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Scientific Literacy, Environmental Issues, and PISA 2006: The 2008 Paul F-Brandwein Lecture

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Abstract In today's world, scientific literacy has become essential to full participation of citizens. Certainly, important components of scientific literacy include resource use and environmental quality. The 2006 Program for International Student Assessment (PISA) centered on scientific literacy and included resources and environments as two contexts for the test and student questionnaire. The article first introduces PISA 2006, and then provides a general overview of results. Using two released units from PISA 2006, I then turn to results and a discussion of students' science competencies and attitudes relative to environmental and resources issues. The article concludes with a discussion of educational policies for science education programs and teaching practices.

Keywords Scientific literacy · PISA 2006 · Environmental issues · Attitudes

Introduction

The opportunity to present the 2008 Paul F-Brandwein lecture leaves me with no small humility and great honor. I thank all Directors of the Paul F-Brandwein Institute, especially those I have known, worked with, and admired for years: Keith Wheeler, Alan Sandler, Cheryl Charles, Marily DeWall, and William Hammond,

I especially want to extend my deepest appreciation to John (Jack) Padalino for his support of my work and the model he provides all of us as a dedicated environmentalist and distinguished educator. Jack has been a colleague and friend for over 40 years. In that time he has taught me many things about the environment and education. Perhaps the greatest bit of wisdom has been insights about the political aspects of science education. I must say that Jack's insights have had significant value beginning with my response to a June 2002 letter of invitation to join PISA through this day.

This is the second time I have presented the Paul F-Brandwein lecture, the first being in 2003 when I selected the title, "The Teaching of Science: Content, Coherence, and Congruence." I based that lecture on two monographs by Paul F-Brandwein: "Elements in a Strategy for Teaching Science in the Elementary School (Brandwein 1962) and "Substance, Structure, and Style in the Teaching of Science" (Brandwein 1965).

This lecture addresses a theme central to Paul F-Brandwein Institute, one to help students realize their interdependence with nature and responsibility for sustaining a healthy and healing environment. Information from PISA 2006 provides insights about how close or distant students are to a realization of this admirable goal.

A Comment About Paul F-Brandwein

The theme of this lecture acknowledges Paul F-Brandwein's long and distinguished career, including serving on the Steering Committee of the Biological Sciences Curriculum Study (BSCS) from the late 1950s into the 1960s. Paul F-Brandwein directed the gifted Student Committee at BSCS and was responsible for initiating a program on student research problems. He felt deeply about giving students the opportunity to engage in scientific inquiry as a means to encourage their future careers as scientists.

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This lecture honors another aspect of Paul's career, that of conservation. His activity as a conservationist was lifelong, indeed it has extended beyond his life in the form of property he and his wife, Mary, bequeathed (as the Rutgers Creek Wildlife Conservancy) to an organization committed to students, teachers, and scientists interested in the environment and natural systems. That Conservancy has been administered through an affiliation with the Pocono Environmental Education Center at Dingman's Ferry, Pennsylvania. John Padalino directed that Center until his retirement.

A Comment on My Interest in Environmental Issues

My interest in environmental issues began in the early 1960s when the environment and ecology emerged as critical issues of smog-filled skies and polluted rivers. My formal connection began with the study of ecology at Otero Junior College, La Junta, Colorado. It has continued from that time to the present work where I had the opportunity to help form questions about resources and the environment for the 2006 Program for International Student Assessment (PISA).

Several of my experiences connect to the life and work of Paul F-Brandwein. I took a plant ecology course that included field study and an independent investigation. It engaged ecological themes/inquiry for my career. Paul F-Brandwein was insightful in his view about opportunities for young students to conduct research as part of their science education.

The study of ecology continued through my undergraduate years. In the early 1960s, I heard about *Silent Spring* by Rachel Carson and after reading sections had the emotional response common to many others who read her book. For me, the response included the sensible idea that science education must somehow connect with the needs of society. The connection was solidified when I enrolled in "Teaching Science in Secondary Schools" at the University of Northern Colorado and had to purchase a high school textbook, then in its first edition, *BSCS Green Version* (*BSCS Biology: An Ecological Approach).* This book established a bond between my interest in ecology and a career in science education.

Graduate work at New York University did not include formal work in ecology, but it did give me time to read works by individuals such as Paul Ehrlich, Garrett Hardin, Barry Commoner, and Rene Dubos. New York University, as it turns out, also is another connection with Paul F-Brandwein as we both completed our PhDs there—he, 35 years before me.

In 1971, I joined the faculty at Carleton College, Northfield, Minnesota. After a few years my experience extended beyond the Education Department and preparation of science teachers. I became acquainted with Ian Barbour, a colleague in the Religion Department. Eventually, Ian and I taught courses on "Environmental Ethics," and "The Sustainable Society." Later, I taught one other course on "Science, Technology, and Public Education."

By the late 1970s, my professional writing turned to themes of ecology and science education (Bybee 1979a, b, c) and, for example, in 1984, the National Association of Biology Teachers (NABT) published *Human Ecology: A Perspective for Biology Education*.

In the 1990s, work as chair of the content group for the *National Science Education Standards* (NRC 1996) allowed me to propose variations on the themes of population growth, resource use, and environmental quality for the standards on "Science in Personal and Social Perspectives." I am simultaneously pleased that these themes are clearly expressed in the *National Science Education Standards* and disappointed that the section on "Science in Personal and Social Perspectives" has been largely overlooked by those states and districts using the national publication as the basis for their standards.

In 2002, I was invited to join and chair the Science Forum, which included representatives of participating countries for PISA Science 2006 and also chair a smaller Science Expert Group which had representatives from Australia, Canada, Japan, Norway, France, Italy, Slovak Republic, Poland, Germany, Great Britain, and the United States. Because PISA presents test items in personal, social, and global contexts, this work again presented an opportunity to include issues associated with resources and the environment. PISA 2006 had a student questionnaire that included queries about the environment. I participated on the questionnaire expert group and assumed responsibility for initial work on questions about the environment. I shall present some of the finding from PISA 2006.

The Environment and Resources as Contexts for Scientific Literacy

Scientific literacy is essential to an individual's full participation in society. The understandings and abilities associated with scientific literacy empower citizens to make personal decisions and appropriately participate in the formulation of public policies that impact their lives. Assertions such as these provide a rationale of scientific literacy as the central purpose of science education. Too often, however, the rationale lacks connections that answer questions such as "personal decisions—*"concerning what?"* "fully participate—*in what?"* or "formulate policies—*relative to what?"* One could answer these questions using contexts that citizens daily confront; for example, personal health, natural hazards, and information at the frontiers of science and technology. Two other domains stand out—national resources and environmental quality.

Environmental and resource issues are a global concern. For more than a decade climate change has been central to science and public policy at local to global levels. Human activities such as the accumulation of waste, destruction of ecosystems, and depletion of resources have had a substantial impact on the global environment. As a result, threats to the environment are prominently discussed in the media, and citizens of every nation are increasingly faced with the need to understand complex environmental issues. Edward O. Wilson summarizes the situation using an economic metaphor:

> What humanity is inflicting on itself and Earth is, to use a modern metaphor, the result of a mistake in capital investment. Having appropriated the planet's natural resources, we chose to annuitize them with a short-term maturity reached by progressively increasing payouts. At the time it seemed a wise decision. To many it still does. The result is rising per-capita production and consumption, markets awash in consumer goods and grain, and a surplus of optimistic economists. But there is a problem: the key elements of natural capital, Earth's arable land, ground water, forests, marine fisheries, and petroleum, are ultimately finite and not subject to proportionate capital growth (Wilson 2002, p. 149).

Wilson's use of an economic metaphor and my selection of this particular quotation were deeper and more insightful than it may seem. Often, citizens will hear economic arguments for continued use of resources and destruction of environments. What Wilson's metaphor points out is the need to understand scientific ideas such as renewable and non-renewable resources and the capacity of ecosystems to degrade waste. Stated succinctly, understanding issues of ecological scarcity directly influences economic stability and social progress (Ophuls 1977). Ecological scarcity directly relates to environmental issues and a citizen's scientific literacy.

A scientifically literate individual has more than knowledge of resources and environmental issues. A scientifically literate individual also must have attitudes that contribute to actions. Although not totally unrelated to civic attitudes and values, the attitudes referred to here are grounded more in an understanding of the environment and less in democratic values. Examples of values associated with the environment include conservation, prudence, and stewardship (Kollmuss and Agyeman 2002; Morrone et al. 2001; Tikka et al. 2000).

PISA 2006 provided an opportunity to survey the scientific literacy of 15-year-olds in 57 countries, the total of which constitutes approximately 90% of the world economy. The next sections introduce PISA and place emphasis on the linkage between scientific literacy and issues related to the environment and resources.

PISA 2006: An Assessment of Scientific Literacy

The PISA presents a unique perspective on the assessment landscape. Most assessments look back at what students were expected to learn and whether they attained the knowledge and skills described in the science curriculum. This observation is true for most classroom, state, national assessments, and the Trends in Mathematics and Science Study (TIMSS) at the international level. The intention of PISA is to look ahead and extrapolate from students' present knowledge, attitudes, and skills to the future. At age 15, how well can students apply their knowledge and skills in novel settings? The key idea here is the ability students have to apply their knowledge and skills, because that is what they will have to do as future citizens. This, too, is the essence of and intended meaning of scientific literacy.

The following sections introduce PISA 2006. This discussion is based on the science portion of *Assessing Scientific, Reading, and Mathematical Literacy: A Framework for PISA 2006* (OECD 2006).

PISA 2006: An Introduction

The PISA is sponsored by the Organization for Economic Cooperation and Development (OECD), an intergovernmental organization of 30 industrialized nations based in Paris, France. In 2006, 57 countries participated in PISA, including 30 OECD countries and 27 non-OECD countries. PISA measures 15-year-olds' competencies in reading literacy, mathematics literacy, and science literacy every 3 years. PISA was first implemented in 2000 and the most recent results are for the 2006 assessment. Each 3-year cycle assesses one subject in depth. The other two subjects also are assessed, but not in the same depth as the primary domain. In 2003, mathematics was the primary subject assessed, and in 2006, it was science. PISA also measures cross-curricular competencies. In 2003, for example, PISA assessed problem solving.

PISA uses the term "literacy" within each subject area to indicate a focus on the application of knowledge and abilities. Literacy refers to a continuum of knowledge and abilities; it is not a typological classification of a condition that one has or does not have; for example, PISA assessments do not provide data to determine who is literate or illiterate.

Scientific Literacy

For purposes of the PISA 2006, scientific literacy referred to an individual's scientific knowledge and use of that knowledge to *identify scientific questions*, to *explain scientific phenomena*, and to *draw evidence-based conclusions* about science-related issues. In addition, the definition includes the understanding of the characteristic features of science as a form of human knowledge and inquiry; an awareness of how science and technology shape our material, intellectual, and cultural environments; and a willingness to engage in science-related issues.

The definition of scientific literacy proposed by PISA provides for a continuum from less developed to more developed scientific literacy—that is, individuals are deemed to be more or less scientifically literate; they are not regarded as either scientifically literate or scientifically illiterate (Bybee 1997; Koballa et al. 1997). So, for example, the student with less developed scientific literacy might be able to recall simple scientific factual knowledge and to use common scientific knowledge in drawing or evaluating conclusions. A student with more developed scientific literacy will demonstrate the ability to create or use conceptual models to make predictions or give explanations, to formulate and communicate predictions and explanations with precision, to analyze scientific investigations, to relate data as evidence, to evaluate alternative explanations of the same phenomena, and to communicate explanations with precision.

For purposes of assessment, the PISA 2006 definition of scientific literacy may be characterized as consisting of four interrelated and complementary aspects:

- Recognizing life situations involving science and technology. This is the *context* for assessment units and items.
- Understanding the natural world, including technology, on the basis of scientific knowledge that includes both knowledge *of* the natural world and knowledge *about* science itself. This is the *knowledge component* of the assessment.
- Demonstrating competencies that include identifying scientific questions, explaining phenomena scientifically, and using scientific evidence as the basis for arguments, conclusions, and decisions. This is the *competency component*.
- Responding with an interest in science, support for scientific inquiry, and motivation to act responsibly toward, for example, natural resources and environments. This is the *attitudinal dimension* of assessment.

This relationship is represented graphically in Fig. 1.

Briefly, PISA 2006 assessed important scientific knowledge relevant to the science education experiences of 15-year-olds in participating countries without being constrained by the common aspects of participants' national curricula. It did this by requiring application of selected scientific knowledge, the use of scientific competencies, and an evaluation of attitudes, in important situations reflecting the world.

Scientific Competencies

The PISA 2006 science assessment gave priority to the competencies listed in Fig. 1; the ability to identify

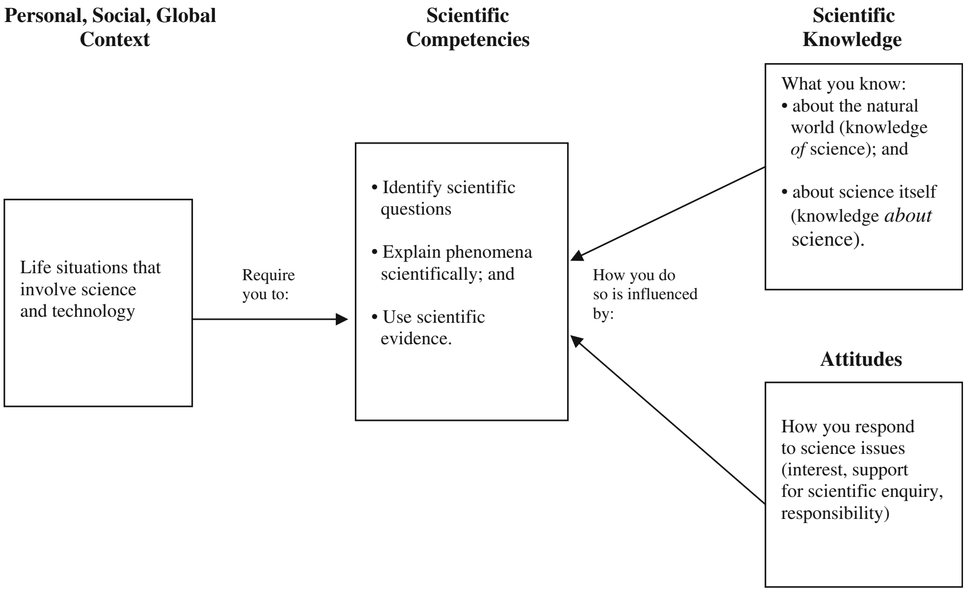


Fig. 1 Framework for PISA 2006 Science Assessment. *Source*: OECD (2007)

scientifically-oriented questions; describe, explain, or predict phenomena based on scientific knowledge; interpret evidence and conclusions; and use evidence to make and communicate decisions. These competencies involve scientific knowledge—both knowledge *of* science and knowledge *about* science.

Some cognitive processes have special meaning and relevance for scientific literacy. Among the *cognitive* processes that are implied in the scientific competencies are: inductive/deductive reasoning, critical and integrated thinking, transforming representations (e.g., data to graphs), constructing explanations based on data, thinking in terms of models, and using mathematics.

Scientific Knowledge

Given that only a sample of students' knowledge *of* science can be assessed in the PISA 2006 science assessment, it was important that clear criteria were used to guide the selection of knowledge that will be assessed. Moreover, the objective of PISA is to describe the extent to which students can *apply* their knowledge in contexts of relevance to their lives. Accordingly, the knowledge that is assessed was selected from the major fields of physics, chemistry, biological science, and Earth and space science, according to the following three criteria:

- Relevance to real-life situations,
- Fundamental to understanding physical, living, and Earth systems, and
- Appropriate to the development level of 15-year-olds.

The knowledge in PISA 2006 required understanding the natural world and making sense of experiences in personal, social, and global contexts. For these reasons, the framework uses the term "systems" instead of "sciences" as descriptors of the major fields. Use of the term "systems" conveys the idea that citizens have to understand concepts from the physical and life sciences, Earth science, and technology, in contexts that have components that interact in a more or less united way. That is, they have to apply scientific knowledge and deploy scientific competencies in considering systems within contexts such as environmental issues. There is no attempt to list comprehensively all the knowledge that could be related to each of the knowledge *of* science categories.

In addition to assessing students' knowledge *of* science, PISA 2006 included assessments of students' knowledge and understanding of ideas *about* science, and of the interactions among science and technology and the material, intellectual, and cultural environments. The first category, "Scientific Inquiry," centered on inquiry as the central process of science and the various components of that process. The next category closely related to inquiry was that of "Scientific Explanations." Scientific explanations are the results of scientific inquiry. One can think of inquiry and explanations as the means of science (how scientists *get* data) and the goals of science (how scientists *use* data) as the basis for explanations of phenomena.

Attitudes

People's attitudes play a significant role in their interest, attention, and response to science and technology in general and to issues that affect them in particular. One goal of science education is students' development of attitudes that support their attending to scientific issues and the subsequent acquisition and application of scientific and technological knowledge to personal, social, and global benefit.

The PISA 2006 science assessment evaluated students' attitudes in three areas: *interest in science*, *support for scientific inquiry*, and *responsibility for sustainable development*. These areas were selected because they will provide an international portrait of students' general appreciation of science, their specific scientific attitudes and values, and their responsibility toward selected science-related issues that have national and international ramifications. Note that this is not an assessment of students' attitudes toward school science programs or teachers. The results provide information about the emerging problem of declining interest for science studies among young people.

Table 1 provides a summary of key components of the PISA 2006 science assessment.

Compared to the curricular orientation of TIMSS, PISA provides a unique and complementary perspective by focusing on the application of knowledge in reading, mathematics, and science in problems and issues in real-life contexts. PISA's goal is to answer the question: "Considering schooling and other factors, what knowledge and skills do students have at age 15?" The achievement scores from PISA represent a "yield" of learning at age 15, rather than a measure of the attained curriculum at grades 4 or 8, as is the case with TIMSS. The framework for assessment is based on content, competencies, and life situations. The competencies describe strategies students use to solve problems, and the situations consist of personal, social, or global contexts in which students might encounter scientific problems.

In PISA, a situation may be presented and several questions asked about it. Although some items are selected response, the majority of items required a constructed response, for which partial credit may be given. The typical PISA item makes more complex cognitive demands on the student than the typical item from TIMSS or the National Assessment of Education Progress (NAEP) (Neidorf et al. 2004).

Table 1 Summary of the assessment areas for PISA 2006—Science

Assessment area	Description
Scientific literacy and its distinctive features	Scientific literacy refers to an individual's • Scientific knowledge and use of that knowledge to identify scientific issues, to explain scientific phenomena, and to use scientific evidence; • Understanding of the characteristic features of science as a form of human knowledge and inquiry; • 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 reflective citizen.
Science content	Areas *of* scientific knowledge and concepts include: • Physical systems • Living systems • Earth and space systems • Technological systems and, knowledge *about* science which includes: • Scientific inquiry • Scientific explanations
Scientific competencies	• Identify scientific questions • Explain phenomena scientifically • Use scientific evidence
Personal, social, and global contexts	Areas of application within the contexts include: • Health • Resources • Environments • Hazards • Frontiers of science and technology
Attitudes	The response to scientific situations include: • Interest in science • Support for scientific inquiry • Responsibility for sustainable development

Source: OECD (2007)

PISA 2006 Science: An Overview of Results

The first part of this section presents the average scores for both OECD and non-OECD countries. These results are presented in order to provide a larger view and locate the U.S. among the countries that participated, many of which are our economic competitors.

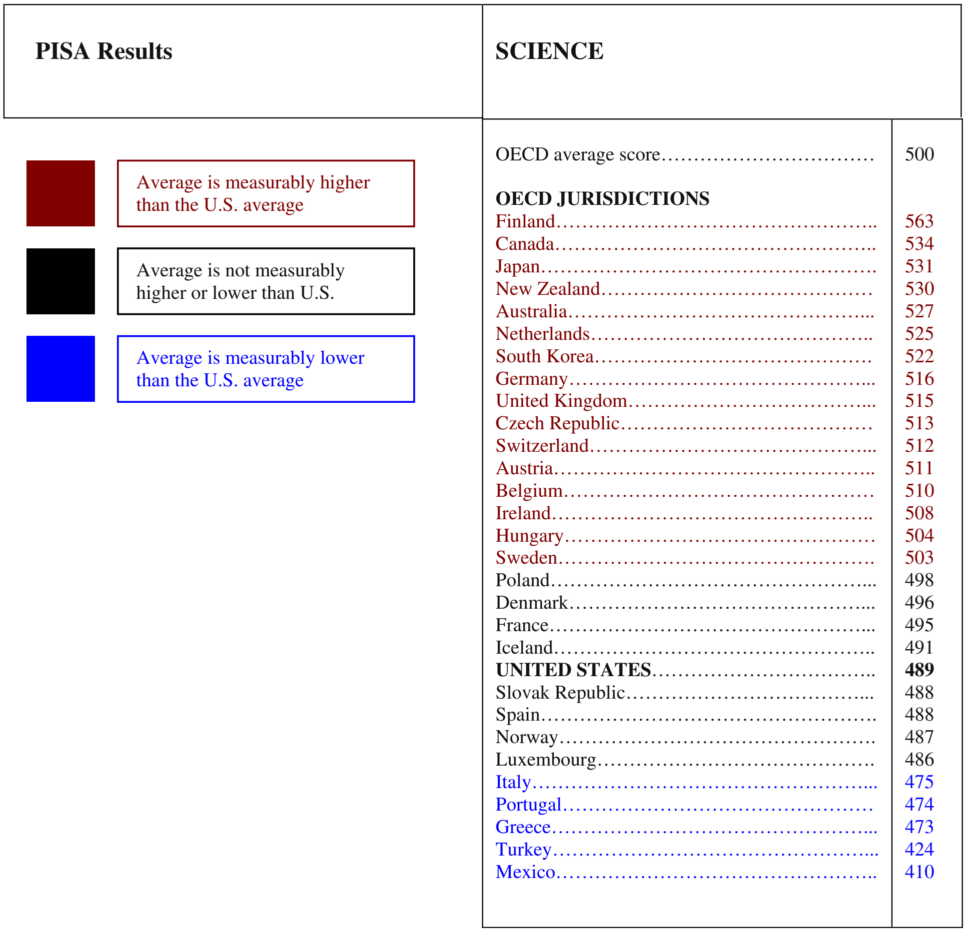
U.S. Students

How do U.S. students score on scientific literacy compared to 15-year-olds in other OECD and non-OECD countries? In 2006 the U.S average score was 489 compared to the OECD average of 500. Sixteen OECD countries had scores that were measurably higher than U.S. students. Top performing countries included Finland (563), Canada (534), Japan (531), New Zealand (530), and Australia (527). In a ranking of countries by scores, the U.S. was 21st (See Fig. 2).

Compared to non-OECD countries or jurisdictions, there were six countries with measurably higher scores than U.S. students. Top performing non-OECD countries included: Hong Kong (542), Chinese Taipei (532), Estonia (531), Liechtenstein (522), Slovenia (519), and Macao (511) (See Fig. 3).

Strengths of U.S. students included the scientific competency: identifying scientific issues, knowledge about science (i.e., scientific inquiry and scientific explanations), and their knowledge of Earth and space systems. U.S. students were weak in the competencies: explaining phenomena scientifically and using scientific evidence. Students also were weak in knowledge of living systems and physical systems.

In the next sections, I turn to more detailed results concerning the environment. These results include students' awareness, performance, concern, optimism, and responsibility, all pertaining to environmental issues. There



PISA Results | **SCIENCE**

🟥 Average is measurably higher than the U.S. average

⬛ Average is not measurably higher or lower than U.S.

🟦 Average is measurably lower than the U.S. average

OECD average score	500
OECD JURISDICTIONS	
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
Poland	498
Denmark	496
France	495
Iceland	491
UNITED STATES	**489**
Slovak Republic	488
Spain	488
Norway	487
Luxembourg	486
Italy	475
Portugal	474
Greece	473
Turkey	424
Mexico	410

Fig. 2 PISA 2006 Survey: OECD Jurisdictions. *Source*: OECD (2007)

is a note of caution since students in different countries may have interpreted the questions in various ways.

PISA 2006: A Unique Approach to Science Literacy Assessment

Most school programs emphasize fundamental knowledge and processes of the science disciplines. These science programs are implicitly intended to provide students with the foundation for professional careers as scientists and engineers. With the centrality of science and technology to contemporary life, full participation in society requires that all adults, including those aspiring to careers as scientists and engineers, be scientifically literate.

The Design of PISA Assessment Units

Consistent with the PISA definition of scientific literacy, assessment items required the application of scientific knowledge and demonstration of the scientific competencies within contexts such as resource or environmental issues. An assessment unit included several items linked to initial stimulus material. Sample units are included in *Assessing Scientific, Reading, and Mathematical Literacy: A Framework for PISA 2006* (OECD 2006) and *PISA 2006: Science Competencies for Tomorrow's World, Volume I Analysis* (OECD 2007).

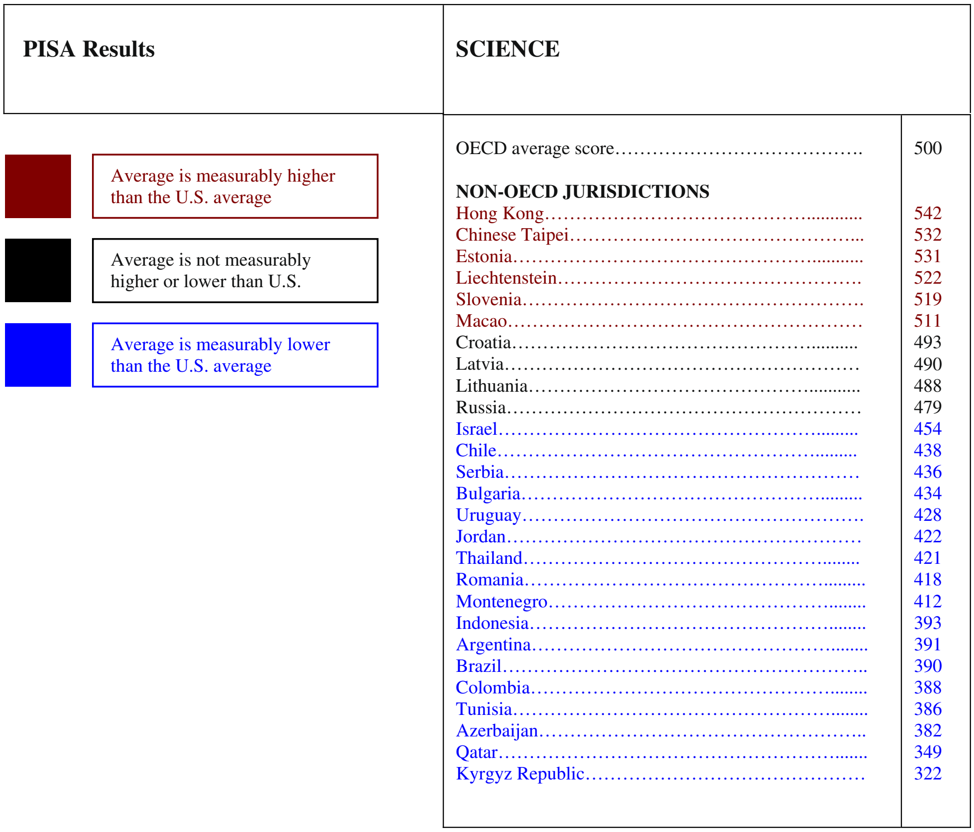
In constructing assessment units, test developers considered the contexts that would serve as stimulus material, the competencies required to respond to the questions or issues, and the scientific knowledge and attitudes central to the exercise.

A test unit was defined by stimulus material, typically a brief written passage, or writing accompanying a table, chart, graph, or diagram. The items included a set of independently scored questions requiring a selected response, a short constructed response, or an open-constructed response. They also may have required review and analysis of drawings, schemes, or graphs.

The Structure and Scoring of PISA 2006 Science

In total, 103 science items were used in PISA 2006. These tasks, along with reading and mathematics tasks, were arranged into half-hour clusters. There were 13 clusters that

Fig. 3 PISA 2006 Survey: Non-OECD Jurisdictions. *Source*: OECD (2007)



PISA Results

🟥 Average is measurably higher than the U.S. average

⬛ Average is not measurably higher or lower than U.S.

🟦 Average is measurably lower than the U.S. average

SCIENCE	
OECD average score	500
NON-OECD JURISDICTIONS	
Hong Kong	542
Chinese Taipei	532
Estonia	531
Liechtenstein	522
Slovenia	519
Macao	511
Croatia	493
Latvia	490
Lithuania	488
Russia	479
Israel	454
Chile	438
Serbia	436
Bulgaria	434
Uruguay	428
Jordan	422
Thailand	421
Romania	418
Montenegro	412
Indonesia	393
Argentina	391
Brazil	390
Colombia	388
Tunisia	386
Azerbaijan	382
Qatar	349
Kyrgyz Republic	322

included 7 science, 4 mathematics, and 2 reading clusters. Although the number of science clusters varied among test booklets, every student completed at least one cluster on science. Each student was given a test booklet with four clusters of items. Students had 2 h of time for the assessment. These clusters were rotated in combinations ensuring that each science item appeared in the same number of test booklets, and that each cluster appeared in each of the four possible positions in the booklet.

Although the majority of the items were dichotomously scored, a number of the open-response items required partial credit scoring. For each open-response item a detailed scoring rubric that allowed for "full credit," possibly "partial credit," and "no credit" was provided. The categories "full credit," "partial credit," and "no credit" divided students' responses into three groups in terms of the extent to which the students demonstrate ability to answer the question. A "full credit' response will exhibit a level of understanding of the topic appropriate for a scientifically literate 15-year-old. Less sophisticated, correct responses qualified for "partial credit," with completely incorrect, irrelevant, or missing responses being assigned "no credit."

The need for students to have a degree of reading literacy in order to understand and answer questions on scientific literacy raised an issue of the level of that reading literacy. Stimulus material and questions used language that is as clear, simple, and as brief as possible while still conveying the appropriate meaning. The number of concepts introduced per paragraph was limited and, generally, care was taken to confine reading to a minimum. Units were designed to present a reading age no higher than that of the average 15-year-old. Questions that predominantly assessed reading literacy, or mathematical literacy, were avoided.

The Assessment of Students' Attitudes

PISA 2006 used both a student questionnaire *and* contextualized questions in test units to gather data about students' attitudes. The inclusion of contextualized items added value to the assessment and provided data on whether students' attitudes differed when assessed in and out of context, whether they vary between contexts, and whether they correlate with performance at the unit level. One aspect of students' *Interest in science* (namely, their *Interest in learning about science*), and students' *Support for scientific inquiry*, was assessed in the test using embedded items that targeted personal, social, and global issues.

The student questionnaire gathered data on students' attitudes in all three areas: *Interest in science, Support for scientific inquiry,* and *Responsibility towards resources and environments*, in a non-contextualized manner. Additional data concerning students' engagement in science and learning and teaching also was collected via the student questionnaire, as was students' views on the value of science for further education and career and for social and economic benefits.

Of significance to this discussion, *Responsible attitude towards resources and environments* is both an international concern and one of economic relevance. In December 2002, the United Nations approved resolution 57/254 declaring the ten-year period beginning on 1 January 2005 to be the "United Nations Decade of Education for Sustainable Development" (UNESCO 2003). The International Implementation Scheme (UNESCO, September 2005) identifies *environment* as one of the three spheres of sustainability (along with society—including culture—and economy) that should be included in all education for sustainable development programs. The UNESCO declaration provided a rationale for including questions about students' responsibility towards resources and the environment.

Examples of Assessment Units from PISA 2006

Appendices I and II present two examples of assessment units from PISA 2006. The units were selected to demonstrate environmental and resource specific scientific issues, competencies, and levels of proficiencies for scientific literacy.

Proficiency Levels in Science

Student scores in science for PISA 2006 were grouped into six proficiency levels. The six proficiency levels represented groups of tasks of ascending difficulty, with Level 6 as the highest and Level 1 as the lowest. The grouping into proficiency levels was undertaken on the basis of substantive considerations relating to the nature of the underlying competencies (See Tables 2–6).

Table 2 is a map of science questions from the two examples, illustrating the proficiency levels and scientific competencies.

Characteristics of the items within assessment units provide the basis for interpreting students' performance at different levels of proficiency and for different scientific competencies. The unit *Acid Rain* (See Appendix I), for example, has questions that can be scored at proficiency levels 2, 3, and 6 and for all three competencies. The *Greenhouse* unit (See Appendix II) has questions at levels 3, 4, 5, and 6 and for the scientific competencies Explaining Phenomena Scientifically and Using Scientific Evidence.

At the very bottom of the scale, proficiency level 1 (below the cut-point) for the competency, students must simply recall information. For example, students might be required to know that fossils of organisms were deposited at an earlier age and that active muscles get an increased flow of blood. At proficiency level 2, students might be required to know the fact that freezing water expands and thus may influence the weathering of rocks. An example for the competency, Using Scientific Evidence is question 3 in *Acid Rain*. This question provides a good example for proficiency level 2. The item asks students to use information provided to draw a conclusion about the effects of vinegar on marble, a simple model for the influence of acid rain on marble.

Table 2 A map of two environmental examples from PISA 2006

Level	Lower score limit	Competency		
		Identifying scientific issues	Explaining phenomena scientifically	Using scientific evidence
6	707.9	ACID RAIN *Question 5.2 (717)* (full credit)	GREENHOUSE *Question 5 (709)*	
5	633.3			GREENHOUSE *Question 4.2 (659)* (full credit)
4	558.7			GREENHOUSE *Question 4.1 (568)* (partial credit)
3	484.1	ACID RAIN *Question 5.1 (513)* (partial credit)	ACID RAIN *Question 2 (506)*	GREENHOUSE *Question 3 (529)*
2	409.5			ACID RAIN *Question 3 (460)* (has embedded attitude item)
1	334.9			

Source: OECD (2007)

Table 3 Students' awareness of selected environmental issues

Environmental issue	Percentage of OECD students who are familiar with or know something about this environmental issue	Percentage of U.S. students who are familiar with or know something about this environmental issue
The consequences of clearing forests for other land use	73	73
Acid rain	60	54
The increase of greenhouse gases in the atmosphere	58	53
Nuclear waste	53	51
Use of genetically modified organisms (GMOs)	35	39

Table 4 Students' level of concern regarding environmental issues

Environmental issue	Percentage of OECD students who believe the following environmental issues to be a serious concern for themselves or other people in their country	Percentage of U.S. students who believe the following environmental issues to be a serious concern to themselves or other people in their country
Energy shortage	82	84
Water shortage	76	81
Air pollution	92	91
Nuclear waste	78	83
Extinction of plants and animals	84	85
Clearing of forests for other land use	83	87

Table 5 Students' level of optimism regarding environmental issues

Environmental issue	Percentage of OECD students who believe the following environmental issues will improve during the next 20 years	Percentage of U.S. students who believe the following environmental issues will improve during the next 20 years
Energy shortage	21	26
Water shortage	18	22
Air pollution	16	21
Nuclear waste	15	17
Extinction of plants and animals	14	18
Clearing of forests for other land use	13	15

For the lower levels of proficiency, items are set in simple and relatively familiar contexts and require only the most limited interpretation of a situation. Items only require direct application of scientific knowledge and an understanding of well known scientific processes of science in familiar situations.

Around the middle of the proficiency scale, items require substantially more interpretation, frequently in situations that are relatively unfamiliar. Items often demand the use of knowledge from different scientific disciplines including more formal scientific or technological representation, and the thoughtful linking of those different knowledge domains in order to promote understanding and facilitate analysis. They often involve a chain of reasoning or a synthesis of knowledge and can require students to express reasoning through a simple explanation. Typical activities include interpreting aspects of a scientific investigation, explaining certain procedures used in an experiment, providing evidence-based reasons for a recommendation, and identifying the origins of chemical

Table 6 Students' responsibility for sustainable development

Statements describing possible policies on student questionnaire

A Industries should be required to prove that they safely dispose of dangerous waste material.

B I am in favor of having laws that protect the habitats of endangered species.

C It is important to carry out regular checks on the emissions from cars as a condition of their use.

D To reduce waste, the use of plastic packaging should be kept to a minimum.

E Electricity should be produced from renewable resources as much as possible, even if this increases the cost.

F It disturbs me when energy is wasted through the unnecessary use of electrical appliances.

G I am in favor of having laws that regulate factor emissions even if this would increase the price of products.

Abbreviated policy statements indicating students' responsibility	Percentage of OECD students who strongly agree with the statement	Percentage of U.S. students who strongly agree with the statement
A (Require safe disposal of waste)	92	88
B (Laws to protect endangered species)	92	90
C (Regular checks on car emissions)	91	89
D (Minimize use of plastic packages)	82	77
E (Produce electricity from renewable resources)	79	75
F (Waste of energy through unnecessary use of appliances)	69	63
G (Laws to regulate factory emissions)	69	56

elements in the atmosphere. In the unit *Acid Rain*, for example, students were provided information about the effects of vinegar on marble (i.e., a model for the effect of acid rain on marble) and asked to explain why some chips were placed in pure (distilled) water overnight. For partial credit at proficiency level 3, they had simply to state it was a comparison. Level 6, for example, required them to state that the acid (vinegar) was necessary for the reaction. These responses were for the competency, Identifying Scientific Issues.

For the competency, Explaining Phenomena Scientifically, *Acid Rain*, question 2, provides an example. Here students are asked about the origin of certain chemicals in the air. Correct responses required students to demonstrate an understanding of the chemicals as originating as car exhaust, factory emission, and burning fossil fuels.

For the competency, Using Scientific Evidence, the unit on *Greenhouse* presents a good example for proficiency level 3. In *Greenhouse*, question 3, students must interpret evidence, presented in graph form, and conclude that the combined graphs support a conclusion that both average temperature and carbon dioxide emission are increasing.

At the top of the proficiency scale, items typically involve a number of different elements requiring even higher levels of interpretation. The selections are unfamiliar to students and require some degree of reflection and review. Items demand careful analysis, may involve more than a scientific explanation and require carefully constructed arguments.

Typical items near the top of the scale involve interpreting complex and unfamiliar data, imposing a scientific explanation on a complex situation, and applying scientific processes to unfamiliar problems. At this part of the scale, items tend to have several scientific or technological elements that need to be linked by students, and their successful synthesis requires several interrelated steps. The construction of evidence-based arguments and communications also requires critical thinking and abstract reasoning.

An example for proficiency level 6 and the competency, Explaining Scientific Phenomena, is question 5 of *Greenhouse*. Students must analyze a conclusion to account for other factors that could influence the greenhouse effect. A final example from *Greenhouse* centers on the competency, Using Scientific Evidence, and asks students to identify a portion of a graph that does not provide evidence supporting a conclusion. Students must locate a portion of two graphs where curves are not both ascending or descending and provide this finding as part of a justification for a conclusion.

Acid Rain serves as an example of a science unit containing embedded questions that query students' attitudes. Question 10 N in *Acid Rain* probes the level of students' interest in the topic of acid rain, and question 10S asks students how much they agree with statements supporting further research.

Students' Knowledge About and Attitudes Toward Environmental Issues

With the assistance of Barry McCrae and Eveline Gebhardt, both of the Australia Council for Education Research (ACER), we reviewed and classified PISA 2006 units in terms of natural resources and environments.

Responses to Cognitive Items About Resources and Environments

PISA 2006 included 10 units and a total of 32 items that assessed aspects of the contextual themes—resources and environments. PISA 2006 consisted 103 items. So, approximately one-third of the contextual situations included resources and environments. Proficiency levels for the items ranged from 1 through 6 with the majority of items at levels 3 and 4. Acid Rain and Greenhouse serve as examples. For the United States students, the average percent correct overall for the environment and resource items versus the average percentage on the remaining 71 items was 47% vs. 53%. The comparative percentages for OECD countries were 50% vs. 55%. The U.S. did not perform as well as OECD countries, but this may be a reflection of the type of questions. We did look at the difference between average percent correct on open-response items versus all other formats (e.g., multiple choice). In general, both U.S. students and students in other OECD countries scored lower on open ended questions.

U.S. Students' Awareness of Environmental Issues

PISA 2006 surveyed students' awareness of selected environmental issues. As you can see in Table 3, the majority of U.S. students, 73%, reported being aware of the consequences of clearing forests for other land use. This percentage was the same as the OECD average. Just over half of U.S. students are aware of acid rain, the increase of greenhouse gases in the atmosphere, and nuclear waste. Over a third of U.S. students (39%) are aware of the use of genetically modified organisms. This is higher than the OECD average which was 35%. In general, the U.S. 15-year-old's awareness of environmental issues varies. The reason most likely has to do with presentation of issues in the media and educational programs.

Data from this survey also suggest that students' levels of awareness of environmental issues are strongly associated with their scientific knowledge. However, the U.S. was one country with a lower mean score in science—the U.S. mean was 489 compared to the OECD average of 500—and students who are more aware of environmental issues. The linkage between scientific knowledge and awareness was true for all participating countries. Conversely, relatively lower scores on scientific knowledge may result in environmental issues being unnoticed, ignored, or dismissed by 15-year-olds and some citizens.

All students from more advantaged socio-economic backgrounds reported higher levels of awareness of environmental issues. The U.S. and 24 of 30 other OECD countries had significant gender differences in students' awareness of environmental issues with boys indicating a greater awareness compared to girls.

U.S. Students' Level of Concern About Environmental Issues

It is one thing to be aware and another to be concerned about environmental issues. PISA 2006 explored the latter by asking students to report whether or not selected issues were a serious concern to them and/or other people in their country. Students are, in general, concerned about global issues. As you can see in Table 4, the percentages are highest for air pollution (91% in U.S. and 92% on average for OECD) and lowest for water shortage (81% in U.S. and 76% for OECD). The levels of concern are, in my view, remarkably high.

In somewhat of a contrast to students' awareness, level of concern does not have a strong association with students' performance on science test items. Further, students' level of concern is not strongly associated with socio-economic background. That is, students from less advantaged backgrounds are equally, if not more concerned, about environmental issues. That said, it also is the case they are less able to explain the issues. Finally, there is a significant gender difference in 29 of 30 OECD countries with girls indicating greater concern than boys about environmental issues.

U.S. Students' Optimism Regarding Environmental Issues

To judge students' optimism about the future, PISA 2006 used the same environmental issues as presented for concern and asked if they thought the problems would improve during the next 20 years (See Table 5). Only a minority of students in the U.S. and OECD countries thought the various environmental issues would improve within the next 20 years. U.S. students are most optimistic about shortages of energy and water (26%) and (22%), respectively. But about three quarters are pessimistic about these two issues. Their optimism about other issues is even lower. Unfortunately, the association between science performance and optimism is weak to moderate. That is, the more students know about science, the less optimistic they seem to be. These results are similar to those found in the ROSE study (Schreiner and Sjoberg 2004).

Students from more disadvantaged socio-economic backgrounds tend to be more optimistic about the improvement of these environmental issues within the next 20 years. Quite strikingly, girls are significantly less optimistic in 28 of 30 OECD countries, including the U.S.

U.S. Students' Responsibility for Sustainable Development

If 15-year-old students express generally high levels of awareness and concern, yet indicate significant pessimism about environmental issues, it seems reasonable to ask about their sense of responsibility for sustainable development. PISA 2006 presented students with a sample of seven possible policies for sustainable development and asked them to respond by indicating the degree to which they agreed or disagreed with the policies. Students who indicated they agreed or strongly agreed were deemed to express a sense of responsibility for sustainable development. The strongest sense of responsibility was expressed for laws to protect endangered species, 90% for U.S. and 92% for OECD, followed by regular checks on car emission, 89% for U.S. and 91% for OECD, and safe disposal of dangerous waste material, 88% for U.S. and 92% for OECD (See Table 6).

Here again higher science performance is associated with a stronger sense of responsibility in all OECD countries. In general, students from more advantaged socio-economic backgrounds tended to indicate a higher sense of responsibility for sustainable development. Very interestingly, girls show significantly more responsibility than boys in 20 of 30 OECD countries, including the U.S.

In conclusion, the results from PISA 2006 suggest that, in general, students with a greater understanding of science also are more aware of environmental issues. They also have a deeper sense of responsibility for sustainable development. However, these same students are not optimistic about how selected environmental issues will improve during the next 20 years. Within this conclusion, boys tend to be more optimistic and girls tend to be more concerned and responsible about environmental issues.

Policy Implications for Science Education

I begin this discussion of policies with a variation from the framework for PISA 2006. I have referred to it as the Sisyphean question in science education: What is it important for citizens to know, value, and be able to do in situations involving natural resources and the environment?

For three decades, I have answered this question in a variety of forms and venues. My answers have generally been consistent, and the urgency of an explicit and direct response has only increased with time. So, I see little need for a different statement, only a greater necessity for a coherent and sensible response by the science education community. The following response is for the most part, a contemporary statement that is consistent with and builds on earlier recommendations (see; e.g., Bybee 1979a, b, c, 1984, 1991, 2003).

Begin with a Clear Purpose

I begin this discussion with a statement of purpose from the Paul F-Brandwein Institute—education should help students understand their interdependence with nature and develop responsibility for sustaining a healthy and healing environment.

Establish Policies for Programs and Practices

This discussion of educational policies presents guidelines for science education programs, instruction, and practices. The policies are based on the fundamental divisions of ecology—individual organisms, environments, and populations of organisms. Using this ecological model and placing it in a human context, I asked: what is it about these three divisions that are essential from a global perspective of sustainable development? My answers include both a conceptual and ethical orientation. Here are the answers, stated as policies. Science education programs and practices should include learning outcomes that include: (1) understanding and fulfilling basic human needs and facilitating personal development, (2) maintaining and improving the physical environment, (3) conserving and wisely using natural resources, and (4) developing an understanding of interdependence and community among people at local, national, and global levels.

The ideas inherent in the first policy are simple and straightforward: All humans have basic physiological needs such as clean air and water and sufficient food. They also need adequate shelter and safety. At higher levels, humans have the need to belong to groups and to perceive themselves as adequate and able. Simply stated, individuals need sustenance, order, community, and purpose for healthy physical and psychological development. Educational programs can contribute directly to the fulfillment of basic needs of students. They can be designed to help individuals gain knowledge about fulfilling these needs, they can inform individuals about the unfulfilled needs of others, and they can present the problems and possibilities associated with fulfilling human needs. The policy has a universal nature. All individuals have basic needs. Food and the development of a personal identity are both needs. Individuals in developed nations often think that alleviation of hunger and freedom from disease are the only basic needs in developing countries. The hierarchy of needs makes it clear that individuals in all nations are influenced by needs, though the needs may be different from one individual to the next and from one country to the next. A principal function of any society is to fulfill the needs of its citizens.

Science educators recognize only part of the problem, however, by presenting ideas that can help fulfill basic human needs. In *State of the World* (1990), Lester Brown and his colleagues clarify the role of values:

> In the end, individual values are what drive social changes. Progress toward sustainability thus hinges on a collective deepening of our sense of responsibility to the earth and to future generations. Without a re-evaluation of our personal aspirations and motivations, we will never achieve an environmentally sound global community. (Brown et al. 1990, p. 175)

To have any effect, policies must include both ideas and values, and it is essential that the values are compatible with the policy and serve to direct personal decisions toward achieving and maintaining sustainable growth. The values of justice and beneficence underlie the policy designed to fulfill basic human needs. With resource scarcity and a majority of world citizens with unfulfilled basic needs such as food, developed countries can no longer afford unnecessary goods and over consumption, even in the cause of economic growth and the claims that all people are living a better life relative to the past.

Achieving this aim requires beneficence toward others, a value that can restrain personal consumption and encourage greater sharing. In turn, justice encourages the fair and equitable distribution of goods and services. This policy is more than an appeal to altruism. Adoption of green lifestyles that make use of appropriate goods and services in developed countries not only helps those in less developed countries, it also better fulfills our own actual needs.

The second policy for programs and practices is designed to care for and improve the natural environment. Air, water, and soil are the common heritage of humankind, and they are essential to fulfilling basic needs. Many individuals perceive the environment as a receptacle of unlimited capacity to receive and degrade waste. But environmental systems are limited. The negative synergistic effects of pollution are becoming clearer every day. Realizing our dependence on the environment establishes a moral obligation to both ourselves and to future generations to see that the environment can sustain life. Education programs should enable individuals to make informed decisions and take appropriate actions, in the short and long terms, to maintain and improve the physical environment.

The third policy concerning the conservation and wise use of resources is closely related to improvement of both the physical environment and to fulfillment of both the physical environment and to fulfillment of basic needs. Just as we once believed in the limitless capacity of the environment to degrade waste, so too we once thought that resources were unlimited. They are not. Education for sustainable development will inform students of the need for resources, transitions to renewable resources, and the conservation of nonrenewable resources.

If one perceives the environment and resources as unlimited, then it is not necessary to make value judgments about their use. The aim of sustainable development has an ecological ethic grounded in the idea of limited environmental capacities and limited depletion of resources. This, in a word, is use based on prudence. Likewise, those with a vision of sustainability must think of themselves as stewards: managers and administrators of our natural environment.

The fourth, and final, policy is to develop increased positive and constructive interactions among people through education. This policy is directed toward establishing a greater sense of community. If fulfillment of human needs and improvement of the environment and conservation of resources are to become realities, we must increase community involvement and cooperative participation at all levels, from local to global. One of the first steps toward productive personal interaction is the elimination of prejudicial barriers to community. Specifically, educational programs should strive to reduce prejudice, such as racism, sexism, ethnocentrism and nationalism. As long as one individual, group, or nation has a need to dominate another, the opportunities for harmonious living are reduced, and the possibilities for disastrous conflict are increased. Establishing a greater sense of community is clearly a prerequisite related to achieving the other three policies.

Cooperation and mutual regard are values essential for effective implementation of the fourth policy concerning growth and sustainable development. Inevitably, conflicts will arise among the crucial choices inherent in managing sustainable development. Societies can no longer afford to hold military force as the dominant means for resolving conflicts because force is ultimately divisive, and results in destructive, not constructive, resolution of conflicts. Cooperative interaction is essential if all parties to a conflict are to achieve their goals and sustain a positive relationship. Finally, there is a profound need for a universal recognition of human rights and compassion for others. This is the value of mutual regard for each other now and consideration for future generations of humankind.

The educational policies form a coordinated system of ideas and values supporting sustainable development. These policies would facilitate sustainable development while preserving personal freedom and minimizing governmental control. Education based on these policies could simultaneously produce changes in the ideas and values of individuals and implement means of regulating social change. Regulations, however, would not necessarily be the unilateral imposition of rules and laws by an authority on the majority. They would be, to use Garrett Hardin's phrase from his classic article "Tragedy of the Commons," "mutual cohesion mutually agreed upon" (Hardin 1968). Two factors justify this assertion. First, the ideas (needs, environment, resources and community) and the values (justice, beneficence, stewardship, prudence, cooperation and mutual regard) are sources of personal obligation as well as sources of social regulation. Individuals with these ideas and values would be inclined to make informed decisions concerning their needs, the needs of others, the environment and resources; practice self-restraint and self-reliance as necessary; and participate in the democratic development of rules based on the concept of sustainability. Second, a specific type of obligation is also inherent in the ideas and values. The obligation is reciprocal. The concern is not only for oneself but for other people and their environments and resources.

Educational programs that emphasize a sense of reciprocal obligation would develop an individual's sense of duty to others and the natural environment. Obligation alone can be engendered through social rules and laws. But this type of obligation is unilateral and can easily become little more than obedience to authority. This tendency is reduced, but not eliminated, through reciprocity among people who respect each other and their environment. Many individuals in social groups are reciprocally obligated to each other, so this idea is neither uncommon nor unachievable. Reciprocal obligations are grounded in empathizing with other people, coordinating efforts to solve problems, recognizing different points of view, balancing good and bad, and cooperating in the resolution of conflict. Humankind must take this direction if it is to avoid human ecological catastrophes and develop patterns of sustainable development.

So, the educational policies proposed here converge on the goal of sustainability and preservation of personal freedom through development of reciprocal obligation. The view presented here follows a course of least restrictive regulation on the individual based on the possibility of changing personal ideas and values through education. In other words, regulations would increasingly influence the decisions of those individuals whose ideas and values are aligned with the old vision of industrial growth. An individual's freedom would be maintained to the degree education achieves the described policies, thus developing personal ideas and values supporting sustainable growth. Education would create a dynamic interaction between self-restraint and social restriction and that interaction would maximize personal freedom while achieving sustainable development.

Conclusion

In the early years of the 21st century, the science education community must respond to several challenges, one of which is helping citizens develop a greater knowledge and appreciation for resources and environmental issues. The PISA 2006 science assessment helps policy makers and educators understand the contemporary knowledge and perceptions of 15-year-olds. Insights from PISA 2006 are not so much an evaluation of the current situation, as they provide indications of the future and how well students will function as citizens who must apply their understanding and abilities to new and unique situations, including those related to natural resources and the environment.

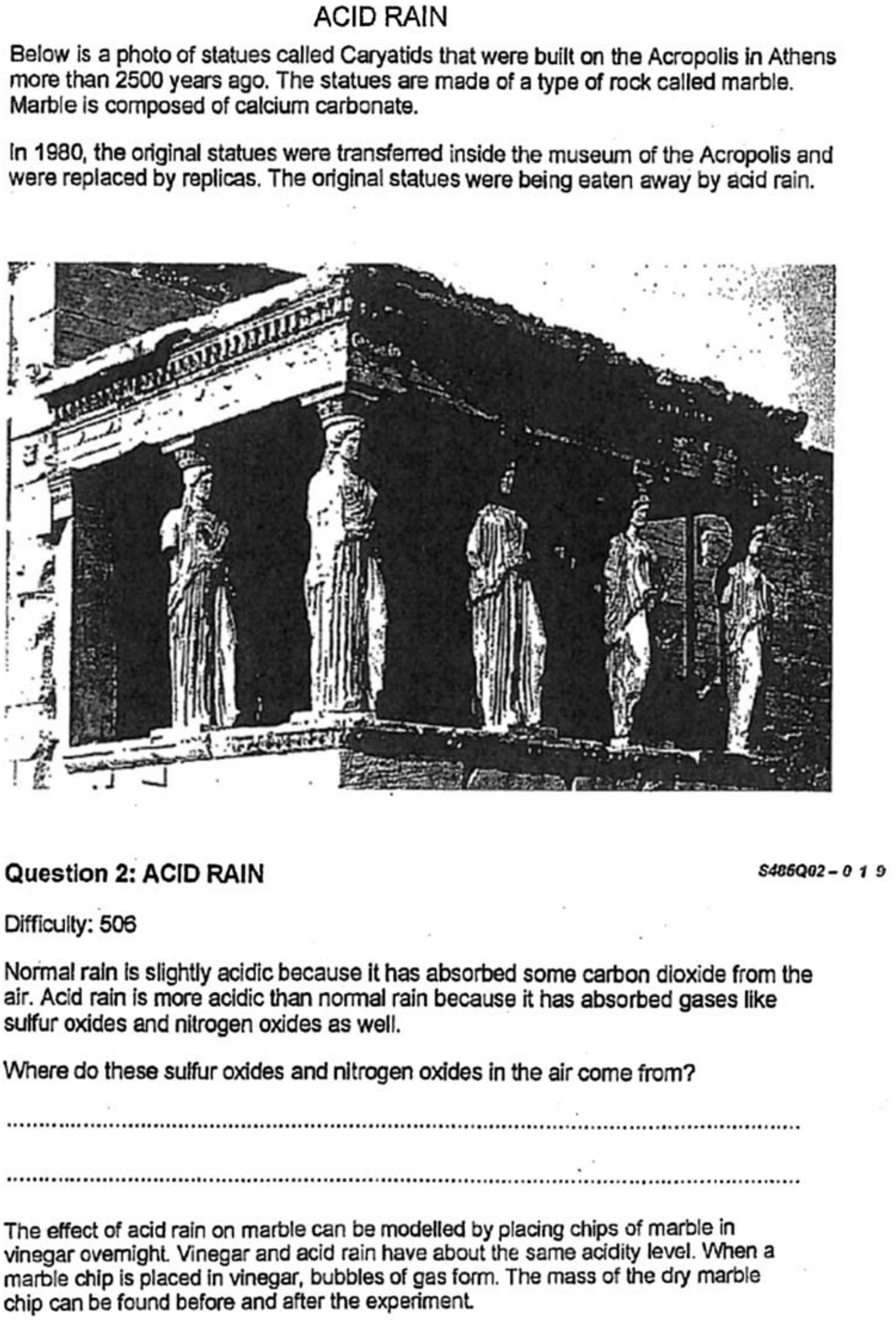
Today, the importance of understanding natural resources and the environment is even more important than it was last year, a decade, or 50 years ago. Being scientifically literate about resources and the environment is essential to all citizens, not only in the U.S. but in the global community.

In an earlier section, I quoted E.O. Wilson who used an economic metaphor in describing the environmental situation and his proposed solution. The contemporary perspective I have described shows the intellectual and attitudinal investment of 15-year-olds. And the science education community should take note of their knowledge and values.

A sound understanding of the dividends on the investment in scientific literacy accrues to all students in the form of enhanced learning and achievement. Science teachers, however, control the rate of interest and, therefore, the potential to increase the investment. The interest rates, and thus dividends, are largely determined by the degree to which the teaching includes challenging science content, increased curricular coherences, and greater congruence with personal, social, and global contexts. To end with an insight from Paul F-Brandwein—we must renew and double efforts to facilitate students' interdependence with nature and responsibility for sustaining a healthy and healing environment.

Appendix I: Acid Rain

PISA 2006—Science—Released Unit and Items



ACID RAIN

Below is a photo of statues called Caryatids that were built on the Acropolis in Athens more than 2500 years ago. The statues are made of a type of rock called marble. Marble is composed of calcium carbonate.

In 1980, the original statues were transferred inside the museum of the Acropolis and were replaced by replicas. The original statues were being eaten away by acid rain.

Question 2: ACID RAIN *S485Q02 – 0 1 9*

Difficulty: 506

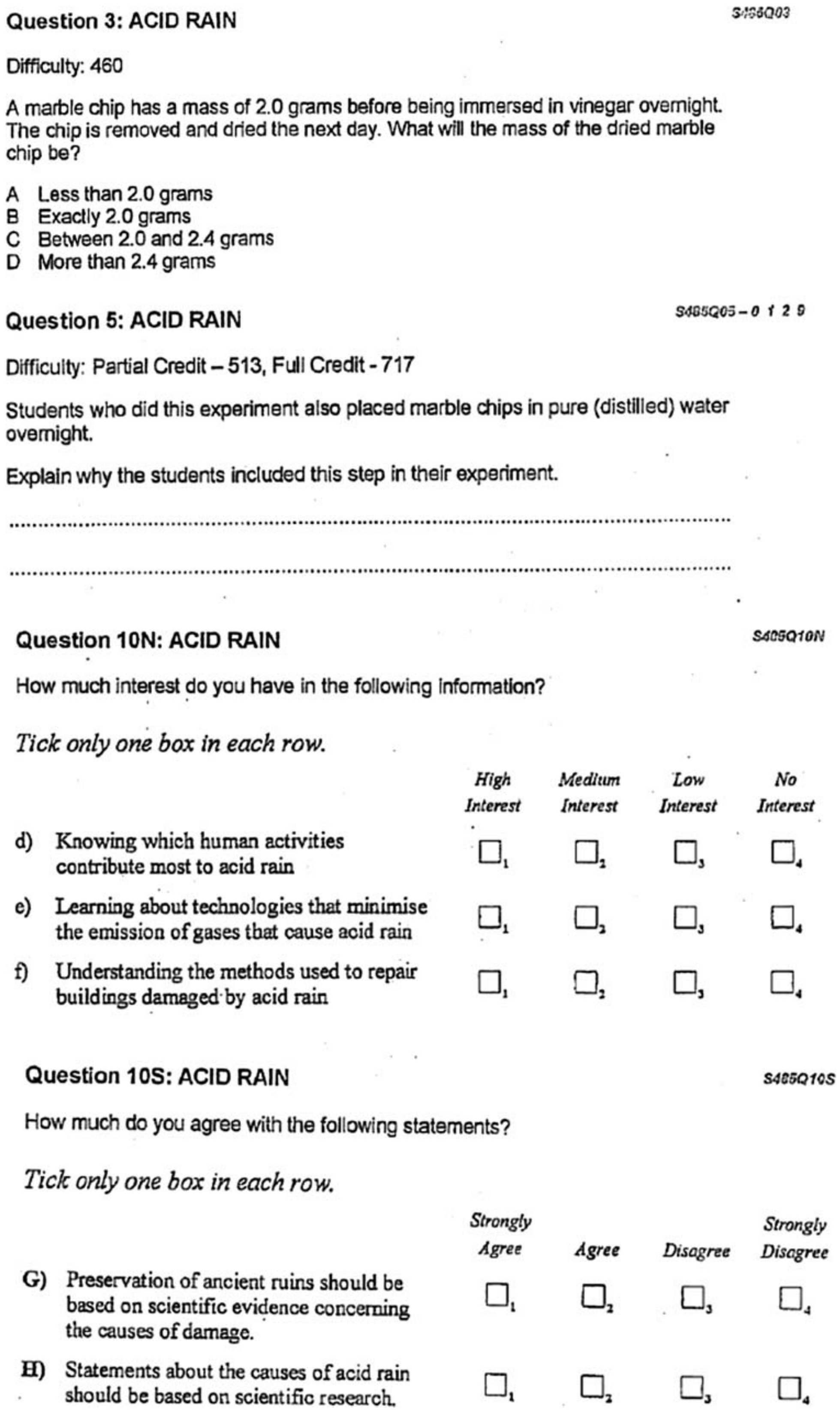
Normal rain is slightly acidic because it has absorbed some carbon dioxide from the air. Acid rain is more acidic than normal rain because it has absorbed gases like sulfur oxides and nitrogen oxides as well.

Where do these sulfur oxides and nitrogen oxides in the air come from?

……………………………………………………………………………………………………

……………………………………………………………………………………………………

The effect of acid rain on marble can be modelled by placing chips of marble in vinegar overnight. Vinegar and acid rain have about the same acidity level. When a marble chip is placed in vinegar, bubbles of gas form. The mass of the dry marble chip can be found before and after the experiment.



Question 3: ACID RAIN S485Q03

Difficulty: 460

A marble chip has a mass of 2.0 grams before being immersed in vinegar overnight. The chip is removed and dried the next day. What will the mass of the dried marble chip be?

A Less than 2.0 grams
B Exactly 2.0 grams
C Between 2.0 and 2.4 grams
D More than 2.4 grams

Question 5: ACID RAIN S485Q05 – 0 1 2 9

Difficulty: Partial Credit – 513, Full Credit - 717

Students who did this experiment also placed marble chips in pure (distilled) water overnight.

Explain why the students included this step in their experiment.

....

....

Question 10N: ACID RAIN S485Q10N

How much interest do you have in the following information?

Tick only one box in each row.

	High Interest	*Medium Interest*	*Low Interest*	*No Interest*
d) Knowing which human activities contribute most to acid rain	☐$_1$	☐$_2$	☐$_3$	☐$_4$
e) Learning about technologies that minimise the emission of gases that cause acid rain	☐$_1$	☐$_2$	☐$_3$	☐$_4$
f) Understanding the methods used to repair buildings damaged by acid rain	☐$_1$	☐$_2$	☐$_3$	☐$_4$

Question 10S: ACID RAIN S485Q10S

How much do you agree with the following statements?

Tick only one box in each row.

	Strongly Agree	*Agree*	*Disagree*	*Strongly Disagree*
G) Preservation of ancient ruins should be based on scientific evidence concerning the causes of damage.	☐$_1$	☐$_2$	☐$_3$	☐$_4$
H) Statements about the causes of acid rain should be based on scientific research.	☐$_1$	☐$_2$	☐$_3$	☐$_4$

Appendix II: Green House

PISA 2006—Science—Released Unit and Items

GREENHOUSE

Read the texts and answer the questions that follow.

THE GREENHOUSE EFFECT: FACT OR FICTION?

Living things need energy to survive. The energy that sustains life on the Earth comes from the Sun, which radiates energy into space because it is so hot. A tiny proportion of this energy reaches the Earth.

The Earth's atmosphere acts like a protective blanket over the surface of our planet, preventing the variations in temperature that would exist in an airless world.

Most of the radiated energy coming from the Sun passes through the Earth's atmosphere. The Earth absorbs some of this energy, and some is reflected back from the Earth's surface. Part of this reflected energy is absorbed by the atmosphere

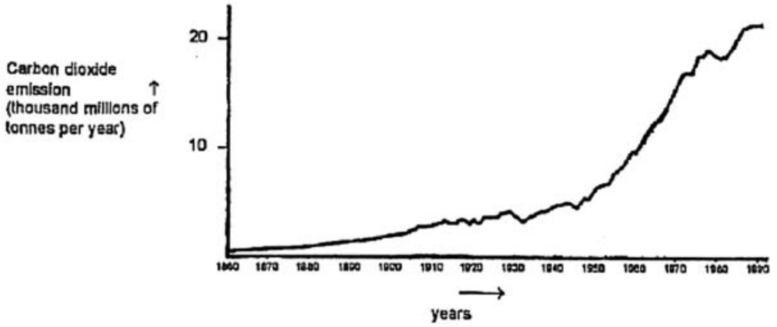
As a result of this the average temperature above the Earth's surface is higher than it would be if there were no atmosphere. The Earth's atmosphere has the same effect as a greenhouse, hence the term *greenhouse effect*.

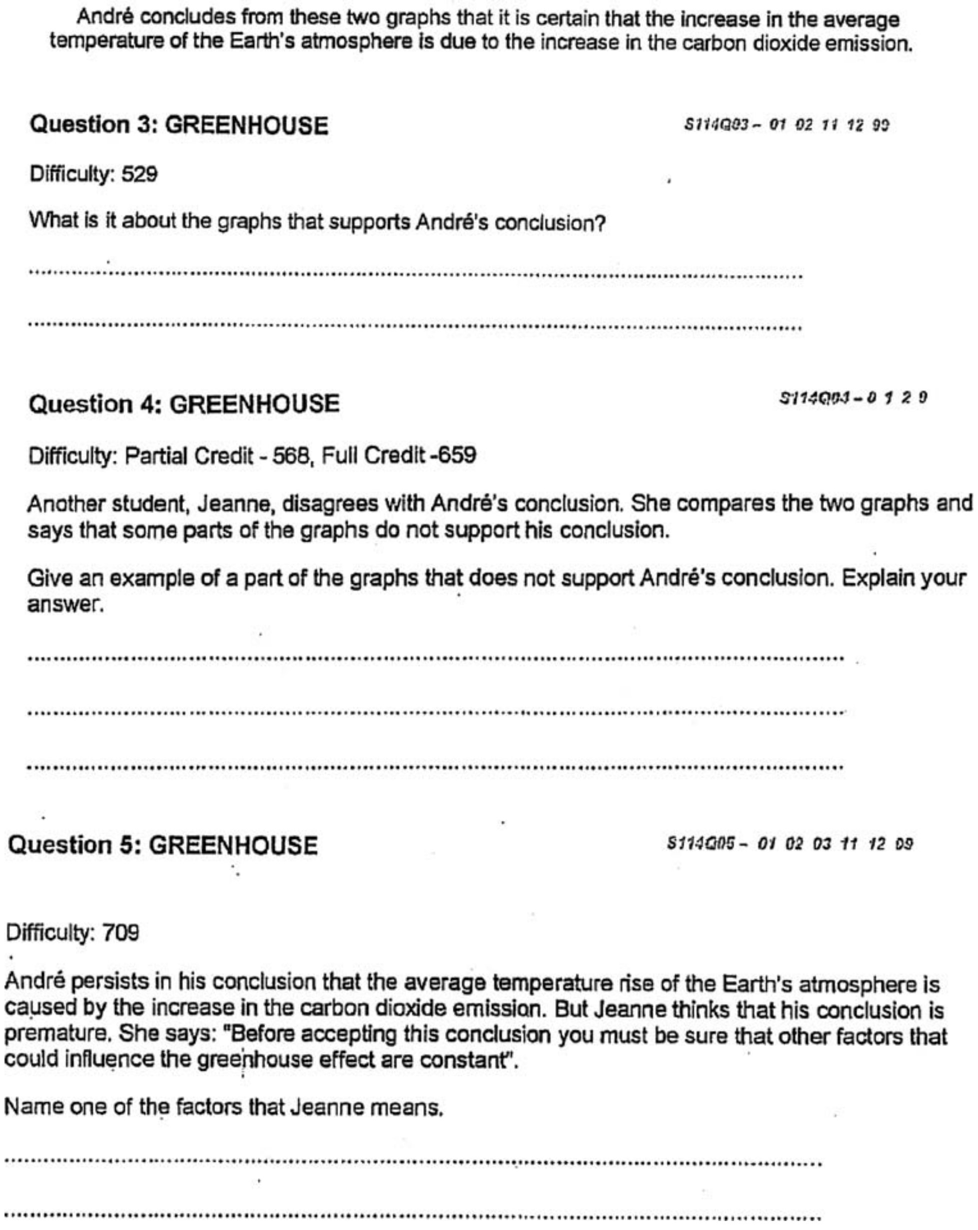
The greenhouse effect is said to have become more pronounced during the twentieth century.

It is a fact that the average temperature of the Earth's atmosphere has increased. In newspapers and periodicals the increased carbon dioxide emission is often stated as the main source of the temperature rise in the twentieth century.

A student named André becomes interested in the possible relationship between the average temperature of the Earth's atmosphere and the carbon dioxide emission on the Earth.

In a library he comes across the following two graphs.





André concludes from these two graphs that it is certain that the increase in the average temperature of the Earth's atmosphere is due to the increase in the carbon dioxide emission.

Question 3: GREENHOUSE S114Q03 – 01 02 11 12 99

Difficulty: 529

What is it about the graphs that supports André's conclusion?

....

....

Question 4: GREENHOUSE S114Q04 – 0 1 2 9

Difficulty: Partial Credit - 568, Full Credit -659

Another student, Jeanne, disagrees with André's conclusion. She compares the two graphs and says that some parts of the graphs do not support his conclusion.

Give an example of a part of the graphs that does not support André's conclusion. Explain your answer.

....

....

....

Question 5: GREENHOUSE S114Q05 – 01 02 03 11 12 99

Difficulty: 709

André persists in his conclusion that the average temperature rise of the Earth's atmosphere is caused by the increase in the carbon dioxide emission. But Jeanne thinks that his conclusion is premature. She says: "Before accepting this conclusion you must be sure that other factors that could influence the greenhouse effect are constant".

Name one of the factors that Jeanne means.

....

....

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