Policies for

Improving Scientific Literacy in

K-12 Education:

An Institutional Approach

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Introduction

Recognizing the its importance to our nation's security and economic prosperity, the United States government has actively pursued a number of policies related to science and technology since World War II. One of those policy commitments has been to support science and mathematics education at the primary and secondary levels. While the national government may seek specific sorts of benefits from science and mathematics education, due to the complex federal public education system as it has developed in our nation, it also finds itself unable to directly mandate or underwrite specific programs to fulfill those national needs. The primary and secondary education system is a study in federalism, with responsibilities divided between the local, state and federal levels. There is also a substantial (and influential) private-sector primary and secondary education sector that in many ways parallels the public sector. Both public and private sectors are intended to produce graduates who, it is hoped, will be wiser individuals, better citizens, and more-productive workers in the economy. Some of these students go directly into employment on completing school, while others enter post-secondary education (ignoring for the moment the portion that drop out without completing school). Some of those students go on to graduate from college and become teachers in the primary and secondary system. This has resulted in complex institutional arrangements and coalitions of stakeholders that seek to influence education policy at all levels.

In recent years, there has been much public debate about whether the nation's system of primary and secondary education is producing adequate levels of knowledge and ability in the students passing through it. At least in the halls of Congress and the state legislatures, as in the White House and many governors' mansions, and in the eyes of many researchers, the accepted answer seems to be, “No.” This answer is predicated in part on ideology, but also on the results of studies conducted by academic and other researchers. Despite the claims of many politicians and analysts (on all sides of the issue), the research is not at all conclusive on the nature and causes of the current educational crisis, nor on the solutions advanced to resolve the crisis. This of course has not deterred action: decision-makers—both elected officials and appointed administrators at the national, state and local levels—have taken action to reform education without any consensus among education researchers or practitioners about the impact those policy changes may have.

One of the key issues in this debate is the quality of education provided to students in the fields of science, technology, engineering and mathematics (often abbreviated, STEM). Indeed, one set of institutional actors has been working diligently for more than two decades to put STEM education at the forefront of educational reform; indeed, their concerns lead to the formation of national committee that produced *A Nation at Risk* in 1983 (Naitonal Commission on Excellence in Education, 1983). This issue is often posed as a debate over the importance of literacy in the sciences, which includes in this case all of the STEM fields. The approach of this project is to consider how proposed changes in educational policy might affect the institutional arrangements and actors in public education. Institutional arrangements mean the “relatively stable sets of formal and informal rules” (Weimer and Vining, 2005) that govern the actions and behavior of the institutional actors, that is, the various individuals, entities and organizations that are involved in education.

To keep this project manageable, the focus is on policies related to science and mathematics education at the primary and secondary levels. The research questions guiding this project are these: given the complex institutional arrangements of primary and secondary public education in the United States, what policy alternatives could the federal government pursue directly to improve science literacy among students? What policy alternatives might be appropriate for state and local governments, if they are not appropriate for the federal government? How might the federal government encourage state and local governments to adopt those policy alternatives (thus, how might the federal government indirectly improve science literacy)?

Institutions in Public Education

Public education is a field made up of a number of well-defined institutional players, and fairly well defined institutional arrangements and relationships between those players. The institutional players include (but are by no means limited to) students, their families, teachers, teachers' unions, school staff and administrators, post-secondary schools of teacher education, and local boards of education. A selection of these institutional players are presented in table 1, below, along with some characteristics.

Table 1. A selection of institutional players in primary and secondary education, and their function, role, and functional level.

Institutional Player	**Function**	**Role**	**Functional Level**
Teacher	Supply	Presentation of information and skills	Individual
Teachers' Unions	Supply (support)	Protect teachers, work for better salaries and working conditions	Local, State, National
Student	Consumption	Learning of information and skills	Individual
Family	Consumption (support)	Encouraging/supporting education of children	Local
Admin/staff	Supply (support)	Support and enable the teacher/student transaction	Local
Boards of Education (Local)	Supply	Oversee the overall educational process	Local
State Boards of Education	Supply	Oversees and encourages education system	State

US Department of Education	Supply	Oversees and encourages education system	National
Teacher Education programs	Supply & consumption	Supplies teachers to P/S schools; consumes P/S-educated individuals to convert them into teachers, etc.	State
Community, Society	Consumption	Benefits from having educated population (more productive, healthier, less crime, more participative, etc.)	Local, State, National
Business Community	Consumption	Employs educated individuals; benefits from skills and knowledge individuals possess, which is gained through education	Local, State, National
Individuals	Consumption	Uses education to carry out life; participation in work, civic responsibilities, social duties and relations, etc.	Individual, Local
Government	Consumption	Employs educated individuals; democracy relies on educated, informed population	Local, State, National

Institutional arrangements include such things as funding mechanisms, teacher professionalism, selection of school boards, state and federally mandated programs and procedures, and age-grade correspondence. A selection of these are presented in table 2, below.

Table 2. A selection of important institutional arrangements or relationship in primary and secondary education.

Institution	**Allows**	**Limits**
Teacher-pupil	Necessary arrangement for learning, with teacher transmitting knowledge and skills to the student	Learning can take place in many ways, including reading, practice, example, mentorship, apprenticeship, etc.
Teacher tenure and salary based on longevity and	Relieves teachers from non-academic threats to positions	Cannot directly reward teachers in needed disciplines,

additional education		nor teachers who have better teaching skills
Teacher Professionalism	Teachers to exercise academic freedom, judgment, etc.	Poor teachers might do more harm than good.
Age-grade relationship	Keeps students with others of their roughly same developmental stage	Students significantly above or below the average are not taught appropriately
Standardized testing	Tests for specific knowledge and abilities at a given age-grade point in time, which allows comparisons across schools and over time	Validity/reliability of tests may be questionable; reliance on single-shot tests for evaluation not well supported; measurement based on averages suspect
Comprehensive "General" education	Provides all students with a basic background in all areas	Doesn't allow students to specialize in areas of interest
Local Elected control of public education	More direct accountability for what and how education is provided	Local prejudices, traditions may interfere with effective education

The central institutional players and relationship of primary and secondary education is that of the teacher and student. Within this relationship, the adult teacher attempts to transfer knowledge and skills to the student child (a supply role), and the student attempts to acquire knowledge and skills from the teacher (a demand or consumption role). In a microeconomics approach, this can be described by graph of supply and demand curves. The teacher supplies while the student demands knowledge and information. We would anticipate that changes in the institutions of education that would increase teacher ability, knowledge and motivation would tend to increase the supply, and thus move the supply curve outward and increase the quantity of education demanded by students, and generally lower the price per unit of education. We would also anticipate that changes in institutions of education that would increase student interest, attention and motivation would cause a change in the demand, but generally by increasing the price per unit of education. The amount of change, of course, depends in large part on the elasticities of both the supply and demand, which are heavily impacted by the costs of changing the factors related to the institutions and the institutional players. For instance, raising the level of teacher ability to motivate and teach students to a certain degree may cost a certain amount, negating the effective efficiency of improving the supply.

All other players and institutional relationships either support the teacher and the supply of education, or the student and the consumption of education, but less directly. This is depicted in table 3, below. A few institutional players, such as teacher education schools, appear on both sides of this divide between production and consumption, sometimes at different levels of activity.

Table 3. Typology of institutional players in primary and secondary education.

Producers		**Consumers**	
Direct	Teachers	Students	**Direct**
Support	Administration Staff School Boards State Ed. Boards	Families Community Employers Higher Education	**Support**
Indirect	Taxpayers Voters Interest Groups Publishers Researchers Higher Education	Society “Democracy” Federal Government	**Indirect**

While some writers point out that the manner in which public education has developed in this country could hardly be described as "systematic," (Chubb and Moe, 1990; Ravitch, 2001), it is also clear that it has indeed become a system through a general incremental change with occasional non-incremental changes. This system has been growing and changing since its inception, which can be dated to the latter half of the 19^{th} Century. Overall, the system may be assumed to have some degree of stability in terms of the players and relations between them. It may also be assumed that changes in one of the players or relations will cause changes in others, but typical of complex systems, the effects will not be completely linear and may occasionally cause results entirely unlike what was intended by the initial change.

There are three broad questions addressed regarding mathematics and science literacy that are of interest in this project. First is the question of whether or not there is indeed a problem. Second, that if there is a problem, what alternatives might be available for its resolution. Third, what are the institutional arrangements that exist, and may have caused and/or may help resolve the problem. The literature related to each of these questions will be dealt with in the following three sections. To be clear, few of the reports, journal articles or books on this subject fall exclusively into any one of these categories, and most cover two or perhaps all three of the possibilities.

Defining the problem

The publication of *A Nation at Risk* (National Commission on Excellence in Education, 1983) is often considered to be the beginning of the modern era of concern over America's K-12 education in general, and science and technology education in particular (National Science Board, 2004). During the ensuing 23 years, a number of investigators have further assessed the indicators suggesting that our primary and secondary schools are not up to meeting the nation's needs, and have proposed a variety of programs for improvement. For example, in late 2005, the National Academies Committee on Science, Engineering, and Public Policy (national Academies, 2005) issued *Rising Above the Gathering Storm*, which expressed concern over America's apparent decline from world technological leadership, and recommended four broad policy responses, including improving K-12 science and mathematics education. The National Science Board of the National Science Foundation issues a biennial report, *Science Engineering Indicators*. In 2000, 2002, and 2004, the board expressed concern about trends in science education and employment in the country. The board reiterated these concerns in supplemental reports in 2000 and 2004, and a special 2003 report, *The Science and Engineering Workforce: Realizing America's Potential*. This report included recommendations to improve the quality of mathematics and science teachers in primary and secondary education. From an institutional standpoint, these committees are generally organized by federal agencies that underwrite science activities around the country, and include large numbers of business and technology executives as well as leading academic researchers and scholars as expert members. Indeed, while the reports acknowledge the general good that education provides to society, the primary emphasis is education to support continued American business dominance in the world economy.

This literature is marked by normative discussions about the nature of science and education in society, and by largely descriptive presentation of data to defend an affirmative or negative response to the question of whether there is a science education crisis. *A Nation at Risk* set the basis for the ongoing debate about America's public education system, with a number of early reform efforts being introduced and implemented in the middle 1980s. DeBoer (2000) and Laugksch (2000) both offer historical perspectives on the origins of the current concern over mathematics and science literacy. Both further note that the term "scientific literacy," while apparently simple and straightforward, in practice reflects a number of hidden assumptions. The effects of these hidden assumptions become clearer when the connection to proposed reforms of science education are made, with particular reforms connected to particular meanings and assumptions. For example, one of the primary assumptions is that the federal government has a duty to respond by devoting significant resources to keeping American business and industry at the forefront of technological development by supporting education and research.

Defining alternative solutions

Granting that there is a crisis in science and mathematics education, what are possible alternatives to remedy the problem? Again, the literature can be divided into both normative (what approaches should be undertaken) and descriptive (how have various alternatives fared where tried, or might be expected to fare). This literature begins with a number of reports from the years immediately following publication of *A Nation at Risk*. For example, the GAO in a series of reports documented the effects of early reform in four school districts (GAO, 1989). In Illinois, the House of Representatives conducted a “community conference” series in 1984 and 1985, which resulted in several changes in Illinois law and programs (Madigan 1985; 1984; Joint Committee on the Oversight of Education Reform, 1986).

Changes in policy are of course based on some level of understanding about the causes and effects of actions. Calls for policy change in a given field at a given time are in response to the understanding of the existing arrangement of institutional players and their interactions, based on some existing model of cause and effect. For at least the last 40 years the one of the major focuses of educational research has been on the factors that influence student academic performance. One of the first of these studies was the Coleman Report in 1962 (Hanushek, 1986; Vandenberghe, 1999), which concluded that characteristics of schools have only minor impact on student performance, but that family, peers and other non-school factors are more important in determining educational outcomes. This was contrary to the common wisdom of the time, which was that the characteristics of schools and teachers had more influence on student performance.

The debate has continued in the decades since, and shows no signs of resolution, as study after study is published, each using slightly differing methodologies and data and coming to differing conclusions. In his review of the literature relevant to determining a production function for education, Hanushek (1986, and updated several times, most recently in 2003) suggests that there is little support for any significant relationship between any of the factors and student performance on standardized tests, with two exceptions: measures of teacher quality, and measures of family influence. However, Hanushek's methods and conclusions have also been challenged (for example, several studies are cited in Vandenberghe, 1999).

Since then, many researchers have investigated particular reform proposals. Some, for example, have addressed aspects of student performance in education reform, such as Bifulco, Duncombe and Yinger (2005) on the effects of several reforms on student performance in New York City schools; Zimmer and Toma (2000) on peer effects on student performance; and Primont and Dmazlicky (2006), Reeves and Bylund (2005), and Hanushek and Raymond (2005) on various aspects of student accountability testing. Other researchers have looked into aspects of improving teacher performance, curriculum change, and other school- and district-level reforms, such as Corcoran, Evans and Schwab (2004), Goldhaber, Perry and Anthony (2004), Dee and Keys (2004), and Donnelley (2005).

Defining institutional arrangements

Primary and secondary education in the United States takes place in a large and complex decentralized federal system, with a number of competing and complementing interests from both the public and private sectors. As in the other two segments of the literature, there are both normative and descriptive approaches. Of the three foci of the literature, this is the most theory-driven, with a number of frameworks used to illuminate various aspects of institutional interaction. DiConti (1996), for example, discusses education reform and the role interest groups play in what was then the latest round of reform efforts. Laugksch (1999), in an overview of the concept of scientific literacy, identifies four groups active in promoting a particular view of and a related need for action to improve literacy, including the science education community, social scientists and public opinion researchers, sociologists of science and science educators is the "informal and nonformal" science education community. Mintrom and Veragi (1996) use the advocacy coalition framework as a basis for understanding school reforms in Michigan. Several writers, such as Gordon (2004), Atkeson and Partin (2001), and Cookson (1995) consider the impact that federalism has on possible educational reforms. McDermott (2006) looks at the role of incentives in the "loosely coupled" educational system of the country, while Soares (2005) and Odden and Wohlstetter (1992) investigate fiscal constraints on reform. Lauglo (1995) considers how decentralization may affect reforms, while Nechyba (2003) tests the effect of state-level centralization.

From the existing literature, it is clear that reform of science and mathematics education is an active field of both practice and research. The available literature should make it possible to consider the merits of several policy options intended to remedy the "scientific literacy" crisis and identify the costs and benefits related to each, especially in light of the complex federal nature of America's primary and secondary education system. The dependent variable in this research and discussion—that is, what researchers are trying to understand and policy makers are trying to change—is scientific literacy. However, there are almost as many definitions of "scientific literacy" as there are writers on the subject (see Laugksch, 2000; and DeBoer, 2000, for example). However, the National Academy of Sciences (1995), gives the following defintion:

> "*Scientific literacy is knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity*."

This combines a definition—*knowledge and understanding of scientific concepts and processes*—with three rationales for having such knowledge and understanding—[1] *personal decision making, [2] participation in civic and cultural affairs, and [3] economic productivity.* These rationales, however, also describe the limits of the education or knowledge necessary for "literacy." Rather than knowing and understanding thousands of specific facts and concepts, what is needed is an understanding sufficient to improve personal decision making, to improve participation, to improve productivity. One need not be able to understand the technical details of how cloning takes place to be able to understand the general process and the political, ethical, social, and economic implications that arise from it. However, even to that more general level of knowledge, it is difficult to establish the what and how of the educational process needed.

This study offers three propositions that relate scientific literacy with primary and secondary science education:

Proposition 1: Scientific literacy appears to be a characteristic of individuals, indicating that the individual student has acquired and mastered certain knowledge and skills that allow them to display an adequate level of knowledge and skills in science-related topics.

Proposition 2: Scientific literacy is (or should be) one of the primary outputs of primary and secondary education in the U.S., given that we have delegated the responsibility for educating our children to those institutions.

Proposition 3: Scientific literacy appears to require instruction by teachers who are knowledgeable and sufficiently talented in the sciences to encourage students to learn.

If these are true (and they will not be tested here), we must differentiate between the attainment of certain educational achievements, as measured by standardized testing or graduating from school, for example, and the attainment of knowledge, as the two are not necessarily related. It is clear, from an institutional standpoint, that increasing scientific literacy among students (and thus, eventually, among the general population) requires improvements to the institutional arrangements that support the teacher-student interaction. As the question of reforms to improve science literacy occurs within a general literature on school and education reform, and the need to increase all kinds of literacy, there are many broad reform proposals that may affect science literacy, and few proposals will be applicable *only* to scientific literacy.

There are currently no standard measures of science literacy, in part because of the disagreement over the definition of the concept. The four proposed measures listed here are proxies for the actual measure of science literacy, and all have some support in existing literature. The implementation of a successful reform alternative will result in a significant increase (exact definition not established) in one or more of the following measures over the five to ten year period following implementation. First, we would expect an effective policy to increase standardized test scores using international comparison tests, the National Assessment of Educational Progress (NAEP), the SAT, the ACT, state-developed assessment tests, and so on (National Science Foundation, 2004; National Academy of Sciences, 2005). Currently, scores on the results of these tests—usually reported as school, district and state composite scores—in the United States tend to be stagnant. Of course, there is research that questions the usefulness of testing, especially single-shot testing, using instruments that may not have been developed for the purpose, and may or may not have been properly normed, validated and proven reliable. There is also debate about the use of averaged or composite scores instead of looking at the distribution of scores within a given test group.

Second, survey measures of science literacy among students and the general public will show that the percent knowing specific scientific concepts and ideas will increase significantly, while those believing in non-scientific concepts and ideas will decline (Miller, 2004; Miller, 1998). For example, the NSF reported in its 2002 report on the fraction of individuals believing in such non-scientific concepts as ghosts, UFOs, astrology and other concepts, as well the fraction understanding basic scientific concepts. Improvement in scientific literacy should result in declines in belief in the former, and a rise in understanding of the latter.

Third, we would expect a successful policy to cause enrollment in high school advanced math and science courses to increase significantly (National Academy of Sciences, 2005).

Finally, we would expect a successful policy to result in significant increases in college enrollment in both undergraduate and graduate level STEM (science, technology, engineering, and mathematics) programs (National Science Foundation, 2004; National Academy of Sciences, 2005).

There are literally hundreds of possible variables that can be investigated, some of which have fairly clear measures and others that can only be approached indirectly. The variables identified that might affect student test scores include: student variables (Bouchey and Winston, 2004; Lynch, 2000; Borman et al, 2005), teacher variables (Borman et al, 2005; Lynch, 2000), school and district level variables (Peddle, 2000; Chubb and Moe, 1990; Lynch, 2000), and community, state, and national variables (Waddock, 1995; Chubb and Moe, 1990; Borman et al 2005; Marshall, Mitchell and Wirt, 1989). Since public education is institutionally very similar all across the nation, comparison of public schools with private schools may be enlightening, because the institutional arrangements around private schools are different, while the central objective of transferring knowledge from teacher to student remains unchanged (Chubb and Moe, 1990). However, the differences between different schools, districts, and states, as well as private educational facilities are subtle and these slight differences can confound even the most carefully arranged study. As Hanusheck (1986, 2003) has repeatedly noted, most studies of commonly investigated variables, such as teacher-pupil ratios, teacher experience, and per-student spending, are inconclusive.

Hanushek (1986) and others (e.g., Vandenberghe, 2001) note that since the Coleman Report in 1962, investigations have fallen basically into one of two categories: those attributing differences in student performance to factors surrounding the student (such as family background, peer characteristics, etc.), and those attributing differences in performance to factors related to schools (such as teacher pay, students per classroom, financial resource availability, and so on). The apparent dichotomy between these two groups has not significantly changed despite decades of research and debate. Institutionally, from a theoretical standpoint, we would expect that any factors that impact on student ability and motivation to learn, and teacher motivation and ability to teach, will result in increased performance if there is indeed a relationship between learning and the standardized tests intended to measure that learning. In the practicality of studies, however, it appears to be difficult to clearly identify which institutions and actors are the most important.

To summarize the discussion to this point, according to a number of commentators and researchers, America is losing its competitive edge because our education system is not producing enough individuals who have adequate scientific literacy (National Science Foundation, 2004; National Science Foundation, 2003). While there is some debate about the validity of this argument on a variety of grounds (such as the wisdom of relying on single-shot assessment testing with instruments that have not been verified as reliable or valid for the purpose; see for example Nelson, Palonsky and Carlson, 2000; Roselli, 2005; and Lynch, 2000), we will assume that the proposition is true: that we as a society are not doing a good enough job educating our children in math and science. Restated in a positive light, society would be better off if more students and citizens developed higher levels of scientific (as well as all other kinds) of literacy, compared to current levels. The question is determining which variables, which institutions of our educational system, are most important and how changes to them can cause—or impede—that desired improvement.

Microeconomic analysis

Education is an exludable, non-rivalrous good; that is, it is possible to prevent individuals from participating in organized education, but there is no theoretical limit to how many individuals can be educated, nor is there a limit to the degree to which they can be educated. Thus, education in its natural state would appear to be a toll good, which is one class of public good. That is, if it is offered free, there will be no private provision of education; if it is offered at a cost, then it will be under consumed by individuals. In part this may stem from the fact that education suffers from two other market failures. First, there is an information asymmetry, specifically, that education is largely a post-experience good from the perspective of the individual student. This means that the full personal benefits of acquiring an education are not clear to the individual at the time of consumption, but only become apparent later, when the individual enters the workforce or higher education. Second, education also has long been recognized as contributing a large positive externality to society. That is, while the individual does eventually benefit economically from acquiring an education as a child, society as a whole also receives significant benefits from that education, through such indirect factors as improved health, better civic participation, a decreased likelihood of involvement in crime, improved economic productivity, and the like. For these reasons (as well as other arguments on ethical or other grounds), the public provision of education was undertaken in the U.S.

At the center of this discussion is a transaction between the teacher and the student, a transaction in which the teacher must expend energy and resources to present knowledge in such a way that the student can perceive and internalize it. The student is not just a passive receptor of this knowledge, however. Learning requires an investment of time, energy and personal resources on the part of the student as well. The teacher is paid for the time and effort made in the educational setting; the student is not—at least not directly and not at the time. Especially at younger ages, student motivation to learn in the school setting seems to be closely associated with parental expectations and involvement in the child’s education, instructional pedagogy, and is also influenced by peer opinion related to educational achievement.

As discussed above, when an effective policy has been implemented, that is, when increased learning has taken place, the students will have increased scientific literacy, which will be demonstrated through improved scores on standardized assessment tests, surveys of student and general population scientific literacy, increased enrollment in higher level and advanced placement courses in high school, and increased undergraduate and graduate enrollment in programs of science, technology, engineering and mathematics (STEM).

Because education is a transaction involving individuals (at its center, the teacher and the student), the local level is probably the best location for the service allocation. However, both the distributive and stabilization functions are best handled more centrally, and thus, both the state and national governments likely have roles to play, especially in funding, but also in equalizing the variation that naturally occurs when a variety of localities attempt to provide similar service, yet must exercise discretion in responding to local constraints and prejudices.

Goals and Policy Alternatives

Obviously, any adopted policy to improve scientific literacy through public education must include as its central goal the improvement of measures of scientific literacy among students in primary and secondary schools. That is, the policy must be *effective* in achieving improvement in dependent variable. In addition to this substantive goal, there are a number of important instrumental goals that in general apply to any government project of this sort, as they deal with the relationship between the stakeholders on this issue. These instrumental goals include (not necessarily in order of importance, and not necessarily limited to):

1) Political feasibility—The selected alternative should be acceptable to the general public, elected officials, and the specific stakeholders in primary and secondary education.

2) Budget and financing—The selected alternative should not result in significant increase or decrease in the amount of money devoted to science education, unless there is a clear relationship to improving the indicators.

3) Equity—The impacts of the selected alternative on all related interest groups should be positive, (or if negative, negative to a lesser degree than the benefits to the other interest groups; that is, demonstrate Pareto optimality), with added emphasis for those groups historically at risk of not excelling in science.

4) Federalism—Any alternative selected should respect existing intergovernmental relationships, or cooperatively develop new relations, between the local, state and federal levels.

5) Efficiency—The selected policy alternative should result in considerable improvement in the measures of the dependent variable with a minimal investment of resources or disruption to economic decision making by actors.

Obviously, there is a potential for conflict between some of these goals. For example, decreasing outside bureaucratic pressure on a school to improve efficiency might conflict with efforts to maintain federalism, or to minimize negative impacts on existing institutional interests (such as school boards, administrators, teachers unions, and state and federal departments of education). The desire for equitable impacts could conflict with political feasibility, if a particular alternative might negatively impact a group in order to gain support for overall changes. Budget and finance constraints might negatively impact an ambitious and rigorous academic program.

There are at least seven classes of variables that policies could address, using the categories of independent variables listed earlier (student, teacher, school, district, community, state, and national variables). A given proposal may include several specific recommendations, each targeted at a specific variable in one or more of the classes. For example, a policy might include provisions intended to improve stability of the student's home life (a student variable), while another provision might be intended to encourage more college students to pursue a teaching career by offering partial or full-ride scholarships (a teacher variable).

A review of bills before the current 109th Congress finds that there are comparatively few policy alternatives under consideration, with most being variations on a very few themes. Of 101 introduced bills categorized under the term "scientific education" by the Congressional Research

Service as of March 6, 2006, only 33 (about 33 percent) included provisions specifically related to improvement of primary and secondary science education. Of these, only three (about 3 percent of the bills on topic) had been placed on the House or Senate calendar for possible action. The remainder had been assigned to committee, but no further action had taken place. In addition, President Bush had proposed the American Competitiveness Initiative as part of his State of the Union address and his proposed FY 2007 budget.

These four proposals include a number of specific provisions. The Preserving America's Competitive Edge Act—Energy (PACE-Energy; S. 2197) includes provisions for the Department of Energy to expand its educational assistance programs by offering student learning opportunities, teacher professional development opportunities, and adjunct teacher and other assistance to schools, at a total cost of about $737 million over the next five years. The PACE-Education bill (S. 2198) provides for new teachers, teacher professional development, advanced placement/international baccalaureate (AP/IB) courses, and a teaching materials clearinghouse, at a total cost of about $3.65 billion over five years. Senate 848 offers changes to incentives for attracting new teachers and teacher professional development, although no cost estimate was available for those particular activities that would affect STEM education. Finally, the President's ACI called for student learning opportunities, new teachers, teacher professional development, adjunct teachers, AP/IB courses and other mathematics program imperatives, a mathematics advisory panel, and new science standards to be tested by states under the No Child Left Behind Act. This would cost between $2 billion and $5 billion over the first five years of implementation. Compared to the nation's total spending on primary and secondary education—about $440 billion this year—these proposals are miniscule, generally less than 1 percent of current spending. Even if targeted on the most responsive factors related to the institutional relationship between the teacher and student (which research has not yet been able to firmly identify to everyone's satisfaction), it is not clear that the proposals would make any significant change in the measures, even if they do meet most of the other evaluative criteria.

On closer inspection, these proposals are incremental changes to the existing institutional structure, with a heavy emphasis on teachers by improving incentives to individuals entering college to select science or mathematics teaching as a profession, to encourage existing teachers to pursue advanced education, or to clear the way for science professionals to quickly earn teaching certification. There is also a thread aimed at standardizing science and mathematics curricula, as through the clearinghouse, the advisory panel, and the NCLB testing requirement. Table 4 below compares the various categories of proposals against the evaluative criteria listed above. The overall effect of the proposed policies is unclear, especially on the goal of effectiveness in improving the measures of scientific literacy. As with many policies, the final effect has at least as much to do with implementation as with policy design, and while it is clear that there could be a positive impact, it is also possible that the impact will be neutral or negative. All of the proposed policies under consideration by Congress are implementable, as they build on existing programs. All of the programs as proposed offer fairly limited impact overall, such as adding 10,000 to 20,000 new STEM teachers in the next few years, when there are at least that many needed each year just to maintain the current numbers.

Table 4. Comparison of primary and secondary science education policies under consideration in 109th Congress to evaluative goals and impacts.

Goals	Impact Categories	Student Learning Opp'tnty	New Teachers	Teacher Profess. Dev.	Adjunct teachers	AP/IB	Advisory Panel/ Clear/hse	NCLB Science Assess.

Effective	*Improve measures*	?	?	?	?	?	?	?
	Implementable	Y	Y	Y	Y	Y	Y	Y
Efficient	*Limit cost to Fed. Gov't.*	Y	N	N	N	N	Y	Y
	Markets utilized	N	Partial	Partial	Partial	N	N	N
Acceptable	*Federalism*	Y	Y	Y	N	N	Y	N
	Institutional	Y	Y	Y	Y,N	Y	Y	Y,N
	Public	Y	Y	Y	Y	Y	Y	Y
Fiscal	*Revenue neutral*	N	N	N	N	N	N	?
	Burden to state/localities	N	N	N	Y	Y	N	Y
Equity	*Taxpayers*	?	?	?	?	?	?	?
	Students	N	?	?	?	N	?	?
	Teachers	?	N	N	N	N	?	?

Thus far, this paper has considered the possible immediate effects of some incremental changes to the existing institutional relationships. Other, larger-scale changes are sometimes Suggested to reform education, including total privatization, states assuming control of education, the federal government assuming control of education, or a combination of these policies. For this last option, we specifically suggest this as a controlled experiment: each district and state can decide via referenda which option to pursue. For a number of years, then, each district will operate under the system they select. This will give researchers and policy makers a direct, controlled comparison of the different policy options in actual practice. While such an arrangement is very unlikely to be approved, it provides an interesting thought experiment about what it might take to demonstrate which, if any, policy alternatives are the best for public education.

These five proposals are compared to the evaluative criteria below in table 5. Supporters of each option suggest reasons why theirs will be the best for the nation's education system. For example, some supporters of privatization cite studies that suggest that private schools get better results (e.g., test scores, graduation rates) with fewer resources than do traditional public schools. Supporters of state or federal control of education note that the general benefits that society receives from publicly-supported education justifies state and/or federal funding and perhaps direction of the provision of education for allocative and stabilization reasons. Clearly, any of these changes could take place without greatly affecting the central teacher-student institution, but again, whether or not measures improve has as at least as much to do with actual implementation as the overall policy design. Thus, as with the criteria and policy options in table 4, there is no clear reason to expect that any of these changes would improve the measures of science literacy. Since implementation of legislative plans usually takes place through a rulemaking process, we can assume that the primary players will have a role in the development of the new formal and informal institutional rules that the law seeks to impose. That interaction will likely affect how any new policy will be implemented. Thus, significant changes to the overall structure of the educational system would require a substantial exercise of authority with the support or at least acquiescence of the major institutional players.

Table 5. Comparison of large-scale systemic changes in institutional structure to goals and impacts.

Goals	**Impact Categories**	**Current System**	**Privatize**	**State Control**	**Nationalize**	**Combination**
Efficient	*Low cost to federal budget*	Y $50 bil	Y $0	Y 0-50 bil	N $440 bil	?
	Markets utilized	Y 25 %	Y 100%	?	?	Y ?%

Effective	*Improve measures*	?	?	?	?	?
	Implementable	Y	?	Possible	Possible	Possible
Acceptable	*Federalism*	Y	N	N	N	?
	Institutional	Y/N	N	N	N	?
	Public	T	N	N	N	?
Fiscal	*Revenue neutral*	Y	N	?	?	?
	Burden to state/localities	Y	?	Y	N	?
Equity	*Taxpayers*	N	?	?	?	?
	Students	N	?	?	?	?
	Teachers	N	?	?	?	?

Conclusion and Recommendations

Changing the institutional relationships in public education is likely an incremental process. Changing the relationships so that measures of science literacy are improved is probably even more difficult, as the policies must focus on changing the teachers' supply and students' demand for the educational transaction. While indirect changes may have significant impact on those desired results, the current research does not clearly demonstrate the connections between any of the independent variables and the dependent variable, scientific literacy, or how changes in those variables might impact scientific literacy.

I recommend, relating to the policies under consideration in Congress, that policymakers look very carefully at whether the implementation of the proposed policy will make a positive impact on the teacher-student learning relationship, and the magnitude of impact that might be expected from those policies. Policies that cannot be expected to have an overall impact should be eliminated from consideration, while consideration should be given to expanding and extending those that will likely cause significant improvements. The grounds for this distinction, or course, rely on research that is not yet conclusive. However, I would recommend that additional resources be devoted to conducting just this kind of research to, one would hope, clearly define effective from ineffective policies. Otherwise, any reforms undertaken will simply be random attempts at change, with essentially random results. We owe ourselves, our society, and especially our children, better.

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