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ABSTRACT

This document discusses reflections of the old and new millennium on education that capture the basic spirit of science. The explanation includes basic scientific ideas in physical sciences, earth systems, solar system and space; living systems; basic scientific thinking; the basic distinction between science and technology; basic connections between science and democratic ideals; and basic contexts for science and technology in society. (Contains 18 references.) (YDS)

The New Millennium and Education That Captures the Basic Spirit of Science

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Paper presented at the Annual Meeting of the Australian Science Teachers Association (Adelaide, South Australia July 4-9, 1998)

The New Millennium and an Education that Captures the Basic Spirit of Science

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With sufficient historical perspective, I predict that historians will make at least three significant observations about the twentieth century, and especially the old millennium. First, it would be difficult to imagine any historical perspective of the past one hundred years without highlighting science and technology. For example, in a survey of journalists and historians who were asked to select the top 100 news stories of the twentieth century, 45 percent of the stories were related in some way to science and technology (see Table 1).

Second, because of technological advances in communication and travel, the size of the globe has, in effect, been reduced to a community within which many of its citizens know about significant events almost instantaneously. Such information may be good news or bad, about advances in science and technology, or about natural disasters, civil strife and cultural conflicts. Awareness of global issues is only a first step in understanding and managing ourselves in a global community while striving for increased global harmony.

Third, historians would have to note the rise of constitutional democracy. This idea has spread from a vision of political thinkers to a reality in many countries that originally had very different forms of government; ones that had denied citizens of political liberties and some of the fundamental freedoms required of the scientific enterprise.

Table 1. Top Science- and Technology-Related News Stories of the Twentieth Century*

Rank for Science and Technology	Overall Rank in Top 100 Stories	Year	Headline
1	1	1945	US drops atomic bombs on Hiroshima, Nagasaki; Japan surrenders to end World War II.
2	2	1969	American astronaut Neil Armstrong becomes the first human to walk on the moon
3	4	1903	Wilbur and Orville Wright fly the first powered airplane
4	11	1928	Alexander Fleming discovers the first antibiotic, penicillin
5	12	1953	Structure of DNA discovered
6	17	1913	Henry Ford organizes the first major U.S. assembly line to produce Model T cars
7	18	1957	Soviets launch Sputnik, first space satellite: space race begins

8	19	1905	Albert Einstein presents special theory of relativity: general relativity theory follows soon after
9	20	1960	FDA approves birth control pill
10	21	1953	Dr. Jonas Salk's polio vaccine proven effective in University of Pittsburgh tests
11	25	1981	Deadly AIDS disease identified
12	28	1939	Television debuts in America at New York World's Fair
13	30	1927	Charles Lindbergh crosses the Atlantic in first solo flight
14	31	1977	First mass market personal computers launched
15	32	1989	World Wide Web revolutionizes the Internet
16	33	1948	Scientists at Bell Labs invent the transistor
17	35	1962	Cuban missile crisis threatens World War III
18	36	1912	'Unsinkable' Titanic, largest man-made structure, sinks
19	40	1909	First regular radio broadcasts begin in America
20	41	1918	Worldwide flu epidemic kills 20 million
21	42	1941	'ENIAC' becomes world's first computer
22	43	1946	Regular TV broadcasting begins in the U.S.
23	46	1909	Plastic invented: revolutionizes products, packaging
24	48	1945	Atomic bomb tested in New Mexico
25	51	1959	American scientists patent the computer chip
26	52	1901	Marconi transmits radio signal across the Atlantic
33	78	1900	Max Planck proposes quantum theory of energy
34	79	1997	Scientists clone sheep in Great Britain
35	80	1956	Congress passes interstate highway bill
36	81	1914	Panama Canal opens, linking the Atlantic and Pacific Oceans
37	83	1986	Space Shuttle Challenger explodes killing crew, including school teacher Christa McAuliffe
38	86	1900	Sigmund Freud publishes The Interpretation of Dreams
39	90	1962	John Glenn becomes first American to orbit the earth
40	92	1997	Pathfinder lands on Mars, sending back astonishing photos
41	95	1978	Louise Brown, first "test-tube baby," born healthy
42	97	1975	Bill Gates and Paul Allen start Microsoft Corp. to develop software for Altair computer
43	98	1986	Chernobyl nuclear plant explosion kills more than 7,000
44	99	1925	Teacher John Scopes' trial pits creation against evolution in Tennessee
45	100	1964	The U. S. Surgeon General warns about smoking-related health hazards

*These stories were taken from a list of the top 100 news stories of the twentieth century. I have provided each ranking on that list. This list represents the results of a survey of journalists and historians.

Thinking about the change from the old millennium to the new millennium centers on human contributions, both positive and negative, to Earth's history. If humans were not here, there would be no ado about the event because there would not be *an* event. This, however, is not the case. We are here, and looking forward to the year 2000 presents a rather grand opportunity to think about both the past and the future. This essay arises from the opportunity to pause and reflect on the recent past, immediate future, and an education that captures the basic spirit of science. Lest you not be disappointed, my perspective is evolutionary, not revolutionary. I do not think there will be a new and unexpected perspective that emerges in January 2000. Rather, there will be steady selection from a variety of scientific ideas, technological innovations, there will be continued science- and technology-related issues, and there will be a steady elaboration of local, national, and global perspectives and a need for greater community and civil discourse. All of these have implications for science education.

Capturing the basic spirit of science

What might be meant by the basic spirit of science? Several themes emerge as answers to this question. First, for purposes of this discussion, spirit does not mean a supernatural being. The phrase "capturing the basic spirit of science" certainly could refer to other commonly understood usages: the essential and activating principles of science, the qualities and inclinations that differentiate science from other disciplines, or the real sense or significance of science as a discipline.

If we begin with the phrase, "the basic spirit of science" and accept that it means some essential principles and activating qualities of the discipline, then what is implied for science education? What is in an education that captures the basic spirit of science? The answer that I propose includes (1) basic scientific ideas that help students understand and explain the natural world, (2) basic ideas and abilities about the procedures of scientific inquiry, (3) distinctions between science and technology, (4) contexts for science and technology in society, and *(5)* understanding connections between science and democratic ideals. Taken together, this set of goals establishes a foundation for scientific literacy (Bybee, 1997), an aim for all students.

Basic scientific ideas

The cultural contributions of science rest on a set of major ideas about the natural world. One could make this claim for the past millennium, but the cultural contributions of science become clearest with the Age of Enlightenment, generally the late seventeenth and eighteenth century. A host of names associated with the Enlightenment and major scientific ideas can be listed, for example, Newton, Linnaeus, Lavoisier, and Hutton. I should briefly note that scientific thinking of the Enlightenment also influenced my theme of constitutional democracy, particularly in America (Commager, 1977; Wills, 1978). If we only examine the scientific advances of the past 100 years, we get a sense of several major ideas that help us explain the natural world, for example, discovering the structure of DNA and proposing the quantum theory of energy. Or, in other cases, we see an understanding of a major idea, such as the germ theory of disease applied to a contemporary problem, discovering the first antibiotic penicillin, or identification of AIDS (refer to Table 1).

Proposing that school science curriculum emphasize major scientific ideas is not unique (Bybee, 1997; DeBoer, 1991; Rutherford & Ahlgren, 1989; NRC, 1996). The traditional categories of physical, life, and Earth science accommodate the major ideas. In most cases, the science curriculum includes these categories and even the major ideas. However, recommending that students develop some

understanding of basic scientific ideas encompasses much more than the numerous topics, terms, labels, and details that one finds in most contemporary science curricula.

Contemporary science consists of a vast body of knowledge ranging from quarks to cosmology. The details of scientific disciplines stagger the mind of many scientists, not to mention students. So, a first step in capturing the spirit of basic scientific ideas in school curriculum is to acknowledge the fact that educators do not have to include everything. A second step is recognizing that school science does not have to address the "frontiers" or "cutting edge advances" in science. After all, these are based on, and elaborations of, major scientific ideas that guide inquiry and if students do not understand the basic ideas that knowledge associated with frontiers will have little or no meaning. The third step is acceptance that regardless of what is included on the list of basic ideas for school science curriculum, one will be criticized for not including other ideas that individuals also claim as basic.

Capturing the basic spirit of science requires educators to provide students with opportunities to learn a set of major ideas that will help learners explain the natural world. Table 2 lists major ideas for science curriculum. My inclination was to base the ideas in this table exclusively on the *National Science Education Standards* (NRC, 1996) or *Benchmarks for Science Literacy* (AAAS, 1993). I did not, however, do this. I used these and other resources (Trefil & Hazen, 1995; Millar & Osborne, 1998) as the basis for a presentation of basic scientific ideas – one that opens the option of historical as well as contemporary presentation of the ideas.

Physical systems

Energy

Basic Idea: The different kinds of energy are interchangeable, and the total amount of energy in an isolated system is conserved.

Curriculum Topics: Types of energy, transfer of energy, interactions of matter and energy, conservation of energy.

Basic Idea: Energy always goes from a more useful to a less useful form. Curriculum Topics: Heat and temperature, heat transfer, the second law of thermodynamics.

Basic Idea: Electricity and magnetism are two different aspects of the electromagnetic force.

Curriculum Topics: Electricity, magnetism, electric circuits, electrical effects from magnetism, magnetic effects from electricity.

The Atom

Basic Idea: All matter is made of atoms. They are chemical building blocks of nature.

Curriculum Topics: Structure of atoms, light and matter, the periodic table.

Basic Idea: Atoms bind in chemical reactions through the rearrangement of electrons.

Curriculum Topics: Types of chemical bonds, electron shells, states of matter, chemical reactions and energy.

Basic Idea: Properties of materials result from the atoms of which it is composed and the arrangement of chemical bonds among the atoms.

Curriculum Topics: Electrical properties of materials, magnetic properties of materials.

Basic Idea: Nuclear energy depends on the conversation of mass.

Curriculum Topics: The atomic nucleus, radioactivity, mass and energy, fission, fusion.

Earth Systems

Earth in Space

Basic Idea: Newton's laws of motion and gravity predict the behavior of objects on Earth and in space.

Curriculum Topics: Observations and ideas of Nicolaus Copernicus, Tycho Brahe, Johannes Kepler, Galilei Galileo, Isaac Newton, universal laws of motion, universal force of gravity.

Basic Idea: The Earth formed *4.5* billion years ago from a cloud of dust. Curriculum Topics: The solar system, nebular hypothesis, evolution of the Earth and moon.

Solar System and Space

Solar System

Basic Idea: The Earth is one of nine planets that orbit the sun.

Curriculum Topics: Rotation and revolution of Earth and planets, features of the planets, evolution of planetary atmosphere, other solar objects (asteroids, comets, meteors), Newton's laws.

The Stars

Basic Idea: Stars convert mass to energy through nuclear fusion. When the nucleus fuel is depleted, it "dies"

Curriculum Topics: Classification of stars, the life cycle of stars.

Space

Basic Idea: The universe began billions of years ago in the big bang, it has been and will continue to expand

Curriculum Topics: Red shift, Hubble's law, The Big Bang, evolution of the universe.

Living Systems

Organisms

Basic Idea: Living systems obey the basic laws of nature

Curriculum Topics: Unity and diversity of organisms, classifying organisms, diversity of living systems and adaptation.

Basic Idea: Living systems have evolved many different strategies to acquire matter and energy, respond to environmental changes, eliminate waste, and reproduce.

Curriculum Topics: Matter, energy, and organization of living systems, behavior of organisms.

Basic Idea: The human organism is both similar to and unique among the Earth's living systems.

Curriculum Topics: The human body, interrelated organ systems, prevention of disease and maintenance of health, the human genome, human ecology, human development and learning.

Organisms

Basic Idea: Cell structures underlie cell functions, the structures are composed of simple molecular building blocks.

Curriculum Topics: Organic molecules, proteins, nucleic acids.

Basic Idea: Cell functions involve chemical reactions.

Curriculum Topics: Food molecules, enzymes, metabolism.

Basic Idea: Cell functions are regulated through changes in functions performed by proteins and through expressions of individual genes.

Curriculum Topics: Environmental response, control and coordination of cell growth and division, mitosis, melosis.

Basic Idea: Plant cells contain chloroplasts. the site of photosynthesis. Curriculum Topics: Photosynthetic process, connections between the sun and the energy needs of living systems.

Genetics

Basic Idea: In all living systems, instructions for specifying characteristics of the organism are carried on DNA.

Curriculum Topics: Classical genetics, replication, transcription, protein synthesis, mutations, expression of genes.

Evolution

Basic Idea: Overtime, species have evolved through natural selection. Curriculum Topics: Interactions of population growth, genetic variation, supply of resources required of life, and selection by environment.

Interdependence

Basic Idea: Interdependent collections of organisms recycle matter while energy flows through the biosphere.

Curriculum Topics: Living and nonliving components of biosphere, energy flow, cooperation and competition.

In addition, I use a systems perspective combined with the traditional physical, boundaries of the disciplines are not as clear as they once were. it is extremely difficult for learners (and many teachers) to integrate the disciplines out of some context, such as a social issue. Third, the content of a discipline is too large for most scientists to embrace, so we need not hold the view that students should learn all the details of a discipline. Finally, introducing students to the idea of systems as units of study that take their integrity and form from the ongoing interaction of component parts, will greatly enhance their ability to develop some understanding of the basic ideas and to find meaningful patterns in their world.

Emphasizing basic scientific ideas has some support from the research literature on the difference between experts and novices and how they conceptualize and solve problems. Expert knowledge is not simply a list of facts and formulas relative to their discipline. Their knowledge is organized by fundamental concepts or what I refer to here as "basic scientific ideas" (NRC, 1999), for example, Newton's laws, theory of evolution, or energy in Earth systems. The implication seems clear, curriculum materials designed for these learning outcomes should be organized in ways that result in

conceptual understanding (NRC, 1999). Too often, the curriculum has only superficial coverage and emphasizes memorization of facts with understanding.

Basic scientific thinking

The spirit of science of necessity includes the procedures of science, that is the basic scientific thinking usually referred to as inquiry. Including scientific inquiry in school programs presents an opportunity to help young people develop both an understanding of inquiry and the abilities of scientific inquiry. Based on their investigations, students can develop critical thinking and reasoning that characterizes process by which claims by scientists result in new knowledge. Having classroom experiences with scientific inquiry provides insights into the procedures of science, what differentiates science from other ways of knowing, and reinforces some practical abilities such as critical thinking and communicating. Table 3 presents the abilities and understandings of inquiry for grades 5-8 from the *National Science Education Standards* (NRC, 1996).

Table 3. Science as Inquiry Grades *5-8*

Abilities Necessary to Do Scientific Inquiry	Understandings about Scientific Inquiry
Identify questions that can be answered through scientific investigation,	Different kinds of questions suggest different kinds of scientific investigations.
Design and conduct a scientific investigation.	Current scientific knowledge and understanding guide scientific investigations.
Use appropriate tools and techniques to gather, analyze, and interpret data.	Mathematics is important in all aspects of scientific inquiry.
Develop descriptions, explanations, predictions, and models using evidence,	Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.
Think critically and logically to make the relationships between evidence and explanation.	Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories.
Recognize and analyze alternative explanations and predictions.	Science advances through legitimate skepticism.
Communicate scientific procedure and explanations. 'Use mathematics in all aspects of scientific Inquiry.	Scientific investigations sometimes result in new ideas and phenomena for study, generate new methods or procedures for investigation, or develop new techniques to improve the collection of data.

Table 3 describes the abilities and understandings of scientific inquiry. It only seems reasonable that helping students formulate those abilities and understandings would be based on a variety of inquiry-based experiences that are a part of the science curriculum. With inquiry-based activities, students can develop an appreciation for the difficulties of designing an investigation; the hurdles of obtaining accurate, valid, and reliable data; the challenges of establishing cause and effect relationships; and the struggles of using evidence to form explanations.

Although essential for developing abilities and understanding of scientific inquiry, more than "hands-on" activities may be required for students to develop a full appreciation of inquiry. Historical case studies relative to some of the basic scientific ideas and contemporary examples can point out the subtle variety and challenges of scientific inquiry. The top news stories of the twentieth century supply excellent examples and cases. Students can learn a great deal from narrative stories about the

discovery of DNA structure, Einstein's development of the theory of relativity, and the invention of the transistor. Such stories present a holistic view of inquiry that students may not gain in other classroom activities.

Basic distinctions between science and technology

Most individuals do not make a distinction between science and technology. The two entities are at best largely seen as one and at worst totally confused. Actually, science and technology are closely related in the discoveries and inventions that most people recognize. In this sense, a distinction may well be artificial. Most scientific inquiry involves the use of some technological device in order to enhance data gathering and most engineering design has to recognize the fundamental laws of nature. This said, I first

argue that it is important to include some introduction to technology in the science curriculum. Such a view is neither new nor unique (Fensham, 1992; AAAS, 1993; NRC, 1996). 1 also argue that it is important to separate the two for pedagogical reasons. Children and most young adults can easily grasp some of the fundamental distinctions if they experience activities that represent scientific inquiry and technological design. What are some of the basic distinctions between science and technology? Figure 1 shows the relationships between science and technology.

Scientific inquiry begins with questions and uses evidence to propose explanations for observations about the natural world. Students might ask questions, such as: How do earthquakes occur? What causes the difference in seasons in the Northern and Southern Hemispheres? Why do some organisms of the same species show variations? Although these questions may seem elementary, the nature of many questions asked by students and scientists is similar; that is, the questions are about phenomena occurring in the natural world.

As scientists answer questions, they employ recognized, though variable, methods of rational inquiry. For example, scientists propose explanations based on evidence derived from observations. Historically, those observations were direct, now many are made using technology.

The word "propose" suggests that scientific explanations are tentative, which is a fundamental tenet in science. Scientific explanations are subject to change and do not

purport to be the final truth. The word "propose" also suggests that scientists make their explanations known to others; that is, the explanations are made public through presentations at professional meetings and publication in refereed journals.

Technology extends the human ability to change the world (Rutherford & Ahlgren, 1989), but the impulse for change originates in the need for humans to adapt to the world. Some technology is an expression of human aspirations, for example, art. This, too, can be thought of as adaptation. Technology often originates in problems of human adaptation to the environment (Figure 1). This adaptation is non-biological. Humans need air, water, food, and safety. They need to move objects and information and need to build shelters and bridge rivers. These and other historical examples of technology, such as the development and use of tools, agriculture, weapons, and compasses, illustrate the origin of technologies in issues of human adaptation.

There are many possible technological solutions to problems of human adaptation, so objectives and requirements must inevitably be considered. Some variables are constraints, such as availability of materials, properties of materials, scientific laws, and cultural requirements. Other variables include cost, benefit, risk, and environmental impact. Engineers often complete several designs for a single project so they can assess trade-offs between constraints and variables before deciding on the best

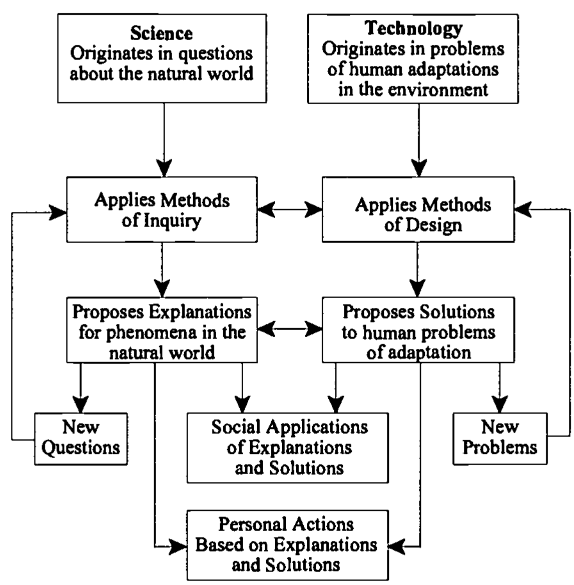
solution. Although the methods of scientific inquiry and technological design have many common elements, technological design is distinguished by a focus on issues, such as constraints, control, materials, cost-risk-benefit analysis, and decision making.

As the center arrows in Figure 1 indicate, there are interactions between the methods of inquiry and design strategies and between scientific explanations and technological solutions. For example, technology depends on accurate scientific information and cannot contravene scientific laws, and science depends on technology to provide instruments and capabilities that enable new or more refined observations.

Scientific and technological enterprises both result in socially beneficial products. The direct outcome of science is a better understanding of the world, whereas technological solutions are generally more tangible, taking the form of information, products, or services. In any case, individuals and society make decisions and take actions in response to these outcomes, which moves science and technology into the realm of personal use and public policy.

Science and technology also influence our perceptions about the natural and designed world. The shift from a geocentric worldview to a heliocentric one is an example of such a change. Another is the aforementioned influence of science on the political views of the Enlightenment. More recently, as science illuminated our understanding of such processes as photosynthesis and the hydrologic cycles, we had to change our perceptions about the interrelatedness of life on Earth and reconsider the effects of industrial pollution and deforestation. One needs only to review the list of top news stories in the past century or to think about computers, cell phones, fax machines, and beepers to realize how technology influences our lives.

Scientific and technological outcomes themselves raise new questions and problems. The processes represented in Figure 1 are therefore iterative and interactive. The interactions can result in the need for us to develop new explanations and solutions or amend those already developed.



Most of the public should expect that science education would introduce students to the basic differences between science and technology, how they are mutually related, and the impact technology has had on our lives. The introduction of technology into science education is in the interest of both science and technology. Table 4 provides a summary of ideas about technology that may be introduced in the science curriculum. The ideas are from an earlier report (Bybee, et. al, 1990).

- Technology is an attempt to provide rational solutions to human problems of nonbiological adaptation.
- Technological solutions are incomplete and imperfect.
- Technologies exist within the context of nature. That is, no technology can contravene biological and physical principles.
- All technologies have side effects.
- Because technologies are incomplete and imperfect, all technologies carry some risk.
- The degree to which any society depends on technology corresponds with the degree to which the society must bear the burden of risk.

Table 4. Several Fundamental Ideas about Technology

Basic contexts for science and technology in society

There stands a great paradox in this story of science and technology as the means of nurturing greater transcultural harmony. On the one hand, there is the potential of science and technology as contributors to human adaptation and to increased social harmony and on the other there are science- and technology-related problems that could result in irreversible damage to the environment, damage that may threaten human existence. The threats associated with changes in the Earth systems require an understanding of science and technology and the science and technology-related global issues that are common to the world's people, those in both less- and more-developed nations.

The list of news stories reveals that there are stories that show generally positive effects of science and technology, for instance, the polio vaccine, transistor, computer chip, and the landing of Pathfinder on Mars. One news event in the twentieth century symbolizes society's initial awareness of environmental problems and the human influence on those problems. I refer to Rachel Carson's *Silent Spring* (1962). This little book stirred a controversy at the time, but in a longer view of history, it is clear that the basic premise about the need to attend to our environment was generally accurate (refer to Table 1).

Even though newsworthy items with negative perspectives, such as DDT, Chernobyl; and other problems, such as ozone depletion, are balanced by items with a positive perspective, such as discovery of antibiotics, plastics, and explorations of space, the public image of science and technology remains mixed and the level of scientific literacy is lower than required for democratic participation (Miller, 1983). Sustaining a democracy with prominent science and technology issues requires a public that understands some of the basic ideas and thinking unique to science. In addition, they need some experience in reviewing science and technology in the context of local and global problems.

It is always tempting to suggest today's problems as content for the science curriculum. It is most productive and appropriate to use organizing principles that underlie historical, contemporary, and future problems. In addition, the ideas should apply to local as well as global problems. My nominations for this category would include: population growth, natural resources, environmental quality, and natural and human-induced hazards, and science and technology in local, national, and global perspectives (see Table 5).

If the past 100 years are an indication of what we will confront in the new millennium, science- and technology-related issues will continue. Individuals and societies will have to decide on many issues involving scientific research and the technological innovations. These decisions will not be easy. They clearly involve basic scientific and technological concepts, but such concepts are often presented in contexts where the issues, much less the solutions, are not clear. Often, individuals harbor the misconception that science can tell us what should happen. A basic education in science must extend beyond the introduction of concepts from the physical, life, and Earth sciences and help students realize the limits of science and technology relative to social issues. Decisions about major issues, such as global climate change or local land use, involve assessment of alternatives, risks, costs, and benefits. Further, and very importantly, students should have the experience of considering who benefits and who suffers, who pays and who gains, and what the perceived and actual risks are and who will bear those risks. In reviewing any science- and technology-related issues about population, resources, environments, and hazards, students will benefit from asking and answering three basic questions. Those questions are

- What can happen?
- What are the odds of it happening?
- How do scientists and engineers know what will happen?

Table 5. Organizing Principles That Underlie Historical, Contemporary, Future Problems

Population Growth

- Populations grow or decline through the combined effects of birth and deaths, and through emigration and immigration.
- Influence on birth rates and death rates include: levels of affluence, education and employment of women, infant mortality rates, costs of raising children, availability of birth control methods, and religious and cultural norms that influence decisions about family size.
- Populations can reach carrying capacity, the maximum number of individuals that can be supported by a given environment.

Natural Resources

- Human populations use resources in order to maintain and improve their existence.
- The Earth has finite resources.
- Humans use many natural systems as resources.

Environmental Quality

- Natural ecosystems provide an array of basic processes and services that affect humans.
- Materials from human societies affect physical, chemical, and biological cycles.
- Factors that influence environmental quality include: population growth, resource use, technology, and economic, political, religious, and cultural views.

Natural and Human-Induced Hazards

- Normal adjustments of Earth may be hazardous for humans.
- Human activities can enhance potential hazards.
- Some hazards are rapid and spectacular; others are slow and progressive.
- Natural and human-induced hazards present the need for humans to assess potential danger and risk.

Science and Technology in Local, National, and Global Perspectives

- Science and technology are social enterprises, but scientists and engineers can only indicate what can happen, not what should happen. The latter involves human decisions about the use of knowledge and applications of techniques and inventions.
- Understanding, basic ideas and thinking relative to science and technology should precede debate about the economics, politics, and ethics of local, national, or global challenges.
- Social issues and challenges can affect progress in science and development of technologies.
- Individuals and societies decide on proposals involving new research and the introduction of new technologies into society.

Basic connections between science and democratic ideals

Helping students develop the abilities of sound reasoning based on evidence is one connection between science and democratic ideals that should be a part of education in the new millennium. I can set the stage for this section by noting that both science and democracy progress through the resolution of differences.

The basic connection between science and democratic ideas centers on the importance of facts and evidence in the resolution of differences. Opinions provide the basis for debate, which we now recognize in terms, such as the "argument culture" (Tannen, 1998) and the "culture of complaint" (Hughes, 1993). For too many, the basis for debate is the expression and unconditional acceptance of one view, and the declaration of any other view is by definition illegitimate. This one view, one truth, runs counter to the democratic idea expressed in Thomas Jefferson's advice:

If there be any among us who would wish to dissolve this Union or change its republican form, let them stand undisturbed as monuments of the safety in which error of opinion may be tolerated where reason is left free to combat it.

A vibrant and productive democracy requires disagreement and resolution of disagreements through debate. Individuals and our legislators debate in order to decide, and they must decide in order to progress. Civil dialogue is knowing and appealing to the facts as opposed to opinions. In science, there may be several explanations for a particular phenomenon, but the explanation with the most supporting evidence will carry the day. In civil discourse, there may be different opinions in a debate, but facts and reason should carry the day.

An education that captures the spirit of science also must recognize the values and ideals that underlie the scientific enterprise. Advances of scientific knowledge are guided by values, such as respect for evidence, openness to skeptical review, public disclosure of methods and procedures. Values such as these make the enterprise work; they are values that most scientists have internalized as part of the process of doing science. In *Science and Human Values,* Jacob Bronowski (1965) expressed this view when he wrote

The society of scientists is simple because it has a directing purpose: to explore the truth. Nevertheless, it has to solve the problem of every society, which is to find a compromise between the individual and the group. It must encourage the single scientist to be independent, and the body of scientists to be tolerant. From these basic conditions, which form the prime values, there follows step by step a range of values: dissent, freedom of thought and speech, justice, honour, human dignity, and self-respect.

Science has humanized our values. Men have asked for freedom, justice, and respect precisely as the scientific spirit has spread among them. (p. 68)

The number one news story of the past century provides the context for Jacob Bronowski's insights about science and democratic ideals. Bronowski (1965) struggled with questions engaged by reviewing the ruins of Nagasaki: Has science left society with a means of destruction that it can neither undo nor master? And, has science numbed our sense of values? Bronowski comes to the conclusion that science has not left society with values that are at odds with the survival values of humankind. In fact, it is the opposite. In light of the aforementioned culture of argument and complaint, note the following view from this scientist and philosopher:

The dilemma of today is not that the human values cannot control a mechanical science. It is the other way about: the scientific spirit is more human than the machinery of governments. We have not let either the tolerance or empiricism of science enter the parochial rules by which we still try to prescribe the behaviour of nations. Our conduct as states cling to a code of self-interest which science, like humanity, has long left behind. (p. 70)

Returning to the educational theme, capturing the spirit of science should introduce students to the tolerance and empiricism of science as they engage in debates and dialogue about various science-and technology-related issues. In the midst of these debates, science teachers can introduce the scientific spirit of sceptical review always with an appeal to evidence that will temper the two sides and focus the discussion on constructive resolutions.

In our own community of science education, I would note an important perspective that has emerged as a result of the Third International Mathematics and Science Study (TIMSS). TIMSS has contributed to an increased understanding of science and mathematics education in the global community. One largely unrecognized but highly important consequence of these studies is that they have clearly established an international perspective for science educators. Although the majority of individuals are first engaged in competitive questions of achievement, in the long term, we can and have turned to questions of the curriculum, teaching, teachers' lives, and students' lives in the participating nations (Schmidt, McKnight & Raizen, 1997; NCES, 1996). One of the great-unnoticed results of TIMSS is the enlarged, international perspective the science education community has developed. This may indeed be a very nice unintended consequence of TIMSS and the basis for our own expression of the connections between science education and democratic ideals.

Conclusion

In this essay, I have advanced several ideas describing an education that captures the basic spirit of science. These ideas include the following:

- scientific ideas,
- scientific thinking,
- distinctions between science and technology,
- contexts for science and technology in society, and
- connections between science and democratic ideals.

I am not, of course, the first to identify these basic themes for science education. Rather, my aim here is to once again advance a case for these ideas as we enter the new millennium.

The new millennium is but a reason to reflect on our past and reaffirm those goals that form the basic structure of science education policies, programs, and practices. Historical perspective does reveal the increasingly vital role of science and technology in our society. Futuristic visions do suggest that science and technology will only become more necessary to the whole of society. As this occurs, it seems evident there will be a need for future citizens to understand scientific ideas and thinking. To

the degree this is accurate, it is incumbent on the science education community to provide students with experiences that capture the basic spirit of science.

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