of its operation. The National Research Council Committee on Indicators of Precollege Science and Mathematics Education uses a simple model in which teacher quantity and quality and curriculum content are considered the major "inputs" of interest, instructional time and course enrollment the primary "processes" of interest, and student achievement the primary outcome of interest [Raizen and Jones, 1985].

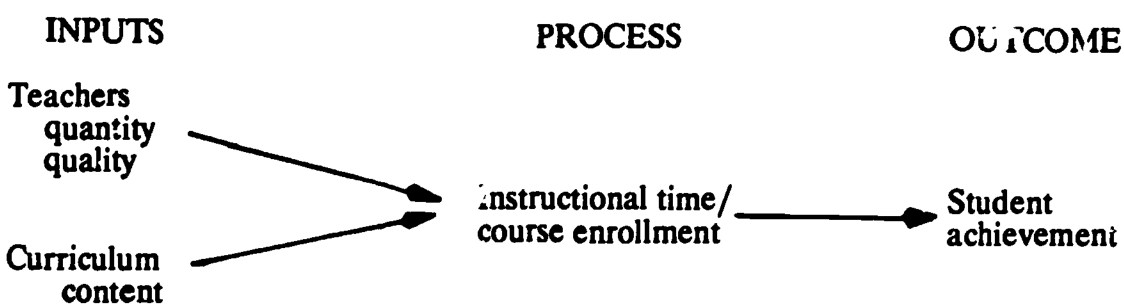

Figure 1: National Research Council
Areas of Science and Mathematics Education to be Monitored

Based on this model, and using a set of criteria that includes feasibility as well as policy-relevance of indicators, the Committee identified 8 high priority indicators:

1. student learning in mathematics and science
2. adult scientific and mathematical literacy
3. time spent in elementary and junior high school science and mathematics
4. enrollment in high school science and mathematics courses
5. nature of student activities during science and mathematics instruction
6. teacher subject matter knowledge
7. quality of the curriculum content
8. teacher salaries relative to those in other occupations.

Six secondary indicators identified by the National Research Council include time spent on science and mathematics homework; teacher course background preparation; teacher time in professional activities; availability and use of materials, facilities, and supplies; level of federal financial support; and commitment of resources by scientific organizations [Murnane and Raizen, 1988].

The Council of Chief State School Officers (CCSSO) has developed an indicators model with three broad components: educational policies and practices, state characteristics, and educational outcomes.

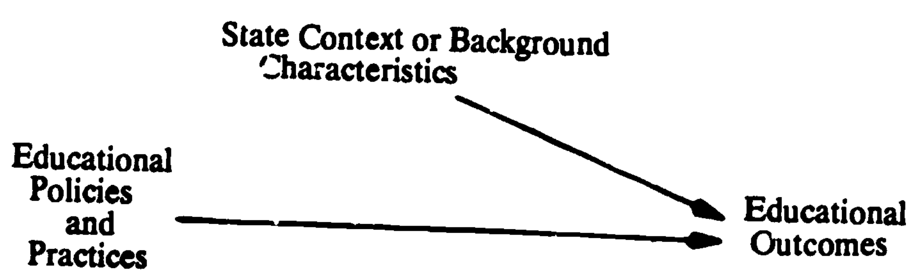

Figure 2: CCSSO Indicators Model

A number of specific indicators have been identified for each of these headings. The category "Policies and Practices" includes measures of changeable educational program features: instructional time, instructional leadership, home-school relations, teacher quality, per pupil expenditures, and teacher salaries. State contextual characteristics include size, urbanicity, and percentage of special needs students. Finally, attendance rates, percent graduating from high school, achievement levels, attitudes, and job placement are included as outcomes of interest [CCSSO, 1985]. The main feature of this model is that it distinguishes those inputs that are "givens" that the educational system must work with from those processes and policies that can be changed. Again there is considerable, but not total, overlap between these indicators and the ones generated using other models.

The RAND Corporation has developed a comprehensive model of the education system that includes fiscal resources, teacher quality, and student background as inputs; school, curriculum, teaching, and instructional quality as processes; and participation, achievement, attitudes, and aspirations as outputs of interest. RAND used a set of criteria similar to those used by the National Research Council to assess the utility of 104 factors that their research had identified as central to the education system; this screening process resulted in 40 potential indicators of the health of science and mathematics education, including many, but not all, of the National Research Council's priority indicators [Shavelson, et al., 1987].

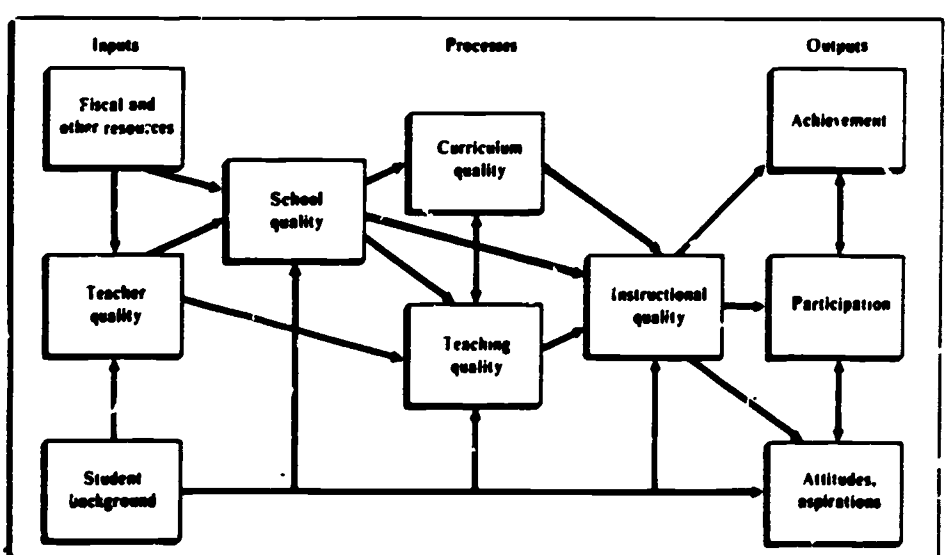

Figure 3: RAND Model Linking Elements of the Educational System

It is clear that these three models, and a host of other existing models, have many similarities -- for example, they typically include components related to fiscal resources, teacher quality, and the curriculum -- but the specific components and their hypothesized relationships vary considerably from model to model. As Oakes [1986] notes, "More than any other factor, the model chosen as the basis for selecting indicators will influence what information an indicator system will provide." Unfortunately, we presently have too many models from which to choose. While there is clear research evidence supporting some aspects of these models (e.g., we know that increased instructional time is in fact related to gains in student achievement), other hypothesized relationships have not been demonstrated. For example, while it seems logical that teachers with a lot of subject matter background will do a better job than those with less preparation, research has thus far been unable to document a relationship between teachers' course-taking background and student achievement.

STATE-BY-STATE INDICATORS: THE FIRST STEPS

It is hard to agree on a set of state level indicators of the health of science and mathematics education when there are so many competing intuitive notions of how the system works and what components seem to make the most difference. But policy decisions cannot be delayed while we wait for the development of a well researched, consensus model of the education process; decisions are being made all of the time. While we are a long way from having a comprehensive, well documented causal model of the education process, we can nevertheless learn a lot about the health of science and mathematics education by monitoring selected important components.

The CCSSO Science/Mathematics Indicators Project took 3 steps to identify state-by-state indicators. First was development of a list of 26 "ideal" indicators in six categories: Student Outcomes, Instructional Time, Curriculum Content, School Conditions, Teacher Quality, and Resources. The list was used to design a survey with state departments of education. Each state was asked to provide information about the types of data collected for each of these areas and the instruments, data sources, and data collection procedures used. The results from the inventory are provided in the report "State Education Indicators on Science & Mathematics" [Blank and Espenshade, 1988].

Cost and response burden considerations make it impractical to collect state-by-state data on all of the "ideal" indicators. For example, teachers' knowledge of their subject and how to teach it has been identified as a high priority indicator, but imposing a direct measure such as tests for all teachers would be very difficult and a proxy measure such as college course preparation is available for analysis in only a few states. Priorities must be established and then feasibility must be assessed. For this reason, as part of the Project, educational researchers and state-level personnel have been involved in merging research findings and feasibility considerations to select a narrower set of "priority indicators".

The Project has chosen to start with three state-by-state indicators that are both important from a policy perspective, and feasible at the present time (with importance being judged based on our current understanding of the science/mathematics education process, and feasibility being judged by the willingness of a large number of states to collect these types of data). These are:

- Secondary Course Enrollment in Science/Mathematics
- Teacher Assignments in Science/Mathematics by Age, Gender, and Race/Ethnicity
- Teacher Assignments by Certification Status in Science/Mathematics

These choices clearly reflect a number of compromises. For example, while student achievement is an essential indicator of virtually any model of the education system, this vitally important indicator is being bypassed temporarily by the Project because state-by-state student outcome data is being planned as part of the National Assessment of Educational Progress. As another example, enrollment by gender will be reported as part of the course enrollment indicator for those states that collect these data; equally important information about enrollment by race/ethnicity will not be reported because so few states currently collect these data and because collecting the data presents many difficulties. Other state-by-state data, including indicators of teacher supply and demand, will be collected by the "Schools and Staffing Survey" of the U.S. Department of Education's Center for Education Statistics.

Education in the United States is primarily the responsibility of the states, which in turn delegate varying amounts of authority to local districts. The development of an indicator system is an evolutionary process, and even in the early stages the collection of these types of data can lead to improved policy decisions. For example, the course enrollment indicator will allow states to track student science and mathematics enrollment over time and to determine the extent to which students elect to take courses beyond those required for high school graduation. Similarly, information about teacher assignments by certification status will allow policymakers to determine the extent of out-of-field teaching and to monitor the severity of this problem over time. With accurate and timely data, states will be better able to decide whether to modify their requirements, e.g., for high school graduation or teacher certification, or to use any of a number of possible incentives as policy levers for improving science and mathematics education.

USING INDICATOR DATA IN POLICY AND PROGRAM DECISIONMAKING AT THE STATE LEVEL

The remainder of this paper looks at some of the ways indicators of science and mathematics education can contribute to informed policymaking and programmatic decisions at the state level. Unless otherwise indicated, the data presented in this section are from the 1985-86 National Survey of Science and Mathematics Education [Weiss, 1987]. Information about state education policies on science and mathematics education and the availability of data at the state level was compiled by the CCSSO Science/Mathematics Indicators Project [Blank and Espenshade, 1987b, 1988].

1. Curriculum and Instruction

CCSSO data indicate that 26 states currently have state policies concerning the amount of instruction in elementary science and mathematics. For science, most states recommend from 20 to 30 minutes per day for grades K-3 and from 35 to 45 minutes for grades 4-6. Nationally, the average amount of time spent on science instruction is 18 minutes per day in grades K-3 and 29 minutes per day in grades 4-6. These figures fall below state recommendations, and they have remained essentially the same for the last decade, even though the need to improve science education has received a great deal of attention in recent years.

Having information about time spent on elementary science available on a state-by-state basis would enable individual states to judge the adequacy of their results and to determine if the trend is in the desired direction. If not, consideration could be given to increasing the time guidelines, publicizing them more widely, or strengthening them to incorporate real incentives. In addition, if data were collected in the state on a district-by-district basis, state level personnel could work with those districts which devote the least time to elementary science, helping to locate appropriate instructional materials, upgrading the skills of elementary teachers, and perhaps having districts with stronger programs serve as models or sources of technical assistance.

While the total amount of time spent on science and mathematics instruction at the junior high school level is no less than that devoted to other subject areas, the way that instructional time is spent may be cause for concern. One of the most discouraging findings of the 1985-86 National Survey of Science and Mathematics Education was the substantial decline in the frequency of hands-on instruction in science. For example, the 1977 survey found that 72 percent of junior high school science lessons included lecture and 59 percent included hands-on activities, a difference of 13 percent. In 1985-86, 83 percent of the junior high school science lessons included lecture and only 43 percent included hands-on activities, a difference of 40 percent.

Mathematics educators may also be concerned about the pattern of instruction in many mathematics classes. Most mathematics lessons at the junior high school level include lecture (89 percent), discussion (90 percent), and seatwork assigned from the textbook (76 percent); only 20 percent include the use of manipulative materials, and only 6 percent involve computers. Depending on their views of the educational process, if individual states find comparable results, they may wish to modify curriculum guidelines and/or recommend instructional materials that will encourage a different mix of instructional activities.

Nationally, 47 of the 54 jurisdictions (50 states, District of Columbia, and 3 territories) had course credit graduation requirements in science and mathematics as of June, 1987; six left graduation requirements up to the local districts, and one specified requirements only at the 7-9 level. According to CCSSO data, there has been a significant increase in science and mathematics requirements in recent years. From 1980 to 1984, 36 states increased graduation requirements in math and 33 states increased requirements in science. From 1984 to 1987, seven more states increased graduation requirements in math and seven also increased requirements in science. Additionally, in that period of time seven states implemented an advanced or honors diploma specifying higher levels of science and math credits [Biank and Espenshade, 1987b]. By tracking course enrollment data in their states, policymakers will be able to determine the types of courses that students are taking to meet these increased requirements (e.g., if the enrollments in advanced courses are increasing or if local districts are creating general and vocational alternative courses) and to make policy modifications if needed.

2. <u>Educational Equity</u>

The 1985-86 National Survey of Science and Mathematics Education found considerable differences in science and mathematics course offerings among rural, urban, and suburban schools, and among schools of varying sizes. For example, only 22 percent of small high schools offer a course in calculus, compared to 57 percent of large high schools.

Policy alternatives available to states that have these types of distributional inequities might include instruction via telecommunications or forging cooperative arrangements among neighboring school districts to pool their enrollments. Similarly, states that find large percentage of female and minority students opting out of higher level science and mathematics courses might wish to implement one or more of the intervention programs, e.g., MESA or SECME, that have proven effective in encouraging the participation of these groups.

3. Pre-Service Teacher Preparation

The CCSSO inventory found considerable variation among the states in teacher certification requirements in science and mathematics. For example, while 21 states and jurisdictions require from 18 to 24 semester course credits in mathematics for secondary certification, 14 require from 27 to 34 credits, and four require from 36 to 45 credits. Some states require twice as many courses as others require. There is even greater variation among science certification requirements: 42 states offer a broad-field certification, with requirements ranging from 18 to 60 credit hours of science. In addition, in many of these states teachers can receive endorsements to teach specific science courses such as biology, earth science, chemistry, physics, or general science; again, course credit requirements for these endorsements vary considerably from state to state.

Also, there is a discrepancy between the current preparation of many science teachers and their teaching assignments. Many science teacher education programs are designed to prepare teachers for a particular discipline, e.g., biology, chemistry, or physics. However, Aldridge [1987] reports that 20 percent of biology teachers, 35 percent of chemistry teachers, and 83 percent of physics teachers teach only one or two sections in that particular discipline. Most schools are not large enough to offer full teaching loads of chemistry and physics. Even in biology, the most popular high school science course, only 40 percent of the schools offer 5 or more sections. The reality, therefore, is that most science teachers will be assigned to teach courses in at least two, and often three or more, disciplines.

The 1985-86 National Survey of Science and Mathematics Education found that the problem of teacher misassignment in science is in fact mainly due to science teachers teaching science courses outside their area of primary specialty; relatively little of the "out-of-field" teaching is due to English and Social Studies teachers teaching science. States may wish to rethink their teacher certification requirements in light of these data. For example, it may make considerably more sense to prepare "chemistry/physics" teachers with an adequate grounding in both of these fields than to have teachers who are well versed in only one of these areas routinely teaching both.

Data about the age of science and mathematics education teachers can be particularly helpful as "early warning" signals to states. While nationally the average age of science and mathematics teachers is about 40, with about 17 percent age 30 or younger and 15 percent age 50 or older, some states report very different age distribution patterns. By tracking changes in these distributions, and noting the differences among race/ethnic groups and subject areas, states will be able to determine when special recruiting efforts such as scholarships and loan-forgiveness programs may be beneficial and where they should be targeted.

4. **In-Service Education**

In two national surveys, one in 1977 and the other in 1985-86, elementary teachers were asked to rate their qualifications for teaching mathematics, science, social studies, and reading. In 1977, most elementary teachers indicated they felt very well qualified to teach reading (63 percent); corresponding figures were 49 percent for mathematics, 39 percent for social studies, but only 22 percent for science. By 1985-86, the differences in teacher perceptions about science and other subjects were even more marked. While 82 percent of the teachers indicated they feel very well qualified to teach reading, 67 percent to teach mathematics, and 47 percent to teach social studies, only 27 percent of elementary teachers feel very well qualified to teach life sciences, 15 percent physical sciences, and 15 percent earth/space sciences.

While modifications in pre-service preparation may improve the situation for future teachers, states must still somehow deal with the fact that large numbers of elementary teachers are not very comfortable teaching science. In the 1985-86 survey, half of all elementary teachers reported having received no in-service education in science or the teaching of science in the last 12 months. Similarly, the 1985-86 survey found large numbers of science and mathematics teachers who feel unprepared to use computers as an instructional tool; percentages ranged from 50 percent of secondary mathematics teachers to 67 percent of elementary science teachers.

The CCSSO inventory found that most states have staff development and in-service programs designed specifically to improve the knowledge and skills of science and mathematics teachers; many of these activities have been supported by federal funds under Title II of the Education for Economic Security Act. One of the three priority indicators of the CCSSO Science/Mathematics Indicator Project will provide data about the extent to which science and mathematics classes are being taught by teachers who are not certified in these fields, a problem that can be addressed in part by in-service education efforts. The Department of Education's Schools and Staffing Survey plans to provide additional information on in-service education programs, including the rates of teacher participation by sex, race/ethnicity, and type of community within each state [Center for Education Statistics, 1987]. State policymakers will be able to use these types of information along with other data about needs in science and mathematics education to help decide where to target in-service resources.

STATE-BY-STATE INDICATORS: THE NEXT STEPS

While efforts to develop a system of state-by-state indicators are still in their infancy, it is encouraging to note the emphasis on the collection of policy-relevant data. Each of the three priority indicators of the CCSSO Science/Mathematics Indicators Project will provide information that can be used to help make decisions at the state level. The success of the "indicators movement" will be judged in the future by the extent to which these data are used to identify and implement changes needed to improve science and mathematics education.

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