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POLICY DECISIONS ON IMPROVING SCIENCE EDUCATION: A COST-EFFECTIVENESS ANALYSIS

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Abstract

A form of policy analysis, cost-effectiveness analysis, is described and applied to the question of the probable impact of a large number of actions advocated in professional and political circles for improving science education. After identifying the objectives sought, the costs and probable effectiveness of 69 widely advocated interventions were estimated. Because of the highly systemic nature of the situation, analysis of the 69 individual actions was only an intermediate step. Models of the interconnections among these actions were developed based on the research on effective schools and educational change. Clusters of interventions were identified which could be extended to recommendations for policy makers at various levels, e.g., local, state, and federal.

A Methodology Whose Time Has Come

Scholars have confronted educational issues in a variety of new ways over the last quarter century or so. Early on, studies seeking generalizable knowledge had to move over and begin to share the stage with evaluation efforts directed toward making decisions in specific settings. Later, persons interested in the results of the abundance of quantitative research studies began to draw upon meta-analyses to integrate and understand the results of these many attempts to produce generalizable knowledge. Throughout this time, both researchers and evaluators expanded their repertoire of techniques, with qualitative approaches gradually acquiring a featured place in both the educational research community generally, as well as specifically among science education researchers. Furthermore, within the last decade, policy analysis has come to the fore, as policy makers at all levels have become aware of the potential of disciplined inquiry for informing major decisions. Symbolic of this evolution of scholarly activity is the creation by the American Educational Research Association in 1979 of a new journal, *Educational Evaluation and Policy Analysis*.

The work reported here is an example of policy analysis applied to an aspect of science education. More specifically, it is the application of a particular method, cost-effectiveness analysis, to major policy matters facing the U.S. in the early eighties. By 1983, literally dozens of different actions for improving science education had been proposed by various political groups from the local to the national level. While many

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experienced political observers expected that this political attention would wane, educational issues proved to be long-lived. Especially at the state level, it seems that even years after the watershed year of 1983, elected officials still considered education to be a high priority matter. Within this climate of urgency for action, there also has been considerable uncertainty about which of the many proposed political actions would "produce the most bang for the buck," or for that matter, produce any bang at all. Fortunately, procedures of policy analysis can be used to systematically and logically analyze the situation based on estimates of the costs involved and research findings about the potential success of various actions to produce educational change. The results have implications for action at both the federal and local level, but given the current political context, most especially at the state level.

The specific technique employed is cost-effectiveness analysis. Defined broadly, it is "any analytic study designed to assist a decision-maker in identifying a preferred choice among possible alternatives" (Quade, 1967, p. 1). More narrowly defined, it involves "a comparison of alternative courses of action in terms of their costs and their effectiveness in attaining some specific objective" (Quade, 1967, pp. 1–2). Scholars from political science and engineering are well represented among its users.

Cost-effectiveness analysis sometimes is considered a variation of cost-benefit analysis, an approach which analyzes alternative actions in terms of cost and benefits, both measured in dollar terms. Cost-effectiveness analysis measures costs in dollar terms but evaluates outcomes in other units. "Cost-effectiveness analysis tries to show how a given level of benefit can be achieved at a minimum cost, or to show how the maximum benefit can be achieved at some given level of cost. The keynote of both orientations is that it is not necessary to attach any explicit money value to benefits" (Sugden & Williams, 1978, p. 190). Analysts such as Quade (1967) and King (1974) describe the process in similar terms although the number of steps and their sequence may vary slightly. The methodology cannot be prescribed as a precise set of standard procedures, but must be viewed as a general approach with a sequence of general steps. These steps as used in this investigation were as follows:

1. Definition of objectives.
2. Identification of alternatives
3. Selection of effectiveness measures
4. Development of cost estimates
5. Selection of a decision criterion
6. Creation of models relating cost and effectiveness (King, 1974, p. 123).

These steps will be elaborated upon and illustrated in the research description reported in a later section of this article.

Potential of the Methodology

The obvious advantage of this type of analysis is its potential for identifying those interventions, i.e., changes in educational practice, which can be initiated at lesser cost and produce effects worthy of the expenditure. The political process employed in reaching such changes in school practice tends to focus on the direct expenditure of tax dollars with insufficient attention to opportunity costs (the cost of forgoing actions that otherwise would occur) and costs to such groups as teachers and students. The advantages of this analysis with respect to effectiveness probably are even greater. It should help counteract the usual tendency in the political process for particular actions to be taken because of such political factors as who is promoting them, rather than some objective appraisal of their effects.

A second major advantage of a rational technique is its clarification of the value judgments involved. "Value judgment or ideology within rational techniques is inevitable and value neutrality impossible. . . . It is essential that value judgments be expected and made as explicit as possible in the analysis" (Carley, 1980, p. 71).

As valuable as this process of analysis is, it has its limitations. First, any analysis is necessarily incomplete. In addition to limitations of resources, one must recognize that there is no way to treat all of the factors that impinge upon the situation. Too many factors are intangible and the result is that the analyst must employ his or her intuition and judgment, even though the decision maker who refers to the analysis at a later time rightfully may choose to apply a different set of judgments and intuition (Quade, 1967).

Second, the process of cost estimation is not as precise as it may appear on the surface. "Unfortunately, the preparation of cost estimates remains for the larger part an art. . . . In sum, the individual skill, experience, and natural resourcefulness of the cost analyst emerge as the critical factors" (McCullough, 1967, p. 70).

Third, measures of effectiveness necessarily are incomplete. Quade notes that in general, "One cannot be as confident about the accuracy of estimates of effectiveness as about cost estimates" (Quade, 1967, p. 10). A variety of measures of educational effectiveness have been used in this study and they are presented here with considerable confidence, but one must not attribute to them more precision than they deserve.

A final limitation is the fact that there is no satisfactory way to forecast future events in our society or educational system. Future events may alter assumed conditions.

As with any policy analytical tool, the user must be aware of its limitations to use it appropriately and increase its likelihood of making positive contributions to policy decisions. With this awareness, one can approach the task with confidence that the analysis has important contributions to make to the decision-making process.

The process, however, is not inexpensive; the study reported here required the equivalent of approximately one person-year of professional time on the part of three people: a university researcher, a graduate research assistant, and a state-government policy analyst. An advisory group including school personnel and such researchers as an economist provided guidance to the endeavor.

A further consideration—a question which applies to all policy analyses—is the extent to which the decision-making processes—whether federal, state, or local—are subject to influence by the results of disciplined inquiry in the midst of the many usual political forces. It is a question worthy of study in its own right.

A Conceptual Framework for the Analysis

The cost-effectiveness analysis in this specific science education study employed the general steps described by King (1974): definition of objectives, identification of alternative actions, selection of effectiveness measures, development of cost estimates, selection of a decision criterion, and creation of models relating cost and effectiveness. As applied in this context, they took the form described below.

Objectives

A cost-effectiveness analysis of alternative means of reaching some objective requires that one know what that objective is. In today's political rhetoric about education, however, as well as in commission and committee reports, the objectives generally are not well defined. The analyst faced a problem defined only in general terms by reports in the media and by proposed legislation announced by elected officials.

After careful consideration, three objectives were selected as representative of the intent of the many interventions which have been proposed in the political arena to improve science education. They are as follows.

a. *Quantity:* Increase the amount of time in which students are engaged in learning science.
b. *Quality:* Increase the quality of instruction in science classes.
c. *Appropriateness:* Increase the "match" between actual classroom objectives and those objectives most appropriate in today's world.

One might argue that the objectives should be expressed in terms of student learning since that ultimately is our goal—to increase student learning. But for purposes of this cost-effectiveness analysis it is better to use objectives expressed in terms of instruction because the connection between the intervention and these instructional outcomes is more direct and there is a better basis for conducting an analysis that will show relative costs and effects.

A current public desire is for a greater *quantity* of science; i.e., that students should know *more* science. Research shows a very direct relationship between the amount of time devoted to learning and the amount of learning that takes place. This research base is important for this analysis because it firmly establishes that additional time spent learning will be effective and that a "point of diminishing returns" is *not* likely to be reached in our typical school settings.

The second objective of increasing the quality of instruction is more difficult to define and more difficult to demonstrate as having an impact on learning, but, nonetheless, it is important. Many of the interventions which have been proposed for improving science education are focused upon what has been labeled here as quality. In this analysis, each intervention is examined individually as to its potential impact on student learning based on the research information available.

The third objective of appropriateness deals with the question of what should be taught; the science taught should be that portion most appropriate for students in today's world. On the surface it is a simple matter, but in reality it is not; it is based upon value judgments. A thorough analysis must take account of the various alternative emphases and combinations of them.

Alternative Actions

The second step of the cost-effectiveness analysis, identification of alternative actions, was a relatively easy step for this project in that most of them have been advocated and widely reported in the popular and professional literature. The number of possible interventions is large, a fact that is evident to anyone familiar with even a few of the many recent commission reports, proposed pieces of legislation, and political statements. In this project an attempt has been made to be inclusive, considering as many interventions as possible, yet limiting the endeavor enough to make it manageable. This approach has been pursued by grouping the possible interventions into broad groups, 11 in number (see Table I), and including within each group at least the major possible interventions. In some cases, the interventions included are essentially all those actions under serious consideration by any leader or leadership group. In other cases, the number of possible interventions is large enough that all cannot be included.

TABLE I
Interventions Grouped by Primary Objective

A. Interventions Primarily Related to Objective #1: Quantity
   1. Increasing Student Requirements
B. Interventions Primarily Related to Objective #2: Quality
   1. Preservice Preparation of Teachers
   2. Enhancing Teaching as a Career
   3. Improving Instructional Practice
   4. Inservice Education
   5. Improving Materials, Facilities and Equipment
   6. Assistance from Business and Industry
C. Interventions Primarily Related to Objective #3: Appropriateness
   1. Improving School Curricula
D. Facilitating Interventions
   1. Improving Local Leadership
   2. Testing Programs
   3. Public Education

The Analysis Process: Effectiveness Measures and Cost Estimates

Conceptually, steps three and four of the analysis process are simple. Each possible intervention or action to improve science education can be analyzed to determine what it will cost to implement and what effect it can be expected to have. In practice it is more complex because of a lack of good information in many cases, and the potential interaction among the interventions.

In principle, for each intervention both the cost and effect with respect to all three objectives must be determined. In the case of most interventions, however, there will be a significant impact on only one of the objectives; most often an intervention has little potential for meeting more than one objective.

The key part of the cost-effectiveness analysis is obtaining the needed cost and effectiveness information. The best cost information is empirical data acquired in typical school settings. In cases where an intervention has not been used previously, estimates can be made based upon descriptions of what the intervention is. A variety of costs must be taken into account in estimating the price of a particular intervention. Some costs are direct and others are opportunity costs; some costs are borne by the taxpayer, some by teachers, and still others by students.

Valid effectiveness information generally is more difficult to obtain. The best sources are well-designed experimental studies which provide data on the effect of the given intervention as compared to the effect of conventional practice without the intervention. The educational research literature is extensive; it is a larger and better data base than often realized. Efforts must be exerted, however, to seek out the data relevant to the effect of a particular intervention through such sources as literature reviews and meta-analyses (Anderson et al., 1983).

Widely publicized problem statements, as well as the specific objectives implied by proposed interventions, point to a variety of effectiveness measures. While for many projects a single effectiveness measure may be appropriate, in this endeavor a total of three distinctly different ones was employed. They relate to (1) time engaged in learning, (2) student learning as measured by tests, and (3) changes in curriculum goals. Although not mutually exclusive, these three effectiveness measures by and large deal with different objectives and different intended changes in science education.

In spite of all these literature review efforts, however, gaps will remain for which no empirical data are available. In these cases the analyst is left with no option but estimates. While such estimates probably are an inadequate basis for all decisions about particular interventions, they may be adequate for eliminating some interventions as so lacking in promise as to be unworthy of a careful test and identifying others as deserving investigation.

A Decision Criterion

The fifth step in the cost-effectiveness analysis is selecting a decision criterion. King notes that, "three types of valid criterion from which the analyst must choose are: 1) maximize effectiveness at a given cost; 2) minimize cost while attaining a given effectiveness; or 3) some combination of these two which recognizes a tradeoff of cost for effectiveness to maximize a selected utility function of the two factors" (1974, p. 125). This latter approach was dictated by the complexity of the given situation.

Creation of Models

Having completed the above steps, there still remains the final problem of identifying analytical relationships among costs, effectiveness, and the context in which the interventions are to be initiated. This task was particularly difficult in this project because the analysis indicated early that the long list of single interventions under consideration could not be treated as single interventions. The situation is highly systemic and some combinations of interventions must be examined within the context of school districts having a wide range of cultural, socioeconomic and political variations. The legislator expecting that the enactment of one or two laws will reform science education obviously is naive. On the other hand, the informed policy maker wishing to select an effective combination of actions with high potential for significant educational improvement faces a complex and demanding challenge.

Projected Costs and Effectiveness of Single Interventions

In spite of the clear need for a systemic look at combinations of interventions, the analysis of necessity had to begin with the lengthy process of calculating the costs and effectiveness of each individual intervention. While they are grouped within the previously indicated 11 categories, each specific intervention in each category must be examined individually to determine its projected cost and effectiveness. Limiting the analysis to separate individual interventions, of course, would be inappropriate because of the systemic nature of the situation under consideration, and in the next section of this article attention will be turned to the value of various combinations of interventions.

For purposes of describing projected costs and effectiveness, the 11 categories of interventions are grouped within four clusters. These four clusters are the three objectives described earlier (quantity, quality, and appropriateness) and a fourth cluster designated as facilitating interventions. Each of the first three of these clusters contains one or more categories of interventions which are expected primarily, though not exclusively, to directly promote attainment of that particular objective. The fourth cluster, facilitating interventions, contains categories of intervention which, though not necessarily promoting directly the attainment of any of these three objectives, potentially are of benefit in changing some aspect of schooling that in turn will foster attainment of one or more of these objectives. The four clusters and the categories of interventions contained within each one are presented in Table I.

Cost Calculation Procedures

Estimating the cost of a particular intervention requires that attention be given to possible costs to a variety of agencies and individuals such as federal and state government and local school district expenditures, teacher and pupil costs, and costs incurred by industry in the case of donations from that sector. The types of costs included are both direct costs and opportunity costs. Table II contains a definition of each of the cost categories including state and local district expenditures (S & L), federal expenditures (F), expense and opportunity costs incurred by teachers (T), educational opportunity costs for pupils (EOC), expense and opportunity costs for pupils and their families (P), and costs incurred by industry (I).

A full description of the costs for each intervention is provided in Table III. The basis on which each was calculated is described in detail in Anderson, DeLarber, and Munsell (1984).

All costs presented in this table are presented as the cost per pupil per year. Some costs were substantial sums which were prorated over a number of years. For example, the cost of remodeling a school classroom to convert it to a science laboratory was prorated over a ten-year span. In another instance, in-service education was assumed to have a "life" of five years and was prorated over that period of time. The only costs not presented in this manner were the costs of educating the public (one of the 11 intervention categories). In most cases, the cost per pupil per year is in essence the cost of providing the particular intervention for the sake of one class in which that student will be participating over the period of one school year. For example, an intervention which causes the student to take an additional course in science is an intervention that affects one class of the student's school day over the period of one school year.

TABLE II
Definitions of Cost Categories

Code	Cost Category	Description
S & L	State and local district expenditures	Includes all direct expenditures by school districts, the source of which generally is state or local funds. It also includes any direct expenditures by the state for programs initiated at that level.
F	Federal expenditures	Includes all direct expenditures by the federal government for the given intervention. To whatever extent federal funds indirectly support an intervention through regular school district budgets, it is included in S & L above. It also includes the cost of tax reductions received by industry for their donated assistance as described below.
T	Expense and opportunity costs incurred by teachers	Includes all direct expenses incurred by teachers or prospective teachers and opportunity costs resulting from their participation in the intervention.
EOC	Educational opportunity costs for pupils	Reduction in non-science education due to reallocations of time and resources to science education. It is valued at its cost.
P	Expense and opportunity costs for pupils and their families	It includes all expense and opportunity costs incurred by either pupils or their families with the exception of educational opportunity costs contained in EOC above.
I	Costs incurred by industry	Costs incurred by industry as a result of their donations to science education reduced by the amount of the tax benefits they receive for their donation.
TOT	Total	Total of all of the above categories.

While the cost calculations assume an "average"-sized school district, it is recognized that the costs and feasibility of many interventions will vary with the size of district. In most cases these variations do not significantly alter the conclusions drawn from the analysis.

Many readers may be inclined to attach more importance to the costs contained in a particular column than some others. For example, the taxpayer or political leader may be inclined to give most weight to tax monies expended and attach lesser importance to a matter such as "Pupil Cost" in the form of opportunity costs or lost wages to the student as the result of spending more time in school. While various individuals may have different value judgments in this regard, one should not lose sight of the fact that *all* the costs described in this analysis are costs to society.

Determining Effectiveness

Determining the effectiveness of the interventions is a more involved process than ascertaining costs. First, as indicated previously, information on effectiveness simply is not as readily available in many cases. Second, there is substantial interaction among

TABLE III
Costs of Single Interventions (Dollars per Science Student per Class per Year)

Intervention	Tax $ (S & L and F)	Teacher Cost (T)	Pupil Cost (P and EOC)	Industry Cost (I)	Total
A. Quantity					
1. Increased Student Requirements					
a. Increase graduation requirements (1 course)	$30.02		$600.00		$630.02
b. Increase college admission requirements (1 course)	30.02		600.00		630.02
c. Increase length of school year (4 weeks)	333.40		536.00		869.40
c.' Increase length of school day (1 hour)	500.00		401.99		901.99
d. Increase homework	1.59		100.50		102.09
e. Increase percentage of class time used for instruction	1.59				1.59
f. Increase scheduled days used for instruction			60.00		60.00
g. Increase academic requirements for participating in athletics			301.50		301.50
B. Quality					
1. Preservice Preparation of Teachers					
a. New standards for teacher preparation programs	2.88	$8.96			11.84
b. Greater science requirements for elementary teachers	1.15	3.58			4.73
c. Specialized science teachers in grades 4-6	2.88	8.96			11.84
d. More courses emphasizing applications of science	1.39	3.58			4.97
e. More "hands-on" work in teacher education programs	10.99				10.99
f. Student teachers only with outstanding cooperative teachers	0.18	0.30			0.48
g. Employ only fully certified teachers					N/A
h. Interest-free loans for prospective teachers	11.39				11.39
2. Enhancing Teaching as a Career					
a. Increasing salaries of all teachers ($3000)	$26.88				$26.88
b. Increasing salaries of science teachers ($3000)	2.15				2.15
c. Performance pay	3.58				3.58
d. Improved professional environment					N/A

(Table continues on p. 562.)

TABLE III (*Continued*)

Intervention	Tax $ (S & L and F)	Teacher Cost (T)	Pupil Cost (P and EOC)	Industry Cost (I)	Total
e. Local teacher recognition campaigns	0.08				0.08
f. Improved teacher recruitment and placement	0.09				0.09
g. Involve teachers in collaborative educational research	5.35				5.35
h. Better supervision and evaluation	3.58				3.58
i. Reduced workload	240.00				240.00
3. Improving Instructional Practice					
a. Improved teacher-student ratio	240.00				240.00
b. Mastery learning	1.82	$0.27			2.09
c. Computer-assisted instruction					N/A
4. Inservice Education of Teachers					
a. Summer institutes for teachers	2.57	0.09			2.66
b. Academic year, full-time institutes	44.15	7.09			51.24
c. Late afternoon or evening institute classes	2.18	0.27			2.45
d. inservice on application of science	1.82	0.27			2.09
e. inservice on more advanced aspects of science	1.82	0.27			2.09
f. Inservice on teaching methods	$1.82	$0.27			$2.09
g. Inservice coordinated with local development	1.82	0.27			2.09
h. Teacher centers	2.11	0.27			2.38
i. Extended year contracts for program development	6.42				6.42
j. Improved teacher evaluation	3.58				3.58
k. Sabbatical leaves	23.12				23.12
5. Improved Materials, Equipment, and Facilities					
a. Improved materials, equipment, and facilities	5.30				5.30
6. Industrial Assistance					
a. Seed money for educational projects	0.72			$1.07	1.79
b. Providing cash awards	0.72			1.07	1.79
c. Equipment donations	0.72			1.07	1.79
d. Loaning lecturers and workshop leaders to schools	0.49			0.73	1.22

TABLE III (*Continued*)

Intervention	Tax $ (S & L and F)	Teacher Cost (T)	Pupil Cost (P and EOC)	Industry Cost (I)	Total
e. Rotating employees into classroom teaching	30.46			45.70	76.16
6. Industrial Assistance (continued)					
f. Evaluating and developing curricula	0.12			0.18	0.30
g. Summer employment for teachers	4.94			7.40	12.34
C. Appropriateness					
1. Improving School Curricula					
a. Developing more courses with science applications (local)	0.59				0.59
a′ Developing more courses with science applications (federal)	0.05				0.05
b. More rigorous courses for college bound (local)	0.59				0.59
b′ More rigorous courses for college bound (federal)	$0.05				$0.05
c. Reducing number of "frill" courses					N/A
d. Federal funding of new curriculum development projects	0.05				0.05
e. Revising "old NSF" courses locally	0.30				0.30
f. Developing model curriculum patterns for districts	0.05				0.05
g. Training for local personnel on curriculum development and implementation	0.13				0.13
h. Regional consortia for curriculum development	0.30				0.30
i. New standards for textbook adoption	0.05				0.05
j. Improving program evaluation	0.03				0.03
D. Facilitation					
1. Improving Local Leadership					
a. Increasing the number of science supervisors	3.00				3.00
b. Revised job descriptions for local science supervisors	0.75				0.75
c. Revised job descriptions for general curriculum personnel	0.75				0.75
d. State or federal funding of local leadership development program	3.50				3.50

(*Table continues on p. 564.*)

TABLE III (*Continued*)

Intervention	Tax $ (S & L and F)	Teacher Cost (T)	Pupil Cost (P and EOC)	Industry Cost (I)	Total
e. Training for school board members	0.05				0.05
2. Testing Programs					
a. Awareness conference for local testing personnel	$0.01				$0.01
b. Test item banks for local personnel	0.02				0.02
c. Awareness conferences for test publishers	0.01				0.01
d. Informing local accountability committee members	0.05				0.05
3. Public Education					
a. Media advertising to promote science education	<0.01				<0.01
b. Science television programs for public	0.35				0.35
c. Adult education courses on science and technology					N/A

many interventions; i.e., a given intervention will not necessarily yield the same effect if introduced singly as it will if introduced in combination with one or more of the others. The first difficulty is dealt with by expending the effect required to locate whatever information is available. The second complication, interactions among the interventions, is more challenging.

When examining 69 different single interventions, one is faced with a most formidable number of possible combinations of interventions; it simply is not feasible to examine all possible combinations. The scope of the task is staggering, and, furthermore, research-based information on the effectiveness of most combinations is not available. The solution to this dilemma was found in the sixth and final stage of a cost-effectiveness analysis as described earlier, namely, the creation of models relating cost and effectiveness. Before turning to this stage, however, attention must be given to the effectiveness of each of the interventions if introduced as a single intervention.

The effectiveness of the interventions is best described in a narrative since the criteria for effectiveness vary among the objectives. While tables could be prepared that summarize numerical indicators of effectiveness (e.g., effect sizes from a meta-analysis), more elaboration and explanation generally are required for each intervention. Space does not permit presentation of such narratives here, even though they have been prepared (Anderson, DeLarber & Munsell, 1984). An example of these narratives, however, pertaining to both costs and effectiveness, is presented below for one intervention.

It is followed by matrices which summarize the relative costs and effectiveness of all of the single interventions within each of the clusters of objectives.

An Example

The first in the list of 69 interventions under consideration is *increasing the graduation requirements in science for all students*. This action consists of increasing the required number of science courses in junior and senior high schools, e.g., a senior high that required one science course for graduation may now require two.

Costs: the costs for this intervention are medium for the taxpayer and high for the pupils. Theoretically at least, the students will simply take less of some other courses so they can take more science. Thus, the total number of teachers, classrooms, textbooks, etc., will not change. But there are some real costs, such as remodeling classroom space to provide science laboratories and stocking them with the necessary supplies and equipment.

There are other less visible costs such as the loss of student learning in areas other than science. In essence it is a simple trade-off but it still must be recognized as a cost, since there are other interventions for increasing time for science that do *not* have this substantial cost.

Yet another potential cost (not included in the cost calculations) relates to the current shortage of qualified science teachers. To whatever extent additional science teachers must be obtained from among persons with substandard qualifications, the overall quality of U.S. science teaching is lowered.

Effectiveness: The effectiveness of this intervention in terms of the given objective is potentially high. To whatever extent the new science requirement is higher than the amount previously taken, it will result in students being engaged in science learning for a greater period of time.

Further analysis, however, leads to some important reservations about the potential effectiveness of this intervention. Most of the college-bound students in a typical school already are taking more than the minimum required amount of science. Thus, the increased requirements will have little effect on this large portion of the school population. The group it will affect is largely the non-college-bound students, sometimes referred to as the general or nonacademic student. Since increasing the scientific literacy of *all* students is generally regarded an important goal, this intervention still seems to be an attractive one, but heed also must be paid to the appropriateness objective. Is the *current* science curriculum of high schools designed for the college-bound students or is it appropriate for all students? In many schools it may not be appropriate for all students to the extent of the new requirement. Thus, the appropriateness issue must be dealt with before a final answer can be given on the effectiveness of this particular intervention. This situation illustrates the systemic nature of the issue at hand and leads to a final conclusion: This intervention will have high effectiveness in increasing the amount of time *engaged* in science learning *if* the appropriateness objective *also* is attained.

Summarizing the Cost-Effectiveness Information for Single Interventions

Analyses similar to the above example were prepared for each of the 69 interventions. Each was described in terms of its cost and effectiveness as a single intervention. For each, a specific cost was calculated along with a discussion of its potential effectiveness as a single intervention.

Cost and effectiveness information is combined for each single intervention and presented in four matrices (Figures 1, 2, 3, and 4)—one for each of the four major objectives: quantity, quality, appropriateness, and facilitation. In each matrix, each specific intervention is given a location designated by the letter or number and letter combination used for it in Table III. This location in the matrix gives its *relative* cost and effectiveness *compared* to the other interventions in the matrix. No scale is given on either axis of the matrix simply because it may imply more precision in the determination of cost or effectiveness than is warranted for a given action. The location of each intervention on the horizontal axis is based on the cost information presented in Table III as compared to the other interventions for that objective (the cost scale for each of the four matrices is *not* the same and the scales are not necessarily linear). Similarly, the vertical axis portrays relative effectiveness. In both cases, the axes are divided into thirds designated as low, medium, and high.

Because of the large variations in cost and effectiveness of the interventions, and the fact that choices must be made among the possible interventions, only those falling in certain sectors of the matrices probably should be considered. First of all, any intervention falling in the low-cost/high-effectiveness sector should be given immediate attention. Unfortunately, they are few in number. Second priority goes to those interventions falling in the medium-cost/high-effectiveness or low-cost/medium-effectiveness sectors. As a third priority, consideration may be given to the medium-cost/medium-effectiveness sector with fourth priority (low), for all others. One caution must be given in this regard, however; an intervention that does not look very attractive as a single intervention may be a *critical component* of some combination of interventions to be discussed later in this report.

While a major theme of this analysis is that interventions should not be viewed singly but in combinations, some comments are in order regarding the single interventions displayed in the four matrices.

Quantity. In the matrix for single interventions for Objective No. 1: Quantity (Figure 1), one intervention is found in the low-cost/high-effectiveness sector, namely, increasing the class time devoted to instruction. There is research to indicate that this intervention will work and the cost of the actions needed to bring it about is quite low when prorated over a five-year period. A second priority intervention is increasing homework for students. While lower in effectiveness and higher in cost than the former intervention, there is still a research basis for its consideration. Finally, attention can be given to the medium-cost/medium-effectiveness category which contains interventions also worthy of consideration.

Quality. No interventions are found in the low-cost/high-effectiveness sector of this matrix (Figure 2). The low-cost/medium-effectiveness category, however, contains several interventions. While considered here as single interventions, many of them imply some coordination with other initiatives; not surprisingly, many of them will arise later in this article in a discussion of combinations of interventions.

Appropriateness. While the scale used for costs in this matrix (Figure 3) could have been arranged to spread the interventions across the whole matrix in the cost dimension, the costs of all of the interventions in this category for improving the school curriculum are so low on a per-pupil basis when compared to the quality interventions described above that they were displayed in a manner that indicates this

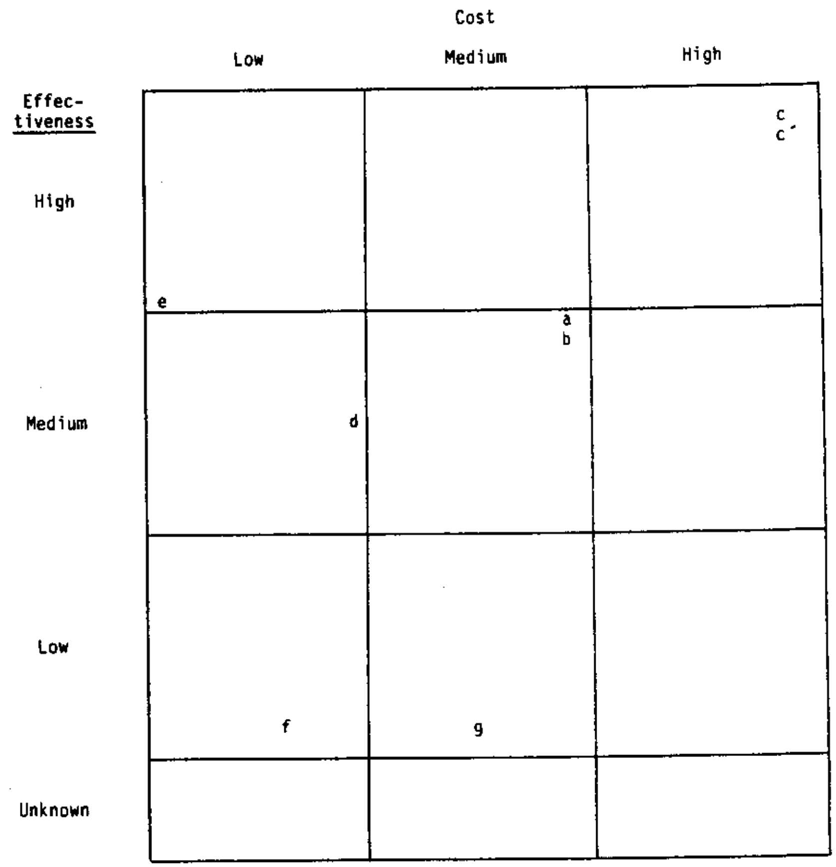

Fig. 1. Cost-effectiveness matrix for single interventions for objective No. 1: Quantity. (See Table III for a description of each of the interventions designated in the matrix.)

very low per-pupil cost. The high effectiveness intervention in this matrix, new standards for textbook adoption, pertains only to a very few states (or consortium of states) where the population is large enough to be a significant market force and where the process *could* be used to insure that the textbooks would in fact have to change substantially. The interventions included in the medium-effectiveness category all involve mechanisms for developing new curricula; there is a variety of approaches. A crucial question that must be raised in connection with development of new curricula, however, is whether or not there is a process by which these new curricula will be implemented in the schools. Though not specifically addressed here in the context of curriculum development, this issue will arise again when consideration is given to a combination of interventions.

Facilitation. This fourth objective deals with interventions which make it possible to bring about change in the schools; they make possible the actions described in the

Effectiveness	Cost: Low	Cost: Medium	Cost: High
High			
Medium	3b 4g 2f	1b 1d 1e 2h 4j 1a 1c	3a 2i 6g
Low	4h 2b 4f 1f 6f 4d 2e 4c 4e 4a	2c4i 5a 1h 2g	2a 4k 4b 6e
Unknown	6a 6b 6d 6c		3c

Fig. 2. Cost-effectiveness matrix for single interventions for objective No. 2: Quality. (See Table III for a description of each of the interventions designated in the matrix.)

three matrices above. Many of these actions may be critically important and essential, if the other actions are to succeed. For purposes of this matrix (Figure 4), however, they are considered on the basis of their effectiveness as independent interventions; not surprisingly, none of them appear in priority sectors.

Combinations of Interventions: An Imperative for Solving a Systemic Problem

The previously mentioned systemic nature of school-improvement processes highlights the inadequacies of examining the situation in terms of single, independent interventions. An adequate analysis most account for the power of combinations of interventions (the effects may not be simple additive) and interactions which may occur among the interventions. This need leads to the sixth and final step of a cost-effectiveness analysis—creating models relating cost and effectiveness.

If it is granted that the situation must be analyzed from the perspective of a combination of interventions, one is still left with the question of what conceptual framework should be used to organize this analysis. Fortunately, the last two decades of educational research have yielded numerous findings which, when taken together, can provide the needed conceptual framework. While such studies are numerous and diverse in topic, there are three streams of research which have been particularly productive and have special potential for providing the guidance needed in this analysis. The three include research on (1) school effectiveness, (2) implementing educational change, and (3) the role of school principals. Each of the three will be examined to identify major findings and implications of particular note for this analysis.

Space does not allow the presentation here of the extensive review of this literature (Anderson et al., 1984) prepared for the final stage of this cost-effectiveness analysis. Suffice it to say that it was reviewed from the perspective of *combinations* of interventions to identify those with implications for the analysis at hand.

Effectiveness	Cost: Low	Cost: Medium	Cost: High
High	i		
Medium	e a a' d b' h b		
Low	g f j		
Unknown			

Fig. 3. Cost-effectiveness matrix for single interventions for objective No. 3: Appropriateness. (See Table III for a description of each of the interventions designated in the matrix.)

Effectiveness	Cost: Low	Cost: Medium	Cost: High
High			
Medium			
Low	1b 1c 1d 2d 2b 1a 2a 1e 2c		
Unknown	3a 3b	3c	

Fig. 4. Cost-effectiveness matrix for single interventions for facilitation. (See Table III for a description of each of the interventions designated in the matrix.)

Implications of This Research

Three major generalizations emerged from these several streams of research upon which further analysis was based.

First, the importance of a combination of interventions is clear. Specific interventions cannot be examined in isolation.

Second, the completeness of a particular combination of interventions may be critical. The research indicates that the lack of one particular intervention from a given combination may be sufficient to eliminate attainment of the goals to which the combination is addressed.

Third, whatever combination of interventions is selected, it must be based upon a multilevel perspective. Some interventions must be introduced at the classroom level, some at the school level, and some at the district level. In addition, whatever interventions

are considered at the state or national level must give full and proper attention to the various lower levels at which research indicates the interventions can be effective.

Combinations of Interventions

With the review of research on effective schools and implementing educational change as a foundation, attention again can be turned to the major objectives (and the 11 categories of interventions within them) and the most effective combinations of selected actions from these categories.

Because of the systemic nature of the situation, the effectiveness information provided for each single intervention must be reappraised in light of its potential interaction with other interventions. As a result, the effectiveness information may vary considerably from that provided for single interventions, even though the cost information is still largely valid and not subject to significant change other than as two interventions overlap to such an extent that it is cheaper to do the two in combination than singly.

Objective No. 1: Quantity

Increasing Student Requirements. Because this category of interventions is not very interactive, the analysis presented earlier for single interventions still largely applies when discussing combinations. Increasing engaged time, i.e., increasing the amount of class time actually used for instruction, probably is the most cost effective. The cost of acquiring it is very small, even if a much greater amount of in-service education and supervisory help is needed to implement the intervention than estimated in this analysis. The cost of increasing productive homework also is relatively low, at least in terms of expenditures of tax monies. It also is worth pursuing.

Increasing science course requirements, either through graduation requirements or college admission standards, is an additional viable approach, but in terms of cost effectiveness, probably only should be considered as additional steps to be taken after the more fundamental ones.

If one wishes to increase the quantity of learning time for science even further, the cost probably increases dramatically. There is little doubt that such measures as increasing the length of the school day or the school year will increase learning, but our society must be willing to pay the price involved.

Objective No. 2: Quality

This objective has a number of categories of interventions, several of which are quite interactive with other categories. Most of these interventions are fairly long term in nature and the level at which they best can be initiated varies. Some of the interventions for this objective are examined in the *sample* categories below.

Preservice Teacher Education. This category of interventions is not very interactive, i.e., it can be considered quite independently of the other interventions. It is a long-term category, however, in that the impact will take considerable time to be noticed. Changes in preparation programs will not be instantaneous and the number of new teachers in any given school will not be large for some years after teacher preparation changes take place.

In-service Education of Teachers. This category of interventions is highly interactive in that in-service education programs in general have not evidenced high impact, while in-service education also has been identified as a critical part of educational change endeavors. In essence, in-service education set up as an isolated endeavor independent of other activities probably will produce few results, while in-service education set up as part of a broader-based implementation effort will be effective and in fact may be essential to the success of the overall endeavor. In-service education is a relatively short-term intervention, although the overall endeavor for implementing change of which it is a part probably has to continue over a period of some years if the innovation is to become established.

Improved Materials, Equipment, and Facilities. This intervention also should be considered from an interactive perspective since there is little evidence to support the notion that substantial educational improvement will result directly from increased materials, equipment, and facilities. (This conclusion may reflect the existence of a minimal base of such support in most schools.) Essentially, they should be viewed as important in the educational process, but not the beginning point for significant educational improvement.

Objective No. 3: Appropriateness

Improving School Curricula. This objective, and the corresponding category of interventions, occupies a pivotal role in efforts to improve science education. It is the most value laden; there is not universal agreement as to what the appropriate curriculum should be. This category of interventions also is moderately interactive. Research on the NSF-funded curriculum projects of the last quarter century shows the development of new curriculum materials, in and of itself, can be successful in terms of student learning. Other evidence indicates, however, that the impact of these curriculum projects could have been much greater if better mechanisms were employed for implementing them in the schools. Thus, to gain the full benefits of new curriculum development endeavors, substantial effort should be devoted to implementation of the resulting products on a long-term basis.

Facilitating Interventions

The facilitating interventions are intended to foster attainment of objectives 1, 2, and 3 as described previously. Obviously interactive, because of their orientation toward facilitating the effectiveness of other interventions, they must be considered in terms of their impact when combined with other interventions. They can be initiated at various levels and be either short term or long term, although they tend toward long term.

Improving Local Leadership. As single interventions, none of those included in the category of improving local leadership received a rating above low in effectiveness On the other hand, the research cited earlier on effective schools and implementing change indicates quite strongly that this local leadership is an essential ingredient that *must* be present if other interventions are to have the desired effect.

Testing Programs. This intervention is interactive in the sense that it can be an important aid to changing the curriculum. Thus, it is closely tied to objective 3 concerning the appropriateness of the curriculum. To whatever extent new curricula are adopted with a somewhat different content than in the past, district testing programs (where they exist) can assist their acceptance by including test items consistent with the new curricula. It is a necessary step for local school districts (or states in those cases where they have state testing programs) to take in support of curricular change. It is a long-term endeavor in that the focus of testing programs rarely changes rapidly and changes which are made can be expected to persist for some time.

Recommendations

Having dealt with the costs and effectiveness of many potential interventions and combinations of interventions, one is still left with the questions of which particular interventions should be initiated, by whom, and under what circumstances. Obviously the most cost-effective interventions are the ones of choice, but the interactions among the interventions, and the many variations in how a given one could be implemented, all point to the need for further judgments. It is recognized at the outset that someone with different values may make a somewhat different set of choices based on the preceding cost-effectiveness analysis. This possibility is no reason, however, to back away from making judgments. In view of the extensive investment in the analysis up to this point, it would be irresponsible not to do so. A recommended state plan of action is developed elsewhere (Anderson, DeLarber, & Munsell, 1984). Similar recommendations could be developed for local school districts of varied sizes.

In developing such recommendations, the importance of viewing them as a totality rather than a listing from which to choose a few interventions is difficult to overemphasize. This perspective is supported by the research on effective schools and implementing educational change reviewed earlier and by the analysis itself.

The question of what goals should be pursued in science instruction permeates the entire analysis of this report. Everyone involved with science instruction in the schools must grapple with this issue. The research on effective schools highlights the importance of a goal orientation, but there is divided opinion on what the goals should be. The results of a survey of Colorado educational leaders (Anderson, DeLarber, and Munsell, 1984), for example, shows there are essentially two different orientations to this question. The majority position is that the applications of science need significant attention in the curriculum, but a significant minority are not persuaded of this importance. Current practice in the schools follows quite closely this minority position (Harms et al., 1981). The issue must be debated and whatever the outcome of the debate, a course must be struck based on clearly understood goals, carefully developed plans of action, effective communication among all parties involved, and a resolve to put the plans into effect. In this manner, substantial improvement in science education can be pursued with optimism.

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