Assessing Scientific Literacy in PISA 2006 and Fostering It in the United States

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Abstract

Scientific literacy has become the term used to express the broad and encompassing purpose of science education. In the United States, for example, the statement "achieving scientific literacy for all students" has wide agreement and common use among educators. The use of the term in the U.S. most likely began with James Bryant Conant in the 1940s (Holton, 1998) and was elaborated for educators in a 1958 article by Paul DeHart Hurd entitled "Science Literacy: Its Meaning for American Schools." Hurd described the purpose of scientific literacy as an understanding of science and its applications to social experience. Science had such a prominent role in society, Hurd argued, that economic, political, and personal decisions could not be made without some consideration of the science and technology involved (Hurd, 1958).

In the fifty years since Paul DeHart Hurd's article, scientific literacy has been used extensively to describe the purposes, policies, programs, and practices of science education. The term scientific literacy, however, is not the reality of science education. Academic researchers debate the real meaning of the term, classroom teachers claim their students are attaining scientific literacy, and national and international assessments provide evidence that somewhere between the abstract purpose and concrete practice the science education community has failed to achieve the goal, at least in the United States. This essay uses PISA 2006 as a contemporary perspective for scientific literacy and addresses several challenges to achieving high levels of scientific literacy.

What Is Meant by Scientific Literacy?

We can begin with the brief description from Paul DeHart Hurd's essay where he linked scientific literacy to social experience and provided a rationale in economic, political, and personal contexts. Hurd made a clear connection between science and citizenship. In contrast, scientific literacy is not exclusively preparation for a professional career, although Hurd's connection does not preclude scientific and technological careers. Scientific literacy as it is manifest in educational policies, programs, and practices has the explicit goal of preparing students for life and work as citizens.

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In my 1997 book, *Achieving Scientific Literacy: From Purposes to Practices*, I attempted to clarify what is meant by scientific literacy and use of the term as a slogan and metaphor. In that discussion, I proposed that scientific literacy clarified the general purposes of science education; implied the same standards for all students; illustrated different emphasis for curriculum, instruction, and assessment; represented a continuum of understandings and abilities; incorporated multiple dimensions; and included both science and technology (Bybee, 1997).

At the time, one of my main concerns was use of scientific literacy as the basis for judgments about individuals or society. For example, one commonly heard or read about individuals or groups being labeled scientifically illiterate—based on the observation that an individual did not know the difference between, for example, an atom and a molecule, a mineral and a rock, or an organism and a species. Because of this observation, I proposed a model that assumed scientific literacy was continuously distributed in a population and had multiple dimensions. At the extremes, there were small numbers of individuals who were scientifically literate and illiterate. But, within the greater population there was a distribution of individuals who demonstrated varying degrees of scientific literacy. The variation was a function of factors such as age, cognitive development, school curricula, and life experiences.

The underlying qualities of scientific literacy continuum (not levels) included illiteracy, nominal literacy, functional literacy, conceptual and procedural literacy, and multidimensional literacy. These characteristics are summarized in Table 1.

Table 1. Characteristics of Scientific Literacy

Nominal Scientific and Technological Literacy
In *nominal* literacy, the individual associates names with a general area of science and technology. However, the association may represent a misconception, naïve theory, or inaccurate concept. Using the basic definition of nominal, the relationship between science and technology terms and acceptable definitions is small and insignificant. At best, students demonstrate only a token understanding of science concepts, one that bears little or no relationship to real understanding.
Functional Scientific and Technological Literacy
Individuals demonstrating *functional* level of literacy respond adequately and appropriately to vocabulary associated with science and technology. They meet minimum standards of literacy as it is usually understood; that is, they can read and write passages with simple scientific and technological vocabulary. Individuals may also associate vocabulary with larger conceptual schemes—for example, that genetics is associated with variation within a species and variation is associated with evolution—but have a token understanding of these associations.
Conceptual and Procedural Scientific and Technological Literacy
Conceptual and procedural literacy occurs when individuals demonstrate an understanding of both the parts and the whole of science and technology as disciplines. The individual can identify the way the parts form a whole vis à vis major conceptual schemes, and the way new explanations and inventions develop vis à vis the processes of science and technology. At this level, individuals understand the structure of disciplines and the procedures for developing new knowledge and techniques.
Multidimensional Scientific and Technological Literacy
Multidimensional literacy consists of understanding the essential conceptual structures of science and technology as well as the features that make that understanding more complete, for example, the history and nature of science. In addition, individuals at this level understand the relationship of disciplines to the whole of science and technology and to society.

In 1997, Thomas Koballa, Andrew Kemp, and Robert Evans published an article in which they presented what they termed the spectrum of scientific literacy (e.g., illiteracy to highest levels of understanding), multiple domains (e.g., biology, history of science), and value attached to pursuing scientific literacy (e.g., low to high). The spectrum of scientific literacy described by Koballa, Kemp, and Evans (1997) included, clarified, and elaborated many aspects of the idea that I had described and includes perspectives later incorporated in PISA 2006 science.

Although this essay is not a review of the literature on scientific literacy, several other authors and reports should be mentioned. George DeBoer (2000) has provided an excellent historical and contemporary review of scientific literacy. In 2006, Robin Millar addressed historic and definitial issues of the term before outlining the role of scientific literacy in the *Twenty First Century Science Course*. Now, that course stands a model curriculum. In discussing the distinctive features of the curriculum, Millar points out the novel content (e.g., epidemiology, health), broad qualitative understanding—whole explanations, and a strong emphasis on ideas about science. In PISA 2006, the reader will recognize variations on these three features as: context, competencies, and knowledge about science.

Two essays stand out when discussions turn to contemporary science education and the challenges of attaining higher levels of scientific literacy. In his essay "Science Education for the Twenty First Century," Jonathan Osborne (2007) makes a clear case that regardless the use of scientific literacy as a stated aim contemporary science education is primarily "foundationalist" in that it emphasizes educating for future scientists versus educating future citizens. Among other results, Osborne argues that such an emphasis results in negative attitudes toward science.

The second notable essay is by Douglas Roberts and published in *Handbook of Research on Science Education* (Abell and Lederman, 2007). Roberts identifies a continuing political and intellectual tension with a long history in science education. The two politically conflicting emphases can be stated in a question—Should curriculum emphasize science subject matter itself, or should it emphasize science in life situations in which science plays a key role? Curriculum designed to answer the former, Roberts refers to as Vision I, and the latter he refers to as Vision II. Vision I looks within science, while Vision II uses external contexts that students are likely to encounter as citizens. The ideas presented by Roberts also form the central theme of *Promoting Scientific Literacy: Science Education Research in Transaction*, the proceedings of a symposium held at Uppsala University, Sweden (Linder, Ostman, Wickman, 2007).

The reader will recognize various points from this discussion in the next section on scientific literacy in PISA 2006. In particular, one should note the place of contexts, scientific knowledge (including knowledge *about* science), and attitudes as they contribute to students' attainment of scientific competencies.

The reader also should note another important feature of PISA 2006. The framework for PISA 2006, *Assessing Scientific, Reading and Mathematical Literacy* (OECD, 2006) and report of results, *PISA 2006: Science Competencies for Tomorrow's World* (OECD, 2007) present an assessment framework and analysis of results, respectively. They are not intended as frameworks for a science curriculum. Designing a curriculum framework based on the qualities and emphasis in PISA 2006 presents a new challenge for the science education community.

How Is Scientific Literacy Defined in PISA 2006?

In PISA 2006, the essential qualities of scientific literacy include the ability to apply scientific understandings to life situations involving science. The central point of the PISA 2006 science assessment can be summarized: The assessment focused on scientific competencies that clarify what 15-year-old students should know, value, and be able to do within reasonable and appropriate personal, social, and cultural contexts.

For purposes of PISA 2006, scientific literacy refers to four interrelated features that involve an individual's:

- Scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomenon, to draw evidence-based conclusions about science-related issues;
- Understanding of the characteristic features of science as a form of human knowledge and enquiry;
- Awareness of how science and technology shape our material, intellectual, and cultural environments; and
- Willingness to engage in science-related issues, and with the ideas of science, as a constructive, concerned, and reflective citizen (OECD, 2006).

Consistent with earlier discussions (Bybee, 1997; Koballa, Andrews, Kemp, 1997), in PISA 2006, scientific literacy was not perceived as a single discrete entity. That is, individual students cannot be categorized as being either scientifically literate or scientifically illiterate. Rather, there is a continuum from less developed to more developed scientific competencies that include proficiency levels, different domains of scientific knowledge, and attitudes. So, for example, the student with less developed scientific literacy might be able to recall simple scientific factual knowledge about a physical system and to use common science terms in stating a conclusion. Students with a more developed scientific literacy demonstrate the ability to create or use conceptual models to make predictions or give explanations, to formulate and communicate predictions and explanations with precision, analyze scientific investigations, to relate data as evidence, to evaluate alternative explanations of the same phenomena, and to communicate explanations with precision.

How Was Scientific Literacy Assessed in PISA 2006?

The translation of a definition of scientific literacy to an international assessment required a way of organizing the domain of scientific literacy so a test could be designed, administered, and the results analyzed. Answering several questions helped organize the assessments.

- What CONTEXTS would be appropriate for assessing 15-year-olds?
- What COMPETENCIES would be appropriate for 15 year-olds?

- What KNOWLEDGE would be appropriate for assessing 15 year-olds?
- What ATTITUDES would be appropriate for assessing 15 year-olds?

PISA 2006 situated its definition of *scientific literacy* and its science assessment questions within a framework that organized and answered the four interrelated questions; namely, contexts (i.e., life situations involving science and technology); the competencies (i.e., identifying scientific issues, explaining phenomena scientifically, and using scientific evidence); the domains of scientific knowledge (i.e., students' understanding of scientific concepts as well as their understanding the nature of science); and student attitudes (i.e., interest in science, support for scientific inquiry, and responsibility towards resources and environments). These four aspects of the PISA 2006 conception of scientific literacy are illustrated in Figure 1.

The *scientific contexts* also align with various issues citizens confront. For example, adults hear about and face decisions concerning health, use of resources, environmental quality, hazard mitigation, and advances in science and technology. PISA 2006 science items were framed within a wide variety of life situations involving science and technology, primarily: "health," "natural resources," "environmental quality," "hazards," and "frontiers of science and technology." These situations were related to three major contexts: *personal* (the self, family and peer groups), *social* (community), and *global* (life across the world). See Table 2.

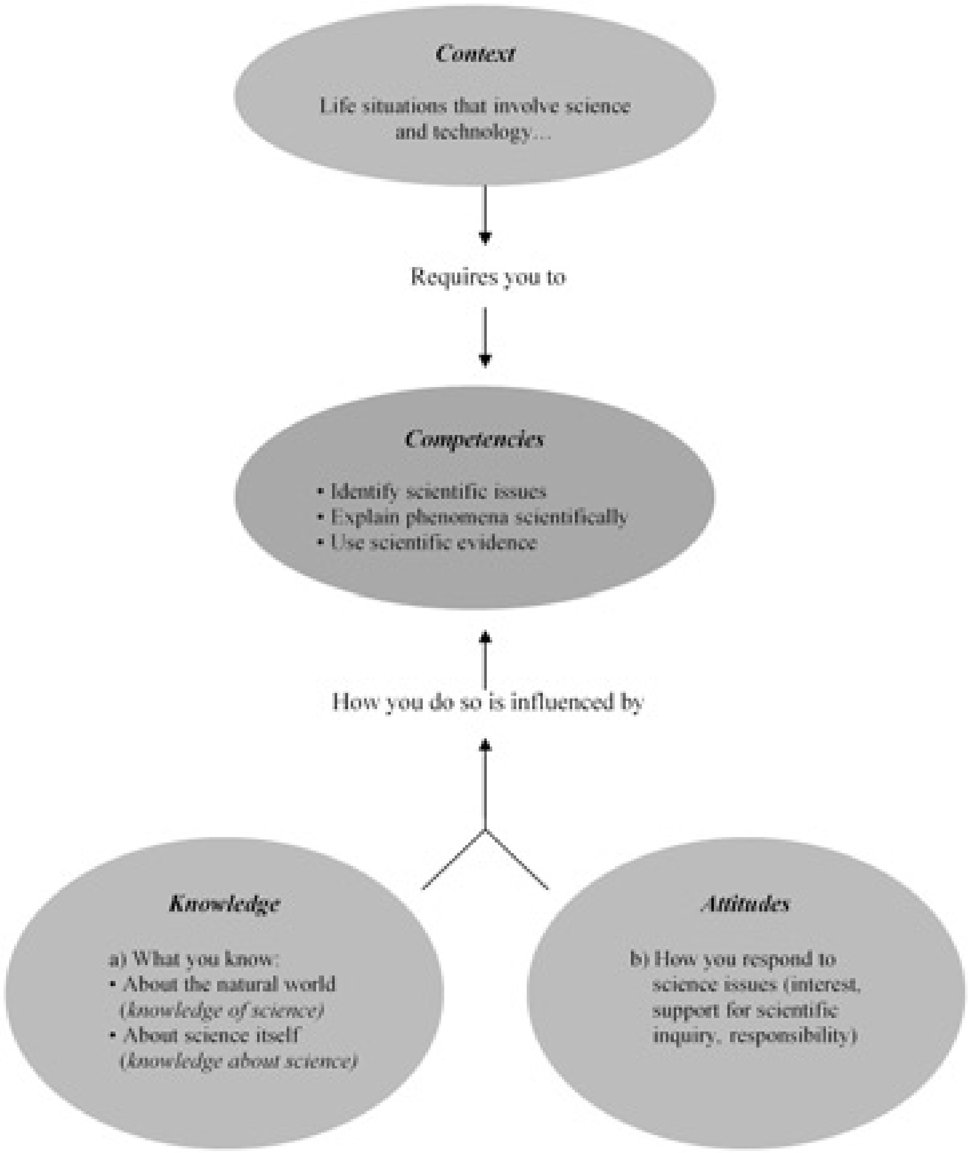

Figure 1. The PISA Science Framework

Table 2. PISA 2006 Scientific Contexts

	Personal	Social	Global
Health	maintenance of health, prevention of accidents, nutrition	control of disease, socialtransmission, food choices, community health	management of epidemics, spread of infectious diseases
Natural resources	personal consumption of materials and energy	maintenance of human populations, quality of life, security, production and distribution of food, energy supply	renewable and nonrenewable, natural systems, population growth, sustainable use of species
Environmental quality	environmentally friendly behavior, use and disposal of materials	population distribution, disposal of waste, environmental impact, local weather	biodiversity, ecological sustainability, control of pollution, production and loss of soil
Hazards	natural and human-induced risks, decisions about housing	rapid changes [earthquakes, severe weather], slow and progressive changes [coastal erosion, sedimentation], risk assessment	climate change, impact of modern warfare
Frontiers of science and technology	interest in science's explanations of natural phenomena, science-based hobbies, sport and leisure, music and personal technology	new materials, devices and processes, genetic modification, weapons technology, transport	extinction of species, exploration of space, origin and structure of the universe

The PISA 2006 *science competencies* required students to identify scientific issues, explain phenomena scientifically, and use scientific evidence. These three key scientific competencies were selected because of their relationship to the practice of science and their connection to key abilities such as inductive/deductive reasoning, systems-based thinking, critical decision making, transformation of information (e.g., creating tables or graphs out of raw data), construction of arguments and explanations based on data, thinking in terms of models, and use of mathematics. Table 3 describes the essential features of each of the three competencies.

Table 3. PISA 2006 Scientific Competencies

Identifying scientific issues
■ Recognizing issues that are possible to investigate scientifically
■ Identifying keywords to search for scientific information
■ Recognizing the key features of a scientific investigation
Explaining phenomena scientifically
■ Applying knowledge of science in a given situation
■ Describing or interpreting phenomena scientifically and predicting changes
■ Identifying appropriate descriptions, explanations, and predictions
Using scientific evidence
■ Interpreting scientific evidence and making and communicating conclusions
■ Identifying the assumptions, evidence and reasoning behind conclusions
■ Reflecting on the societal implications of science and technological developments

The competencies can be illustrated with any number of contemporary examples. Global climate change has become one of the most talked about and threatening global issues. As people read or hear about climate change, they must separate the scientific reasons for change from economic, political, and social issues. Scientists explain, for example, the origins and material consequences of releasing carbon dioxide into the Earth's atmosphere. This scientific perspective is often countered with an economic argument against reduction of greenhouse gases. Citizens should recognize the difference between scientific and economic positions. Further, as people are presented with more, and sometimes conflicting, information about phenomena, such as climate change, they need to be able to access scientific knowledge and understand, for example, the scientific assessments of bodies such as the Intergovernmental Panel on Climate Change (IPCC). Finally, citizens should be able to use the results of scientific studies about issues such as health, prescription drugs, and safety to formulate arguments supporting their conclusions about scientific issues of personal, social, and global consequence.

In PISA 2006, *scientific literacy* also encompassed both *knowledge of science* and *knowledge about science* itself. The former includes understanding fundamental scientific concepts; the latter includes understanding inquiry and the nature of science. Because PISA describes the extent to which students can apply their knowledge in contexts relevant to their lives, assessment material was selected from the major domains of physical, life, Earth science, and technology using the following criteria: relevance to life situations; representative of important scientific concepts; and, appropriateness to the developmental level of 15-year-olds. Table 4 shows the *knowledge of science* categories and examples of content selected by applying these criteria. This knowledge is required by adults for understanding the natural world and for making sense of experiences in the *personal*, *social* and *global* contexts. PISA 2006 used the term "systems" instead of "sciences" in the descriptors of the major fields. We did this in order to convey the idea that people should understand varied concepts and contexts based on the components themselves and the relationships between them.

PISA 2006 used two categories for *knowledge about science*. We used "scientific inquiry," which centers on inquiry as the central process of science and "scientific explanations," which are the results of scientific inquiry. Inquiry is the means of science (how scientists get evidence) and explanations are the goals of science (how scientists use evidence). The examples listed in Table 5 convey the general meanings of the two categories.

Attitudes toward science play a significant role in scientific literacy. They underlie an individual's interest in, attention to, and response to science and technology. An important goal of science education is for students to develop interest in and support for scientific inquiry as well as to acquire and to subsequently apply scientific and technological knowledge for personal, social, and global benefit. That is, a person's scientific literacy includes certain attitudes, beliefs, motivational orientations, self-efficacy, and values that influence actions. The inclusion of attitudes and the specific areas of attitudes selected for PISA 2006 is supported by and builds upon reviews of attitudinal research (OECD, 2006). The PISA 2006 science assessment evaluated students' attitudes in three areas: ***interest in science, support for scientific inquiry***, and ***responsibility towards resources and environments*** (See Table 6).

Table 4. PISA 2006 Knowledge of Science

Physical systems ■ Structure of matter (*e.g.* particle model, bonds) ■ Properties of matter (*e.g.* changes of state, thermal and electrical conductivity) ■ Chemical changes of matter (*e.g.* reactions, energy transfer, acids/bases) ■ Motions and forces (*e.g.* velocity, friction) ■ Energy and its transformation (*e.g.* conservation, dissipation, chemical reactions) ■ Interactions of energy and matter (*e.g.* light and radio waves, sound and seismic waves)
Living systems ■ Cells (*e.g.* structures and function, DNA, plant and animal) ■ Humans (*e.g.* health, nutrition, disease, reproduction, subsystems [such as digestion, respiration, circulation, excretion, and their relationship]) ■ Populations (*e.g.* species, evolution, biodiversity, genetic variation) ■ Ecosystems (*e.g.* food chains, matter, and energy flow) ■ Biosphere (e.g. ecosystem services, sustainability)
Earth and space systems ■ Structures of the Earth systems (*e.g.* lithosphere, atmosphere, hydrosphere) ■ Energy in the Earth systems (*e.g.* sources, global climate) ■ Change in Earth systems (*e.g.* plate tectonics, geochemical cycles, constructive and destructive forces) ■ Earth's history (*e.g.* fossils, origin and evolution) ■ Earth in space (*e.g.* gravity, solar systems)

Table 5. PISA 2006 Knowledge About Science

Scientific inquiry ■ Origin (curiosity scientific questions) ■ Purpose (*e.g.* to produce evidence that helps answer scientific questions, current ideas/models/theories guide inquiries) ■ Experiments (*e.g.* different questions suggest different scientific investigations, design) ■ Data (*e.g.* quantitative [measurements], qualitative [observations]) ■ Measurement (*e.g.* inherent uncertainty, replicability, variation, accuracy/precision in equipment and procedures) ■ Characteristics of results (*e.g.* empirical, tentative, testable, falsifiable, self-correcting)
Scientific explanations ■ Types (*e.g.* hypothesis, theory, model, scientific law) ■ Formation (*e.g.* existing knowledge and new evidence, creativity and imagination, logic) ■ Rules (*e.g.* logically consistent, based on evidence, based on historical and current knowledge) ■ Outcomes (*e.g.* new knowledge, new methods, new technologies, new investigations)

Table 6. PISA 2006 Assessment of Attitudes Toward Science

Interest in science ■ Indicate curiosity in science and science-related issues and endeavors ■ Demonstrate willingness to acquire additional scientific knowledge and skills, using a variety of resources and methods ■ Demonstrate willingness to seek information and have an ongoing interest in science, including consideration of science-related careers
Support for scientific inquiry ■ Acknowledge the importance of considering different scientific perspectives and arguments ■ Support the use of factual information and rational explanations ■ Express the need for logical and careful processes in drawing conclusions
Responsibility toward resources and environments ■ Show a sense of personal responsibility for maintaining a sustainable environment ■ Demonstrate awareness of the environmental consequences of individual actions ■ Demonstrate willingness to take the action to maintain natural resources

Research has shown that an early *interest in science* is a strong predictor of lifelong science learning or selecting a career in science or engineering (OECD, 2006). PISA 2006 collected data about students' engagement in science-related social issues, their willingness to acquire scientific knowledge and skills, and their consideration of science-related careers.

Support for scientific inquiry was assessed because of its long standing importance in science education. Appreciation of and support for scientific inquiry implies that students value scientific ways of thinking, reasoning, responding and communicating conclusions as they confront life situations related to science. Thus, support is not simply a matter of being interested in science, but of an informed engagement that bases support on an understanding of the roles that science plays. In PISA 2006, support for inquiry included the use of evidence (knowledge) in making decisions and the appreciation for logic and rationality in formulating conclusions.

I have a long standing interest in *responsible attitudes toward resources and environment*, because it is both an international concern and one of economic relevance for countries (Bybee and Mau, 1986). This aspect of attitudes in PISA 2006 presents information in reference to mounting global problems specifically related to the environment and resources; for example, biodiversity, deforestation, and water resource management.

PISA 2006 gathered extensive data on students' attitudes toward science not only by using a student questionnaire but also by embedding questions about student attitudes toward science in the actual units of the assessment. This inclusion of items in the context of the science assessment unit enabled PISA to investigate whether students' attitudes differ when assessed in or out of context, whether they vary between contexts and whether they correlate with students' performance on the items in the unit.

Education for scientific literacy and PISA 2006

As an assessment framework (OECD, 2006) and analysis (OECD, 2007), PISA 2006 provides definite clarity and international results concerning the challenges and possibilities for achieving higher levels of scientific literacy. The conceptualization and assessment of scientific literacy in PISA 2006 aligns very well with Vision II as described by Roberts (2007) and the views expressed by contemporary scholars such as Millar (2007), Osborne (2007), DeBoer (2000) and Linder, Ostmen, and Wickman (2007).

One of the insights that emerge from this review is the consistency of PISA 2006 with the views of scientific literacy and the contrast of that perspective with school science programs and classroom practices. To be clear, if the purpose of science education is to attain higher levels of scientific literacy for citizens, then science curricula should emphasize something like the competencies defined by PISA 2006. Although the PISA framework (OECD, 2006) was not conceptualized as a guide for the design of science programs, it does give direction and ideas about emphasis including the contexts, content of the curriculum, and the competencies that students should develop. The implications of the PISA 2006 perspective or scientific literacy will vary for countries and local schools, but the general purposes are clear and the translation to educational policies, programs, and practice should not be difficult if the science education community can change from the current dominant perspective to one that values the scientific, economic, and social advantages of scientific literacy.

What Is the Scientific Literacy of 15-Year-Olds?

This section presents results from PISA 2006. The discussion provides some insights about the scientific literacy of 15-year-olds. Figure 2 and Figure 3 present the average scores for both OECD and non-OECD countries that participated in the 2006 assessment.

For purposes of describing scientific literacy in greater detail, PISA 2006 used six proficiency levels with Level 6 representing the most difficult tasks on the test and Level 1 the lowest. Table 7 summarizes the six proficiency levels. Each level represents a synthesis of the three aforementioned scientific competencies for that level. I have included the percentage of OECD students and the percentage of U.S. students at the respective levels.

Table 8 through 10 present summary descriptions of the six proficiency levels for identifying scientific issues, explaining phenomena scientifically, and using scientific evidence, respectively.

Examination of proficiency levels in Table 7 through 9 indicates a distribution of students from highest to lowest levels. My primary purpose here is not to engage in country-by-country analysis. Rather, it is to indicate some features of scientific literacy as demonstrated by PISA 2006. Individual countries can examine their results in *PISA 2006: Science Competencies for Tomorrow's World, Volume I Analysis and Volume II Data* (OECD, 2007).

A couple of observations are worth noting. The percentages of students at the highest levels indicate those 15-year-olds with the aptitude for future careers in highly skilled areas of science and technology. For countries either at or wishing to be at the frontiers of science and technology, schools should attend to the interests and education of these students.

For the largest percentages of students, the middle levels of proficiency, levels 3 and 4, there is the challenge of increasing their competencies, interests, and skill levels as this increase has advantages for economic growth (Hanushek and Woessman, 2007).

Countries with significant numbers of students at the lowest levels of proficiency also have to attend to their scientific literacy, because these students will have to participate in the labor market and society. PISA 2006 established Level 2 as the baseline for scientific competencies that will enable adequate participation in society. On average, 19.2% of students in OECD countries are not at the baseline. The implication seems clear. It is in the economic and social interest to help those students attain higher levels of scientific literacy.

How Did U.S. Students Do On PISA 2006?

The early years of the 21st century have presented the United States with circumstances that support scientific literacy as an aim of science education. One example supporting this point comes from numerous reports released by business and industry (BSCS, 2007). Collectively, the reports claim there is a need for individuals with the knowledge, attitudes, and skills that will enable full participation in the 21st century workforce. PISA 2006 provides insights concerning the role of scientific literacy and the necessity of focusing on this as a primary goal of science education. Results from PISA indicate significant challenges for the U.S. if it is to reform programs to attain higher levels of scientific literacy.

PISA 2006 has a unique and important, if not essential, approach to understanding science as an educational goal. Unlike most state tests and the National Assessments of Educational Progress (NAEP), PISA does not measure students' achievement of knowledge and abilities based on school science curricula. Rather, PISA measures students' ability to identify scientific issues, explain phenomena scientifically, and use scientific evidence as they make decisions in the context of life situations. The results of PISA 2006 can inform decisions about U.S. educational policies, programs, and practices that will foster higher levels of scientific literacy in the United States.

The United States was one of 57 countries and economies participating on PISA 2006. This number includes 30 OECD countries and 27 partner countries and economies. Students in the U.S. scored an average of 489 points which is 11 points below the OECD average of 500 points. The U.S. trend in science is of great concern. The U.S. dropped from 14th in science on PISA 2000 to 19th in 2003 and

21st in 2006. Whatever the combination of other countries doing better and a decline in science education in U.S. science education, the results provide concern as they relate to the general scientific literacy in the U.S. In practical terms, the U.S. scientific literacy translates to the supply of skilled workers, technological innovation, and economic growth.

Overall U.S. performance. To say the least, U.S. results on PISA 2006 were disappointing for the United States. U.S. 15-year-olds lag behind a majority of developed nations that participated in the survey. Out of 30 OECD countries participating, 16 countries' average score was measurably higher than the U.S. average (See Figure 2). The average score for Finland, the highest achieving country, was 74 points above the U.S. Other high achieving countries included Canada, Japan, New Zealand, and Australia. Among non-OECD countries and economies, six countries' average score was measurably higher than the U.S. Those countries and economies were: Hong Kong—China, Chinese Taipei, Estonia, Liechtenstein, Slovenia, and Macao—China (See Figure 3).

PISA Results	SCIENCE	
	OECD average score	500
	OECD JURISDICTIONS	
Average is measurably higher than the U.S. average	Finland	563
	Canada	534
	Japan	531
	New Zealand	530
	Australia	527
	Netherlands	525
	South Korea	522
	Germany	516
	United Kingdom	515
	Czech Republic	513
	Switzerland	512
	Austria	511
	Belgium	510
	Ireland	508
	Hungary	504
	Sweden	503
Average is not measurably higher or lower than U.S.	Poland	498
	Denmark	496
	France	495
	Iceland	491
	UNITED STATES	**489**
	Slovak Republic	488
	Spain	488
	Norway	487
	Luxembourg	486
Average is measurably lower than the U.S. average	Italy	475
	Portugal	474
	Greece	473
	Turkey	424
	Mexico	410

Figure 2. PISA 2006 Survey: OECD Jurisdictions

PISA Results	SCIENCE	
	OECD average score	500
	NON-OECD JURISDICTIONS	
Average is measurably higher than the U.S. average	Hong Kong	542
	Chinese Taipei	532
	Estonia	531
	Liechtenstein	522
	Slovenia	519
	Macao	511
Average is not measurably higher or lower than U.S.	Croatia	493
	Latvia	490
	Lithuania	489
	Russia	488
Average is measurably lower than the U.S. average	Israel	479
	Chile	454
	Serbia	438
	Bulgaria	436
	Uruguay	434
	Jordan	428
	Thailand	422
	Romania	421
	Montenegro	418
	Indonesia	412
	Argentina	393
	Brazil	391
	Colombia	390
	Tunisia	388
	Azerbaijan	386
	Qatar	382
	Kyrgyz Republic	349
		322

Figure 3. PISA 2006 Survey: Non-OECD Jurisdictions

Proficiency levels for scientific literacy. In PISA 2006, performance levels were defined for the purpose of describing in greater detail the scientific competencies and overall scientific literacy. Student scores in science were grouped into six proficiency levels: Level 6 representing the most difficult tasks and Level 1 the lowest. The grouping into proficiency levels was undertaken on the basis of combining scientific knowledge and abilities underlying scientific competencies. Proficiency at each of the six levels can be understood in relation to descriptions of the kind of scientific competencies that students need to attain the respective levels. Table 7 summarizes the levels and represents a synthesis of individual competencies for *science literacy*.

U.S. students at higher levels of proficiency. Scientific advances and technological innovations require a labor force with high levels of scientific literacy. Additionally, achieving and staying at the frontiers of science and technology require educated individuals with high levels of knowledge and scientific competencies. Research by Eric Hanushek (2005), for example, has shown the positive economic benefit of attaining skills one standard deviation above the mean on the International Adult Literacy Study.

At Level 6, for example, students can consistently identify, explain, and apply both knowledge of science and knowledge about science in a variety of complex situations involving science. For OECD countries, 1.3% of students perform at Level 6 on the science scale. In the U.S., 1.5% reach Level 6. If we consider both Level 5 and 6, the U.S. is the same as the OECD average at 9.0%. This is the good news. However, other countries have much higher percentages at Levels 5 and 6; for example, Finland (20.9%), New Zealand (17.6%), Japan (15.1%). These countries have remarkable potential for creating scientists and engineers and prominent scientific literacy among all citizens.

U.S. students at lower levels of proficiency. In PISA 2006, Level 2 was identified as the baseline for the competencies. This is the level at which students begin to demonstrate science competencies that will allow them to participate actively as citizens. Students at Level 2 can identify key features of a scientific investigation, recall concepts, and use results of an investigation represented in a data table as they support a personal decision. Across the OECD, 19.2% of students are categorized as below the baseline, Level 2. For the U.S. this average is 24.5%. Below Level 2, students may confuse key features of an investigation, apply incorrect scientific information, and confound scientific evidence with personal opinions and beliefs. The U.S. has 7.6% of students who only perform at Level 1 or below. These percentages are greater than the OECD average at 5.2%. These results indicate that about one quarter (24.5%) of U.S. students do not demonstrate the competencies that will allow them to productively engage in science and technology related life situations. This finding should be a concern for policy makers and all associated with science education in the U.S.

U.S. students and scientific competencies. Among the unique insights gained from PISA 2006 is information on student performance on the three scientific competencies—*identifying scientific issues, explaining phenomena scientifically*, and *using scientific evidence*. Examining the scientific competencies individually suggests possible areas to strengthen science education.

Table 7. Summary Descriptions for the Six Levels of Proficiency on the Combined Science Scale

Level	What students can typically do at each level	Percentage of all students across OECD who can perform tasks at least at this level	Percentage of U.S. studentswho can performtasks at least at this level
6	At Level 6, students can consistently identify, explain and apply scientific knowledge and *knowledge about science* in a variety of complex life situations. They can link different information sources and explanations and use evidence from those sources to justify decisions. They clearly and consistently demonstrate advanced scientific thinking and reasoning, and they use their scientific understanding in support of solutions to unfamiliar scientific and technological situations. Students at this level can use scientific knowledge and develop arguments in support of recommendations and decisions that center on personal, social, or global situations.	1.3%	1.5%
5	At level 5, students can identify the scientific components of many complex life situations, apply both scientific concepts and *knowledge about science* to these situations, and can compare, select and evaluate appropriate scientific evidence for responding to life situations. Students at this level can use well-developed inquiry abilities, link knowledge appropriately and bring critical insights to these situations. They can construct evidence-based explanations and arguments based on their critical analysis.	9.0%	9.0%
4	At Level 4, students can work effectively with situations and issues that may involve explicit phenomena requiring them to make inferences about the role of science and technology. They can select and integrate explanations from different disciplines of science or technology and link those explanations directly to aspects of life situations. Students at this level can reflect on their actions and they can communicate decisions using scientific knowledge and evidence.	29.3%	27.3%
3	At Level 3, students can identify clearly described scientific issues in a range of contexts. They can select facts and knowledge to explain phenomena and apply simple models or inquiry strategies. Students at this level can interpret and use scientific concepts from different disciplines and can apply them directly. They can develop short statements using facts and make decisions based on scientific knowledge.	56.7%	51.3%
2	At Level 2, students have adequate scientific knowledge to provide possible explanations in familiar contexts or draw conclusions based on simple investigations. They are capable of direct reasoning and making literal interpretations of the results of scientific inquiry or technological problem solving.	80.8%	75.5%
1	At Level 1, students have such a limited scientific knowledge that it can only be applied to a few, familiar situations. They can present scientific explanations that are obvious and follow explicitly from given evidence.	94.8%	92.3%
	Below Level 1	5.2%	7.6%

One way to think of the science competencies is in terms of a sequence that individuals might go through as they encounter and solve science-related problems. First, they must identify the scientific aspects of a problem, then apply appropriate scientific knowledge about that problem, and finally, they have to interpret and make sense of their findings in support of a decision or recommendation. Traditional science courses in the U.S. tend to concentrate on the middle segme nt—explaining phenomena scientifically—and give much less emphasis to identifying scientific issues and using scientific evidence.

On identifying scientific issues, U.S. students ranked 15th among OECD countries, but not statistically significantly different from the OECD average. Paradoxically, given the curricular emphasis, U.S. students were statistically significantly below the OECD average on explaining phenomena scientifically and using scientific evidence. There were gender differences as girls performed better on identifying scientific issues and using scientific evidence and boys performed better on explaining phenomena scientifically. This finding was consistent with performance by other OECD countries.

For the competency, identifying scientific issues, U.S. students performing at the highest levels, 5 and 6, were about equal to the percentage of all OECD students, 9.7% for OECD students, and 9.3% for U.S. students. Below the baseline, the U.S. had 21.6% on identifying scientific issues. At the lower levels, 1 and below 1, 5.6% of U.S. students were at or below these levels for this competency (See Table 8).

On explaining phenomena scientifically, the U.S. had slightly more students in the upper two levels of proficiency, 11.8% (U.S.) and 11.6% (OECD). However, the U.S. had 26.3% of students below the baseline and 8.4% at least 1 or below (See Table 9).

Finally, for using scientific evidence, 13.7% of U.S. students did well by achieving at the top levels on this proficiency. However, this percentage was lower than the percentage of OECD students (14.2%). The disappointing result was at the lower level where 26.1% of U.S. students were below the baseline. This is compared to 21.9% of all OECD students (See Table 10).

On the higher levels of scientific competencies (Levels 5 and 6), U.S. students compare favorably with the percentages of students across OECD countries. However, U.S. students do not compare favorably with high achieving countries such as Finland, Canada, and Japan. There should be particular concern about the fact that between one fifth and one quarter of U.S. students do not achieve at the baseline level on scientific competencies. These percentages have the potential for a significant negative economic and social impact on these individuals and for the U.S. as a nation.

Table 8. Identifying Scientific Issues: *Summary descriptions of the six proficiency levels*

Level	Proficiency at each level	Percentage of allstudents across OECD who can perform tasks at this level	Percentage of U.S. students who can perform tasks at this level
6	Students at this level demonstrate an ability to understand and articulate the complex modelling inherent in the design of an investigation.	1.3%	1.2%
5	Students at this level understand the essential elements of a scientific investigation and thus can determine if scientific methods can be applied in a variety of quite complex, and often abstract contexts. Alternatively, by analyzing a given experiment can identify the question being investigated and explain how the methodology relates to that question.	8.4%	8.1%
4	Students at this level can identify the change and measured variables in an investigation and at least one variable that is being controlled. They can suggest appropriate ways of controlling that variable. The question being investigated in straightforward investigations can be articulated.	28.4%	26.5%
3	Students at this level are able to make judgments about whether an issue is open to scientific measurement and, consequently, to scientific investigation. Given a description of an investigation can identify the change and measured variables.	56.7%	53.2%
2	Students at this level can determine if scientific measurement can be applied to a given variable in an investigation. They can recognize the variable being manipulated (changed) by the investigator. Students can appreciate the relationship between a simple model and the phenomenon it is modelling. In researching topics students can select appropriate key words for a search.	81.3%	78.4%
1	Students at this level can suggest appropriate sources of information on scientific topics. They can identify a quantity that is undergoing variation in an experiment. In specific contexts they can recognize whether that variable can be measured using familiar measuring tools or not.	94.9%	94.4%
	Below Level 1	5.1%	5.6%

Table 9. Explaining Phenomena Scientifically: ***Summary description for the six proficiency levels***

Level	Proficiency at each level	Percentage of all students across OECD who can perform tasks at this level	Percentage of all U.S. students who can perform tasks at this level
6	Students at this level draw on a range of abstract scientific knowledge and concepts and the relationships between these in developing explanations of processes within systems.	1.8%	2.0%
5	Students at this level draw on knowledge of two or three scientific concepts and identify the relationship between them in developing an explanation of a contextual phenomenon.	9.8%	9.8%
4	Students at this level have an understanding of scientific ideas, including scientific models, with a significant level of abstraction. They can apply a general, scientific concept containing such ideas in the development of an explanation of a phenomenon.	29.4%	26.7%
3	Students at this level can apply one or more concrete or tangible scientific ideas/concepts in the development of an explanation of a phenomenon. This is enhanced when there are specific cues given or options available from which to choose. When developing an explanation, cause and effect relationships are recognized and simple, explicit scientific models may be drawn upon.	56.4%	50.1%
2	Students at this level can recall an appropriate, tangible, scientific fact applicable in a simple and straightforward context and can use it to explain or predict an outcome.	80.4%	73.7%
1	Students at this level can recognize simple cause and effect relationships given relevant cues. The knowledge drawn upon is a singular scientific fact that is drawn from experience or has widespread popular currency.	94.6%	91.7%
	Below Level 1	5.4%	8.4%

Table 10. Using Scientific Evidence: *Summary descriptions of the six proficiency levels*

Level	Proficiency at each level	Percentage of all students across OECD who can perform tasks at this level	Percentage of all U.S. students who can perform tasks at this level
6	Students at this level demonstrate an ability to compare and differentiate among competing explanations by examining supporting evidence. They can formulate arguments by synthesizing evidence from multiple sources.	2.4%	2.5%
5	Students at this level are able to interpret data from related datasets presented in various formats. They can identify and explain differences and similarities in the datasets and draw conclusions based on the combined evidence presented in those datasets.	11.8%	11.2%
4	Students at this level can interpret a dataset expressed in a number of formats, such as tabular, graphic and diagrammatic, by summarizing the data and explaining relevant patterns. They can use the data to draw relevant conclusions. Students can also determine whether the data support assertions about a phenomenon.	31.6%	29.0%
3	Students at this level are able to select a piece of relevant information from data in answering a question or in providing support for or against a given conclusion. They can draw a conclusion from an uncomplicated or simple pattern in a dataset. Students can also determine, in simple cases, if enough information is present to support a given conclusion.	56.3%	51.8%
2	Students at this level are able to recognize the general features of a graph if they are given appropriate cues and can point to an obvious feature in a graph or simple table in support of a given statement. They are able to recognize if a set of given characteristics apply to the function of everyday artifacts in making choices about their use.	78.1%	73.9%
1	In response to a question, students at this level can extract information from a fact sheet or diagram pertinent to a common context. They can extract information from bar graphs where the requirement is simple comparisons of bar heights. In common, experienced contexts students at this level can attribute an effect to a cause.	92.1%	90.0%
	Below Level 1	7.9%	10.0%

Fostering Scientific Literacy: A Different Perspective

In the United States most school science programs do not emphasize scientific literacy as a major aim of education. To be clear, the term scientific literacy is stated constantly as the purpose of science education, but school programs primarily emphasize facts, information, and knowledge of the science disciplines and only secondarily emphasize the applications of science related to citizens' life situations. The difference may seem subtle, but it is important to understand.

Although some scientists and educators had used the term scientific literacy before 1958 (Holton, 1998), in that year Paul DeHart Hurd placed the term fully into the rhetoric of science education with his article, "Science Literacy: Its Meaning for American Schools." Hurd made the case that scientific literacy centered on an understanding of science and its applications to the social experiences of citizens. In the late 1950s, science had such a prominent place in society that contemporary issues could not be considered without reference to science. From this 1958 article, scientific literacy has had a continual place in the literature of science education and arguments for reform (See e.g., Bybee, 1997; DeBoer, 2000; Roberts, 2003).

The critical challenge based on Hurd's original article and the subsequent 50-year discourse about scientific literacy centers on the difference between two perspectives of science curriculum and teaching. One perspective is ***internal*** to science itself. In this perspective, educational policies, programs, or practices center on questions such as: What knowledge of science and its processes should students have? What facts and concepts from physics, chemistry, biology, and the Earth sciences should be the basis for school science programs? In contrast, there is an ***external*** perspective that begins with life situations that citizens might encounter. When thinking about educational policies, programs, and practices from this perspective, questions center on: What science should students know, value, and be able to do as future citizens? What contexts could be the basis for introducing science and technology? The difference between these two perspectives is significant, because the design of curricula and selection of instructional strategies differ, and the subsequent outcomes—what students learn—also differ.

Based on this discussion, I will point out what is perhaps the single most significant challenge facing those who wish to foster scientific literacy in the U.S. Most individuals involved in science education hold the internalist perspective that school science programs should first and foremost emphasize the basic knowledge and processes of science and secondarily make some links to social issues, if time and opportunity permit—which usually do not. Further, their position is deeply held and strongly defended.

If the United States wants to foster higher levels of scientific literacy, then it is essential to recognize the external perspective and accept the importance of designing and developing programs and selecting instructional strategies consistent with that purpose.

PISA 2006 presents a framework (OECD, 2006) and assessment results (OECD, 2007) with a scientific literacy perspective. This view also is generally consistent with contemporary discussions of scientific literacy by Millar (2006), Osborne (2007), and Roberts (2007) and my 1997 book, Achieving Scientific Literacy.

Fostering Scientific Literacy: A Rationale

The rationale for shifting to an emphasis on scientific literacy rests on the influence of science and technology advances and their influence on national economy, the central place of information technologies in employment, and the increasing presence of science and technology related issues such as health, resources, environments, and hazards. The scientific competencies described in PISA 2006 present an excellent new focus for science education programs, and the fact that significant percentages of U.S. students are at very low proficiency levels is an important indication of their capacity to participate in the 21st century workforce and society. The next sections address some of the challenges for fostering scientific literacy in the United States.

Socioeconomics and science achievement. One of the major insights from PISA 2006 is the fact that when compared to other nations, poverty had a greater affect on PISA scores in the U.S. Socioeconomic background accounted for an 18% variation on U.S. student achievement. This finding should cause alarm about the importance of scientific literacy as it relates to social inequities. To be specific about what schools and science education might do, it is clear that students of lower socioeconomic status do not have the same opportunities to learn science as students in higher socioeconomic groups. The U.S. system of education does not provide underprivileged students with demanding science curricula, high quality science teachers, and other resources such as well equipped laboratories. To place this in contemporary terms, in spite of the No Child Left Behind legislation, we are leaving some children behind, and they tend to be the less privileged.

The difficulty with the socioeconomic problem is that it is a huge, complex social problem. Schools cannot change the larger social problem, but the education system can respond to inequities within the system. I refer to those mentioned above—curriculum, instruction, teachers, and the allocation of resources. Research by Akiba, LeTendre, and Scribner (2007) indicates that investing in teacher quality produces higher achievement in mathematics. This was a 46 nation review. Teacher quality also figures as a major factor in an analysis of *How Fins Learn Mathematics and Science* (Pehkonen, Ahtee, Lavonen, 2007). The next sections are based on an article entitled "Does the U.S. Need Another Sputnik?" (Bybee, 2007) and a report I directed entitled *A Decade of Action: Sustaining Global Competitiveness"* (BSCS, 2007).

Confronting contemporary challenges. The United States now confronts challenges associated with the economy, health and the environment, and natural resources. The National Research Council report, *Rising Above the Gathering Storm* (NRC, 2007), has become one of several major reports signaling the need for a national response. Thomas Friedman has sustained public attention for a new reform in his book, *The World Is Flat* (Friedman, 2005). Friedman has a compelling premise: The international economic playing field is level, hence the metaphor the world is flat. The "flattening" that Friedman refers to is a result of information technologies and associated innovations that have made it technically possible and economically feasible for U.S. companies to locate work "offshore," for example, call centers in India. The revolution of informational technologies has developed a generation of digital natives and left many of us as digital immigrants. The implications for education are significant.

Friedman addresses educational questions in a chapter entitled "The Quiet Crisis." According to Friedman, "The American education system from kindergarten through twelfth grade just is not stimulating enough for young people to want to go into science, math, and engineering" (p. 270). Friedman continues:

> Because it takes fifteen years to create a scientist or advanced engineer, starting from when that young man or woman first gets hooked on science and math in elementary school, we should be embarking on an all-hands-on-deck, no-holds-barred, crash program for science and engineering education immediately. The fact that we are not doing so is our quiet crisis (p. 275).

The science education community is left with the fundamental question—what should be done to address the quiet crisis?

The United States must again reform science education, in this case because we are losing our competitive edge in the global economy and clearly must attend to health, environmental, and resource issues because they often underlie economic realities. The primary goal is clear and complex—to prosper in a global economy. And, the timeline for achievement is at least a decade.

Although some insights are not as clear, most agree that central to the global economy is scientific excellence and technological innovation. A logical extension of the proposition is that the United States needs scientists and engineers. This was emphasized by Friedman. I argue that the country also requires higher levels of scientific literacy for all citizens. Finally, few would disagree with the assertion that the K-12 education system can and should play a central role in the responses. I propose specific responses for K-12 science education. First, I outline *what* must be done, and then I elaborate *how* we might achieve these changes.

Fostering Scientific Literacy: What Must We Do?

I begin with a recommendation that will facilitate reform by beginning with teachers and their standard request when asked to change—Where are the materials?

Develop a new generation of curriculum materials for scientific literacy. Specifications for the curriculum materials build on the contexts and competencies from PISA 2006 and the content builds both national and international frameworks. Based on PISA 2006, Figure 4 presents a framework for the curriculum. Contexts for the curriculum are described in Table 11.

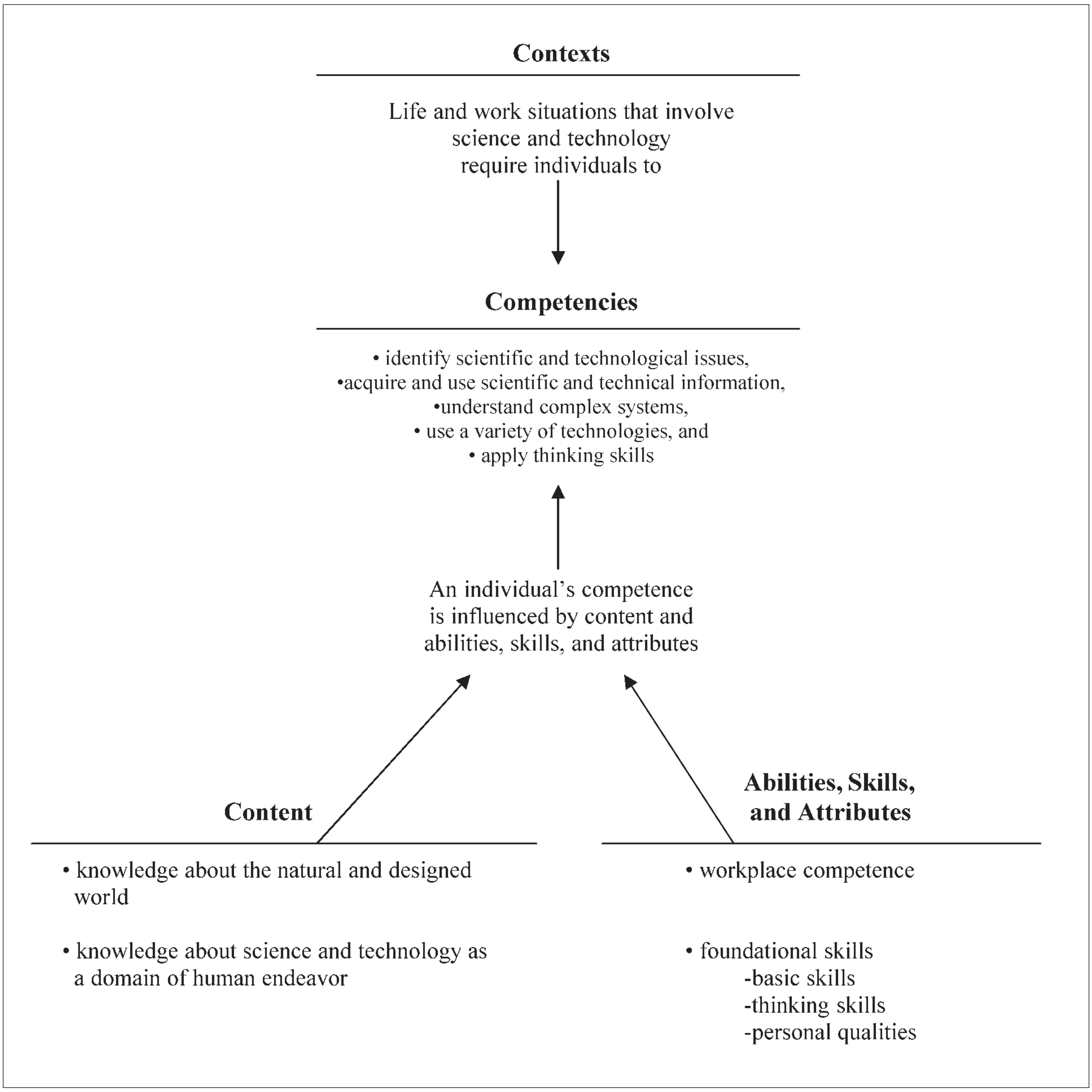

Figure 4. A Perspective for K-12 Scientific and Technological Literacy

Table 11. Contexts for Scientific and Technological Literacy

Context	Personal	Social	Global
Careers	Scientific research, engineering, technical, and teaching	Scientific research, medicine, engineering, information and communication technology	World health, economic progress, security
Health	Maintenance of health, accident prevention, nutrition	Control of disease and social transmission, nutrition, food choices, community health	Epidemics and spread of infectious diseases
Resources	Control of personal consumption of materials and energy	Maintenance of human populations, quality of life, security, production and distribution of food, and the energy supply	Renewable and non-renewable energy, natural systems, population growth, and sustainable use of species
Environment	Research of environmentally friendly behavior, use and disposal of materials	Research of population distribution, disposal of waste, environmental impact, local weather	Biodiversity, ecological sustainability, control of pollution, production and loss of soil
Hazards	Natural and human-induced hazards, decisions about housing	Rapid changes (earthquakes, severe weather), slow and progressive changes (coastal erosion, sedimentation), risk assessment	Climate change, impact of modern warfare
Research and development	Interest in science and technology, science-based hobbies, sport and leisure activities, and use of personal technology	Aerospace engineering, biotechnology,information andcommunications tech-nology, pharmaceuticals	Exploration of space, transportation, agriculture, applications to resolve global problems

Contexts for the curriculum would be based on the *National Science Education Standards* (NRC, 1996), the *Benchmarks for Scientific Literacy* (AAAS, 1993), and aligned with the *Science Assessment and Item Specifications for the 2009 National Assessment of Educational Progress* (National Assessment Governing Board [NAGB], 2005).

Support professional development of science and technology teachers. Specific actions are recommended to achieve this goal. First, establish summer institutes that focus on building teachers' content and pedagogical knowledge and skills. There would be follow-up experiences during the academic year. Second, develop online communities to support all participating teachers. These professional development programs should be concentrated and continuous, have an educational context, focus on content, and establish professional learning communities.

The professional development programs should provide enough initial time to establish a clear foundation for teaching and learning. In addition to an early concentration, the program should extend over a year (or more) and include continuous work on selecting curriculum materials and improving instruction. The educational context for the professional development programs should include curriculum; that is, content and pedagogy with a direct and purposeful meaning for teachers. Core concepts for scientific and technological literacy must be the programs' focus. Finally, the programs require the establishment of professional learning communities with teams of teachers analyzing teaching, engaging in lesson study, reviewing content, and working on the implementation of curriculum materials.

Align certification and accreditation with contemporary priorities of scientific literacy. This recommendation uses the critical leverage of science teacher certification to facilitate reform of undergraduate teacher education programs. No discussion of improving science education escapes acknowledging the need to change teacher education. This includes changes in states' certification and national accreditation, e.g., NCATE. In addition, federal support to colleges and universities that prepare significant numbers of future science teachers will be a major contribution to their reform. To this recommendation I add special support to colleges and universities with significant populations of Hispanic, African American, and Native American students so the institutions can recruit and prepare a greater diversity of science teachers.

Build district-level capacity for continuous improvement of programs for scientific literacy. Specific actions necessary for this priority include: developing leaders; providing summer programs and assistance during the year; centering on critical leverage points such as selection of instructional materials; and, designing programs so the district builds an infrastructure that is sustainable.

This priority connects to other priorities with the goal of sustaining the initial results attained through professional development, curriculum reform, and reform of undergraduate education. Although the federal costs will initially be high, by building district-level capacity one could anticipate reduced support in the long term.

Explain to the public this school science reform and why it will benefit their children and the country. One of the great insights from the Sputnik era was the fact that national leaders provided clear and compelling explanations of what the reform was and why it was important. Further, there was continued support for science teachers and a national enthusiasm for reform.

Fostering Scientific Literacy: How We Can Begin

This section describes the larger picture of how we can initiate and bring about the changes described in the last section to a scale that matters within the U.S. education systems.

Plan a decade of action. Achieving higher levels of scientific literacy cannot be accomplished quickly; it will take a minimum of ten years. Table 12 and 13 present specifications for reform and phases for a decade of reform centering on improving scientific literacy in the United States.

Table 12. Specifications for Action

Unit of change	School districts
Time frame for change	Ten years
Critical components of change	Teachers and teaching, content and curricula, and assessment and accountability
Components of change	Educational policies, curriculum programs, and teaching practices
Theory of action for change	Curriculum reform with complementary professional development and changes in assessment

Table 13. A Decade of Action: Phases and goals

Phase	Timeline	Goal
Initiating the reform	Two years	Design, develop, and implement model instructional units
Bringing the reform to scale	Six years	Change policies, programs, and practices at local, state, and national levels
Sustaining the reform	Two years	Build capacity at the local level for continuous improvement of school scienceand technology programs
Evaluating the reform	Continuous, with a major evaluation in 10 years	Provide formative and summative data on the nature and results of the reform efforts

The primary work for the initial phase of reform occurs in the first two years. I term this phase "Introducing little changes with big effects." This phase centers on the funding and the development of *model instructional units* for scientific literacy. The model instructional units use major sectors of the economy as the "topics," (e.g., aerospace, biotechnology, energy, hazard mitigation, health, and pharmaceuticals sectors) and emphasize contextual themes such as careers and research and development. This phase includes field-testing and final production of the units and complementary assessments. Participating districts select schools, and implementation begins with accompanying professional development.

Providing model instructional units, professional development, and exemplary assessment at the elementary, middle, and high school levels would have an impact on the system, increase understanding among school personnel, and increase support by policy makers and administrators. Further, the units would provide a basis for answering the public's questions about what changes involve and why they are important—especially for children.

The second phase is "Systemic changes that make a difference." Bringing the reform to scale takes six years. After the initial phase, efforts to bring the reform to a significant scale expand. Evaluations of teachers' responses and students' achievement, abilities, and attributes are reviewed and analyzed. These data form the basis for revision of the original models of instructional units, the development of new models of instructional units, and a compelling case statement for the continued expansion of the reform. This phase includes major efforts to review and revise state policies and standards and create new criteria for local and state adoptions of instructional materials. With the revision of standards, states also would initiate changes in assessments. Publishers would begin developing new editions of core and supplemental programs. Through this entire period, professional development of science and technology teachers continues.

Districts begin the process of selecting and implementing curriculum that emphasizes scientific literacy as they become available. Professional development aligned with the new programs is ongoing. The central goal of this phase is to revise local, state, and national policies; develop new school science and technology programs; and align teaching practices with the goals of scientific literacy.

By the end of this phase, states would have new standards and assessments, new teacher certification requirements would be in place, new instructional materials for core and supplemental programs would be available, and the professional development of teachers would be aligned with the new priorities. This phase likely would present the most difficulty as policy makers, and educators directly confront resistance to change and criticism of the new initiatives and changes in policies, programs, and practices.

The work of sustaining "building local capacity for a national purpose" is concentrated in the final two years of the decade. The work focuses on building local capacity for ongoing improvement of science and technology education at the district level. These efforts phase out the use of external funds for the reform effort and phase in the school districts' use of resources in response to the new advances in science and technology and the implied changes for the school programs.

Evaluation involves continuous feedback about the work and changes in content and curricula, teachers and teaching, and assessment and accountability. Clearly, feedback occurs during all phases for "monitoring and adjusting to change." The feedback informs judgments about the models of instructional units and issues associated with their implementation and the professional development of teachers. Evaluations and feedback are conducted and available at the school district, state, national, and even international levels. School districts and states implement their own evaluations. Results from the National Assessment of Education Progress (NAEP), TIMSS, and PISA also provide results from national and international levels.

Concluding Discussion

Having stated these recommendations, I will note some important features. First, they center on critical leverage points to address immediate and long-term problems. Second, the direct implication for federal policy is financial support versus unfunded mandates, requests for cooperation, general recommendations to state and local governments, or appeals for support from business and industry. Third, priorities include multiple and coordinated efforts among, for example, the U.S. Department of Education, the National Science Foundation, the National Institutes of Health, and other agencies. Fourth, where possible, the initiatives should build on current research such as ***How Students Learn: Science in the Classroom*** (NRC, 2006), ***America's Lab Report*** (NRC, 2006), and ***Taking Science to School*** (NRC, 2007). Finally, policy makers can support these priorities from a nonpartisan perspective. It is in the United States' interest to achieve higher levels of scientific and technological literacy.

In conclusion, addressing the theme of fostering scientific literacy in the United States presents a critical and complex set of issues. Results from PISA 2006 indicate that U.S. students are not doing well in general on scientific competencies. PISA results combined with other reports support the need for a major era of reform.

After a general discussion of U.S. results on PISA 2006, I have described what we must do and then elaborated a plan of action with specific details that could increase U.S. students' scientific literacy.

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