Communicating and Learning About Global Climate Change

An Abbreviated Guide for Teaching Climate Change, from Project 2061 at AAAS

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About Project 2061

Project 2061 began its work in 1985—the year Halley's Comet was last visible from earth. Children starting school then and now will see the return of the Comet in 2061—a reminder that today's education will shape the quality of their lives as they come of age in the 21st century amid profound scientific and technological change.

A long-term initiative of the American Association for the Advancement of Science (AAAS), Project 2061's mission is to help all Americans become literate in science, mathematics, and technology. To that end, Project 2061 conducts research and develops tools and services that educators, researchers, and policymakers can use to make critical and lasting improvements in the nation's education system.

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www.Project2061.org

About AAAS

The American Association for the Advancement of Science (AAAS) is the world's largest general scientific society and publisher of the journal, *Science* (www.sciencemag.org). AAAS was founded in 1848, and serves 262 affiliated societies and academies of science, reaching 10 million individuals. *Science* has the largest paid circulation of any peer-reviewed general science journal in the world, with an estimated total readership of 1 million. The non-profit AAAS (www.aaas.org) is open to all and fulfills its mission to advance science and serve society through initiatives in science policy, international programs, science education, and more. For the latest research news, log onto EurekAlert!, www.eurekalert.org, the premier science-news Web site, a service of AAAS.

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©Cover images are courtesy of Lonnie Thompson, Ohio State University, and show the retreating Qori Kalis glacier in the Andes of Peru in 1978 (left) and in 2000 (right). The lake began to form in 1991. It's now more than 200 feet deep, covering some 84 acres.

We would like to gratefully acknowledge Timothy Eichler of the National Oceanic and Atmospheric Administration (NOAA) and Frank Niepold, a UCAR visiting scientist at NOAA Climate Program Office's education program, for their advice and contributions to this guide.

About this Guide

Dear Colleague,

When *Science for All Americans* was first published in 1989, its authors recognized that all adults would benefit personally and professionally from being science literate. They also knew that citizens who understand science and its potential would be vital to addressing some of the most pressing problems facing the nation and the world. Today, we face the challenges of global climate change—understanding the evidence for it, appreciating its potential impacts, and developing new technologies and policies that can help us adapt to it.

A first step toward preparing ourselves to meet these challenges is to ensure that all of our young people get the best possible education in science, mathematics, and technology. Only with a sound understanding of the underlying scientific concepts can people make sense of relevant real-world phenomena—such as rising sea levels; melting glaciers; and the increased likelihood of severe heat waves, floods and droughts—that are associated with global climate change. And only with an appreciation of how science works—its demand for evidence and logical arguments to support claims, its continuing search for ever more powerful theories—can they interpret and evaluate accounts of climate change in the media and elsewhere and distinguish scientific fact from opinion.

This guide is designed to give you a brief overview of Project 2061's recommendations for the relevant ideas and skills that all students should learn. Drawing on several Project 2061 resources, the guide focuses on the ideas and skills that are central to understanding the science of climate change, the process of scientific inquiry, and the trade-offs and constraints implicit in making choices about technology. For each of these topics, the guide maps out what students should be learning in kindergarten through 12th grade and describes what a science literate adult should know and be able to do.

We applaud your interest in this important issue and your efforts on behalf of the science literacy of our young people. We hope this guide will be helpful.

Sincerely,

Jo Ellen Roseman

Jo Ellen Roseman, Ph.D.
Director, Project 2061

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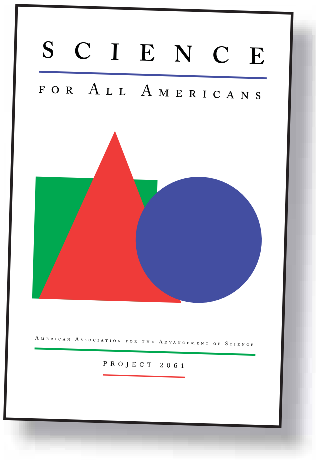


About *Science for All Americans*

With expert panels of scientists, mathematicians, and technologists, Project 2061 set out to identify what was most important for the next generation to know and be able to do in science, mathematics, and technology—what would make them science literate. *Science for All Americans* defines a science literate person as one who:

- is familiar with the natural world.
- understands some of the key concepts and principles of science.
- has a capacity for scientific ways of thinking.
- is aware of some of the important ways in which mathematics, technology, and science depend on one another.
- knows that science, mathematics, and technology are human enterprises and what that implies about their strengths and weaknesses.
- is able to use scientific knowledge and ways of thinking for personal and social purposes.

Published in 1989, *Science for All Americans* lays the groundwork for state and national science standards and is one of the most influential books in the field of science education. Available from Oxford University Press, 1-800-451-7556 or online at **http://www.project2061.org/publications/sfaa/online/**. Copyright ©1990, American Association for the Advancement of Science.

About *Atlas of Science Literacy*

Atlas of Science Literacy displays in map-like form how key ideas related to important topics in science, mathematics, and technology connect with each other and from one grade to the next. *Atlas, Volume 1*, published in 2001, gave educators access to conceptual strand maps for nearly 50 topics. *Atlas, Volume 2*, to be published in 2007, will complete the set with another 44 maps.

Each conceptual strand map in *Atlas* displays the benchmarks—from primary school to high school—that are most relevant to understanding a particular topic along with earlier benchmarks they build on and later benchmarks they support. The ideas and skills presented in the maps are specific goals for student learning and are derived from both *Science for All Americans* and its companion volume *Benchmarks for Science Literacy* (also available from Oxford University Press at 1-800-451-7556 or online at http://www.project2061.org/publications/bsl/online/bolintro.htm). Each map is accompanied by commentary on the topic and on features of the map itself and a brief summary of any topic-specific research on student learning.

Connections

Connections between benchmarks are based on the logic of the subject matter and, insofar as possible, on the published research into how students learn—both in general and with regard to specific concepts. A connection between two benchmarks, represented in the maps by an arrow, means that one "contributes to achieving" the other. The occasional double-headed arrow implies mutual support.

Strands

Strands are pointed out at the bottom of each map to help the reader find things in the map and get a sense of its content. Where possible, relevant benchmarks are positioned in a column above each label.

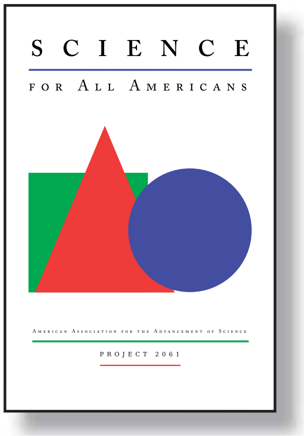
Grade Ranges

Grade ranges are delineated by horizontal gray lines. Benchmarks may be achieved in higher or lower grades depending on students' interests, abilities, and experience.

Connections to Other Maps

Connections to other maps are identified to help the reader keep in mind the notion of a larger set of ideas from which a subset have been teased out for each topic.

See p. 31 for information on ordering both *Atlas 1* and the forthcoming *Atlas 2.*



From Chapter 1: The Nature of Science

The Scientific World View

Scientists share certain basic beliefs and attitudes about what they do and how they view their work. These have to do with the nature of the world and what can be learned about it.

The World Is Understandable

Science presumes that the things and events in the universe occur in consistent patterns that are comprehensible through careful, systematic study. Scientists believe that through the use of the intellect, and with the aid of instruments that extend the senses, people can discover patterns in all of nature.

Science also assumes that the universe is, as its name implies, a vast single system in which the basic rules are everywhere the same. Knowledge gained from studying one part of the universe is applicable to other parts. For instance, the same principles of motion and gravitation that explain the motion of falling objects on the surface of the earth also explain the motion of the moon and the planets. With some modifications over the years, the same principles of motion have applied to other forces—and to the motion of everything, from the smallest nuclear particles to the most massive stars, from sailboats to space vehicles, from bullets to light rays.

Scientific Ideas Are Subject To Change

Science is a process for producing knowledge. The process depends both on making careful observations of phenomena and on inventing theories for making sense out of those observations. Change in knowledge is inevitable because new observations may challenge prevailing theories. No matter how well one theory explains a set of observations, it is possible that another theory may fit just as well or better, or may fit a still wider range of observations. In science, the testing and improving and occasional discarding of theories, whether new or old, go on all the time. Scientists assume that even if there is no way to secure complete and absolute truth, increasingly accurate approximations can be made to account for the world and how it works.

Scientific Knowledge Is Durable

Although scientists reject the notion of attaining absolute truth and accept some uncertainty as part of nature, most scientific knowledge is durable. The modification of ideas, rather than their outright rejection, is the norm in science, as powerful constructs tend to survive and grow more precise and to become widely accepted. For example, in formulating the theory of relativity, Albert Einstein did not discard the Newtonian laws of motion but rather showed them to be only an approximation of limited application within a more general concept. (The National Aeronautics and Space Administration uses Newtonian mechanics, for instance, in calculating satellite trajectories.) Moreover, the growing ability of scientists to make accurate predictions about natural phenomena provides convincing evidence that we really are gaining in our understanding of how the world works. Continuity and stability are as characteristic of science as change is, and confidence is as prevalent as tentativeness.

Science Cannot Provide Complete Answers to All Questions

There are many matters that cannot usefully be examined in a scientific way. There are, for instance, beliefs that—by their very nature—cannot be proved or disproved (such as the existence of supernatural powers and beings, or the true purposes of life). In other cases, a scientific approach that may be valid is likely to be rejected as irrelevant by people who hold to certain beliefs (such as in miracles, fortune-telling, astrology, and superstition). Nor do scientists have the means to settle issues concerning good and evil, although they can sometimes contribute to the discussion of such issues by identifying the likely consequences of particular actions, which may be helpful in weighing alternatives.

Scientific Inquiry

Fundamentally, the various scientific disciplines are alike in their reliance on evidence, the use of hypothesis and theories, the kinds of logic used, and much more. Nevertheless, scientists differ greatly from one another in what phenomena they investigate and in how they go about their work; in the reliance they place on historical data or on experimental findings and on qualitative or quantitative methods; in their recourse to fundamental principles; and in how much they draw on the findings of other sciences. Still, the exchange of techniques, information, and concepts goes on all the time among scientists, and there are common understandings among them about what constitutes an investigation that is scientifically valid.

Scientific inquiry is not easily described apart from the context of particular investigations. There simply is no fixed set of steps that scientists always follow, no one path that leads them unerringly to scientific knowledge. There are, however, certain features of science that give it a distinctive character as a mode of inquiry. Although those features are especially characteristic of the work of professional scientists, everyone can exercise them in thinking scientifically about many matters of interest in everyday life.

Science Demands Evidence

Sooner or later, the validity of scientific claims is settled by referring to observations of phenomena. Hence, scientists concentrate on getting accurate data. Such evidence is obtained by observations and measurements taken in situations that range from natural settings (such as a forest) to completely contrived ones (such as the laboratory). To make their observations, scientists use their own senses, instruments (such as microscopes) that enhance those senses, and instruments that tap characteristics quite different from what humans can sense (such as magnetic fields). Scientists observe passively (earthquakes, bird migrations), make collections (rocks, shells), and actively probe the world (as by boring into the earth's crust or administering experimental medicines).

In some circumstances, scientists can control conditions deliberately and precisely to obtain their evidence. They may, for example, control the temperature, change the concentration of chemicals, or choose which organisms mate with which others. By varying just one condition at a time, they can hope to identify its exclusive effects on what happens, uncomplicated by changes in other conditions. Often, however, control of conditions may be impractical (as in studying stars), or unethical (as in studying people), or likely to distort the natural phenomena (as in studying wild animals in captivity). In such cases, observations have to be made over a sufficiently wide range of naturally occurring conditions to infer what the influence of various factors might be. Because of this reliance on evidence, great value is placed on the development of better instruments and techniques of observation, and the findings of any one investigator or group are usually checked by others.

Science Is a Blend of Logic and Imagination

Although all sorts of imagination and thought may be used in coming up with hypotheses and theories, sooner or later scientific arguments must conform to the principles of logical reasoning—that is, to testing the validity of arguments by applying certain criteria of inference, demonstration, and common sense. Scientists may often disagree about the value of a particular piece of evidence, or about the appropriateness of particular assumptions that are made—and therefore disagree about what conclusions are justified. But they tend to agree about the principles of logical reasoning that connect evidence and assumptions with conclusions.

Scientists do not work only with data and well-developed theories. Often, they have only tentative hypotheses about the way things may be. Such hypotheses are widely used in science for choosing what data to pay attention to and what additional data to seek, and for guiding the interpretation of data. In fact, the process of formulating and testing hypotheses is one of the core activities of scientists. To be useful, a hypothesis should suggest what evidence would support it and what evidence would refute it. A hypothesis that cannot in principle be put to the test of evidence may be interesting, but it is not likely to be scientifically useful.

The use of logic and the close examination of evidence are necessary but not usually sufficient for the advancement of science. Scientific concepts do not emerge automatically from data or from any amount of analysis alone. Inventing hypotheses or theories to imagine how the world works and then figuring out how they can be put to the test of reality is as creative as writing poetry, composing music, or designing skyscrapers. Sometimes discoveries in science are made unexpectedly, even by accident. But knowledge and creative insight are usually required to recognize the meaning of the unexpected. Aspects of data that have been ignored by one scientist may lead to new discoveries by another.

Science Explains and Predicts

Scientists strive to make sense of observations of phenomena by constructing explanations for them that use, or are consistent with, currently accepted scientific principles. Such explanations—theories—may be either sweeping or restricted, but they must be logically sound and incorporate a significant body of scientifically valid observations. The credibility of scientific theories often comes from their ability to show relationships among phenomena that previously seemed unrelated. The theory of moving continents, for example, has grown in credibility as it has shown relationships among such diverse phenomena as earthquakes, volcanoes, the match between types of fossils on different continents, the shapes of continents, and the contours of the ocean floors.

The essence of science is validation by observation. But it is not enough for scientific theories to fit only the observations that are already known. Theories should also fit additional observations that were not used in formulating the theories in the first place; that is, theories should have predictive power. Demonstrating the predictive power of a theory does not necessarily require the prediction of events in the future. The predictions may be about evidence from the past that has not yet been found or studied. A theory about the origins of human beings, for example, can be tested by new discoveries of human-like fossil remains. This approach is clearly necessary for reconstructing the events in the history of the earth or of the life forms on it. It is also necessary for the study of processes that usually occur very slowly, such as the building of mountains or the aging of stars. Stars, for example, evolve more slowly than we can usually observe. Theories of the evolution of stars, however, may predict unsuspected relationships between features of starlight that can then be sought in existing collections of data about stars.

Scientists Try to Identify and Avoid Bias

When faced with a claim that something is true, scientists respond by asking what evidence supports it. But scientific evidence can be biased in how the data are interpreted, in the recording or reporting of the data, or even in the choice of what data to consider in the first place. Scientists' nationality, sex, ethnic origin, age, political convictions, and so on may incline them to look for or emphasize one or another kind of evidence or interpretation. For example, for many years the study of primates—by male scientists—focused on the competitive social behavior of males. Not until female scientists entered the field was the importance of female primates' community-building behavior recognized.

Bias attributable to the investigator, the sample, the method, or the instrument may not be completely avoidable in every instance, but scientists want to know the possible sources of bias and how bias is likely to influence evidence. Scientists want, and are expected, to be as alert to possible bias in their own work as in that of other scientists, although such objectivity is not always achieved. One safeguard against undetected bias in an area of study is to have many different investigators or groups of investigators working in it.

Science Is Not Authoritarian

It is appropriate in science, as elsewhere, to turn to knowledgeable sources of information and opinion, usually people who specialize in relevant disciplines. But esteemed authorities have been wrong many times in the history of science. In the long run, no scientist, however famous or highly placed, is empowered to decide for other scientists what is true, for none are believed by other scientists to have special access to the truth. There are no preestablished conclusions that scientists must reach on the basis of their investigations.

In the short run, new ideas that do not mesh well with mainstream ideas may encounter vigorous criticism, and scientists investigating such ideas may have difficulty obtaining support for their research. Indeed, challenges to new ideas are the legitimate business of science in building valid knowledge. Even the most prestigious scientists have occasionally refused to accept new theories despite there being enough accumulated evidence to convince others. In the long run, however, theories are judged by their results: When someone comes up with a new or improved version that explains more phenomena or answers more important questions than the previous version, the new one eventually takes its place.

From Chapter 3: The Nature of Technology

Issues in Technology

The Human Presence

The earth's population has already doubled three times during the past century. Even at that, the human presence, which is evident almost everywhere on the earth, has had a greater impact than sheer numbers alone would indicate. We have developed the capacity to dominate most plant and animal species—far more than any other species can—and the ability to shape the future rather than merely respond to it.

Use of that capacity has both advantages and disadvantages. On the one hand, developments in technology have brought enormous benefits to almost all people. Most people today have access to goods and services that were once luxuries enjoyed only by the wealthy—in transportation, communication, nutrition, sanitation, health care, entertainment, and so on. On the other hand, the very behavior that made it possible for the human species to prosper so rapidly has put us and the earth's other living organisms at new kinds of risk. The growth of agricultural technology has made possible a very large population but has put enormous strain on the soil and water systems that are needed to continue sufficient production. Our antibiotics cure bacterial infection, but may continue to work only if we invent new ones faster than resistant bacterial strains emerge.

Our access to and use of vast stores of fossil fuels have made us dependent on a nonrenewable resource. In our present numbers, we will not be able to sustain our way of living on the energy that current technology provides, and alternative technologies may be inadequate or may present unacceptable hazards. Our vast mining and manufacturing efforts produce our goods, but they also dangerously pollute our rivers and oceans, soil, and atmosphere. Already, by-products of industrialization in the atmosphere may be depleting the ozone layer, which screens the planet's surface from harmful ultraviolet rays, and may be creating a buildup of carbon dioxide, which traps heat and could raise the planet's average temperatures significantly. The environmental consequences of a nuclear war, among its other disasters, could alter crucial aspects of all life on earth.

From the standpoint of other species, the human presence has reduced the amount of the earth's surface available to them by clearing large areas of vegetation; has interfered with their food sources; has changed their habitats by changing the temperature and chemical composition of large parts of the world environment; has destabilized their ecosystems by introducing foreign species, deliberately or accidentally; has reduced the number of living species; and in some instances has actually altered the characteristics of certain plants and animals by selective breeding and more recently by genetic engineering.

What the future holds for life on earth, barring some immense natural catastrophe, will be determined largely by the human species. The same intelligence that got us where we are—improving many aspects of human existence and introducing new risks into the world—is also our main resource for survival.

Technological and Social Systems Interact Strongly

Individual inventiveness is essential to technological innovation. Nonetheless, social and economic forces strongly influence what technologies will be undertaken, paid attention to, invested in, and used. Such decisions occur directly as a matter of government policy and indirectly as a consequence of the circumstances and values of a society at any particular time. In the United States, decisions about which technological options will prevail are influenced by many factors, such as consumer acceptance, patent laws, the availability of risk capital, the federal budget process, local and national regulations, media attention, economic competition, tax incentives, and scientific discoveries. The balance of such incentives and regulations usually bears differently on different technological systems, encouraging some and discouraging others.

Technology has strongly influenced the course of history and the nature of human society, and it continues to do so. The great revolutions in agricultural technology, for example, have probably had more influence on how people live than political revolutions; changes in sanitation and preventive medicine have contributed to the population explosion (and to its control); bows and arrows, gunpowder, and nuclear explosives have in their turn changed how war is waged; and the microprocessor is changing how people write, compute, bank, operate businesses, conduct research, and communicate with one another. Technology is largely responsible for such large-scale changes as the increased urbanization of society and the dramatically growing economic interdependence of communities worldwide.

Historically, some social theorists have believed that technological change (such as industrialization and mass production) causes social change, whereas others have believed that social change (such as political or religious changes) leads to technological change. However, it is clear that because of the web of connections between technological and other social systems, many influences act in both directions.

The Social System Imposes Some Restrictions on Openness in Technology

For the most part, the professional values of engineering are very similar to those of science, including the advantages seen in the open sharing of knowledge. Because of the economic value of technology, however, there are often constraints on the openness of science and engineering that are relevant to technological innovation. A large investment of time and money and considerable commercial risk are often required to develop a new technology and bring it to market. That investment might well be jeopardized if competitors had access to the new technology without making a similar investment, and hence companies are often reluctant to share technological knowledge. But no scientific or technological knowledge is likely to remain secret for very long. Secrecy most often provides only an advantage in terms of time—a head start, not absolute control of knowledge. Patent laws encourage openness by giving individuals and companies control over the use of any new technology they develop; however, to promote technological competition, such control is only for a limited period of time.

Commercial advantage is not the only motivation for secrecy and control. Much technological development occurs in settings, such as government agencies, in which commercial concerns are minimal but national security concerns may lead to secrecy. Any technology that has potential military applications can arguably be subject to restrictions imposed by the federal government, which may limit the sharing of engineering knowledge—or even the exportation of products from which engineering knowledge could be inferred. Because the connections between science and technology are so close in some fields, secrecy inevitably begins to restrict some of the free flow of information in science as well. Some scientists and engineers are very uncomfortable with what they perceive as a compromise of the scientific ideal, and some refuse to work on projects that impose secrecy. Others, however, view the restrictions as appropriate.

Decisions About the Use of Technology Are Complex

Most technological innovations spread or disappear on the basis of free-market forces—that is, on the basis of how people and companies respond to such innovations. Occasionally, however, the use of some technology becomes an issue subject to public debate and possibly formal regulation. One way in which technology becomes such an issue is when a person, group, or business proposes to test or introduce a new technology—as has been the case with contour plowing, vaccination, genetic engineering, and nuclear power plants. Another way is when a technology already in widespread use is called into question—as, for example, when people are told (by individuals, organizations, or agencies) that it is essential to stop or reduce the use of a particular technology or technological product that has been discovered to have, or that may possibly have, adverse effects. In such instances, the proposed solution may be to ban the burial of toxic wastes in community dumps, or to prohibit the use of leaded gasoline and asbestos insulation.

Rarely are technology-related issues simple and one-sided. Relevant technical facts alone, even when known and available (which often they are not), usually do not settle matters entirely in favor of one side or the other. The chances of reaching good personal or collective decisions about technology depend on having information that neither enthusiasts nor skeptics are always ready to volunteer. The long-term interests of society are best served, therefore, by having processes for ensuring that key questions concerning proposals to curtail or introduce technology are raised and that as much relevant knowledge as possible is brought to bear on them. Considering these questions does not ensure that the best decision will always be made, but the failure to raise key questions will almost certainly result in poor decisions. The key questions concerning any proposed new technology should include the following:

- What are alternative ways to accomplish the same ends? What advantages and disadvantages are there to the alternatives? What trade-offs would be necessary between positive and negative side effects of each?
- Who are the main beneficiaries? Who will receive few or no benefits? Who will suffer as a result of the proposed new technology? How long will the benefits last? Will the technology have other applications? Whom will they benefit?
- What will the proposed new technology cost to build and operate? How does that compare to the cost of alternatives? Will people other than the beneficiaries have to bear the costs? Who should underwrite the development costs of a proposed new technology? How will the costs change over time? What will the social costs be?
- What risks are associated with the proposed new technology? What risks are associated with not using it? Who will be in greatest danger? What risk will the technology present to other species of life and to the environment? In the worst possible case, what trouble could it cause? Who would be held responsible? How could the trouble be undone or limited?
- What people, materials, tools, knowledge, and know-how will be needed to build, install, and operate the proposed new technology? Are they available? If not, how will they be obtained, and from where? What energy sources will be needed for construction or manufacture, and also for operation? What resources will be needed to maintain, update, and repair the new technology?
- What will be done to dispose safely of the new technology's waste materials? As it becomes obsolete or worn out, how will it be replaced? And finally, what will become of the material of which it was made and the people whose jobs depended on it?

Individual citizens may seldom be in a position to ask or demand answers for these questions on a public level, but their knowledge of the relevance and importance of answers increases the attention given to the questions by private enterprise, interest groups, and public officials. Furthermore, individuals may ask the same questions with regard to their own use of technology—for instance, their own use of efficient household appliances, of substances that contribute to pollution, of foods and fabrics. The cumulative effect of individual decisions can have as great an impact on the large-scale use of technology as pressure on public decisions can.

Not all such questions can be answered readily. Most technological decisions have to be made on the basis of incomplete information, and political factors are likely to have as much influence as technical ones, and sometimes more. But scientists, mathematicians, and engineers have a special role in looking as far ahead and as far afield as is practical to estimate benefits, side effects, and risks. They can also assist by designing adequate detection devices and monitoring techniques, and by setting up procedures for the collection and statistical analysis of relevant data.

SCIENTIFIC INQUIRY:

SCIENTIFIC INVESTIGATIONS

CLUSTER: SCIENTIFIC INQUIRY

MAPS:
EVIDENCE AND REASONING IN INQUIRY ER
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SCIENTIFIC THEORIES ST
AVOIDING BIAS IN SCIENCE AB

Scientific investigations may look very different and serve different purposes, but they include some common aspects that are important for literacy. This map develops along four strands of benchmarks about the different forms of investigations, good record-keeping and communication, the importance of reliability, and the control of conditions that reliability requires. *Science for All Americans* and *Benchmarks* ask that students understand how scientists go about their work, but do not call for them to be able to perform scientific investigations exactly as scientists do. Some skill benchmarks, however, appear in this map because they contribute to students' understanding of investigations and are themselves important for literacy.

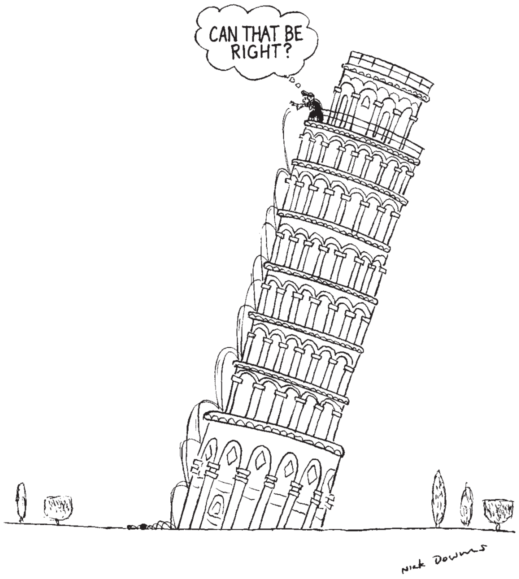
Students can make progress toward understanding almost all topics in the physical and life sciences through investigations. Used together with maps on a specific topic, this map can suggest what general scientific ideas and skills students should come away with beyond understanding the phenomena under investigation. Students' understanding of investigations could be enhanced by topics that will be mapped in the next edition of *Atlas*, including ethics and values in science, and the role of technology in extending scientists' ability to accurately observe and analyze.

NOTES

A 6-8 benchmark about controlling variables in experiments appears in the *control and conditions* strand. An important precursor to this benchmark is "fairness" in comparisons, which students can likely understand in 3-5. Controlling variables and isolating the effects of a single variable are important as ways of explaining discrepancies between similar investigations and as ways of obtaining evidence. The 9-12 benchmark in this strand also appears in the **EVIDENCE AND REASONING IN INQUIRY** map.

The *reliability of results* strand focuses on expectations and interpretations of differing results in similar investigations. The notion that similar investigations should give similar results, in K-2, contributes to students' later understanding of the importance of discrepancies. Nearly all of this strand is also part of the **AVOIDING BIAS IN SCIENCE** map.

Describing and interpreting evidence generated through investigations typically requires statistics. Benchmarks about summarizing, interpreting, and comparing data can be found on maps in the STATISTICS cluster (in Chapter 9).

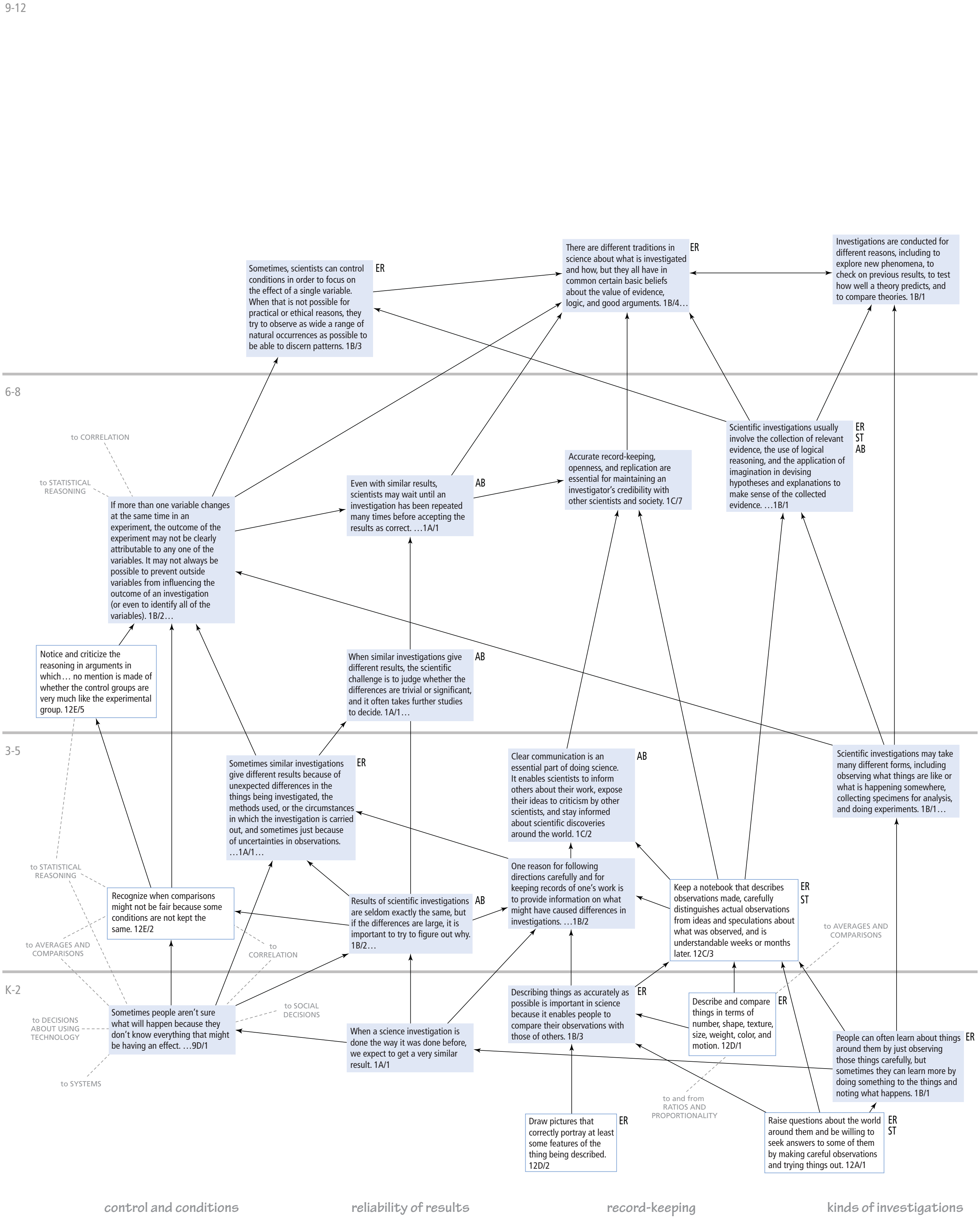


RESEARCH IN *BENCHMARKS*

Upper elementary- and middle-school students may not understand experimentation as a method of testing ideas, but rather as a method of trying things out or producing a desired outcome (Carey et al., 1989; Schauble et al., 1991; Solomon, 1992). With adequate instruction, it is possible to have middle-school students understand that experimentation is guided by particular ideas and questions and that experiments are tests of ideas (Carey et al., 1989; Solomon et al., 1992). Whether it is possible for younger students to achieve this understanding needs further investigation.

When engaged in experimentation, students have difficulty interpreting covariation and noncovariation evidence (Kuhn, Amsel, & O'Loughlin, 1988). For example, students tend to make a causal inference based on a single concurrence of antecedent and outcome or have difficulty understanding the distinction between a variable having no effect and a variable having an opposite effect.

Upper elementary-school students can reject a proposed experimental test where a factor whose effect is intuitively obvious is uncontrolled, at the level of "that's not fair" (Shayer & Adey, 1981). "Fairness" develops as an intuitive principle as early as 7 to 8 years of age and provides a sound basis for understanding experimental design. This intuition does not, however, develop spontaneously into a clear, generally applicable procedure for planning experiments (Wollman, 1977a, 1977b; Wollman & Lawson, 1977). Although young children have a sense of what it means to run a fair test, they frequently cannot identify all of the important variables, and they are more likely to control those variables that they believe will affect the result. Accordingly, student familiarity with the topic of the given experiment influences the likelihood that they will control variables (Linn & Swiney, 1981; Linn, et al., 1983). After specially designed instruction, students in 8th grade are able to call attention to inadequate data resulting from lack of controls (see for example Rowell & Dawson, 1984; Ross, 1988).



9-12

Sometimes, scientists can control conditions in order to focus on the effect of a single variable. When that is not possible for practical or ethical reasons, they try to observe as wide a range of natural occurrences as possible to be able to discern patterns. 1B/3 ER

There are different traditions in science about what is investigated and how, but they all have in common certain basic beliefs about the value of evidence, logic, and good arguments. 1B/4… ER

Investigations are conducted for different reasons, including to explore new phenomena, to check on previous results, to test how well a theory predicts, and to compare theories. 1B/1

6-8

If more than one variable changes at the same time in an experiment, the outcome of the experiment may not be clearly attributable to any one of the variables. It may not always be possible to prevent outside variables from influencing the outcome of an investigation (or even to identify all of the variables). 1B/2…

Even with similar results, scientists may wait until an investigation has been repeated many times before accepting the results as correct. …1A/1 AB

Accurate record-keeping, openness, and replication are essential for maintaining an investigator's credibility with other scientists and society. 1C/7

Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence. …1B/1 ER ST AB

Notice and criticize the reasoning in arguments in which… no mention is made of whether the control groups are very much like the experimental group. 12E/5

When similar investigations give different results, the scientific challenge is to judge whether the differences are trivial or significant, and it often takes further studies to decide. 1A/1… AB

3-5

Sometimes similar investigations give different results because of unexpected differences in the things being investigated, the methods used, or the circumstances in which the investigation is carried out, and sometimes just because of uncertainties in observations. …1A/1… ER

Clear communication is an essential part of doing science. It enables scientists to inform others about their work, expose their ideas to criticism by other scientists, and stay informed about scientific discoveries around the world. 1C/2 AB

Scientific investigations may take many different forms, including observing what things are like or what is happening somewhere, collecting specimens for analysis, and doing experiments. 1B/1…

Recognize when comparisons might not be fair because some conditions are not kept the same. 12E/2

Results of scientific investigations are seldom exactly the same, but if the differences are large, it is important to try to figure out why. 1B/2… AB

One reason for following directions carefully and for keeping records of one's work is to provide information on what might have caused differences in investigations. …1B/2

Keep a notebook that describes observations made, carefully distinguishes actual observations from ideas and speculations about what was observed, and is understandable weeks or months later. 12C/3 ER ST

K-2

Sometimes people aren't sure what will happen because they don't know everything that might be having an effect. …9D/1

When a science investigation is done the way it was done before, we expect to get a very similar result. 1A/1

Describing things as accurately as possible is important in science because it enables people to compare their observations with those of others. 1B/3 ER

Describe and compare things in terms of number, shape, texture, size, weight, color, and motion. 12D/1 ER

People can often learn about things around them by just observing those things carefully, but sometimes they can learn more by doing something to the things and noting what happens. 1B/1 ER

Draw pictures that correctly portray at least some features of the thing being described. 12D/2 ER

Raise questions about the world around them and be willing to seek answers to some of them by making careful observations and trying things out. 12A/1 ER ST

ISSUES IN TECHNOLOGY:

INTERACTION OF TECHNOLOGY AND SOCIETY

CLUSTER: **ISSUES IN TECHNOLOGY**

MAPS: **INTERACTION OF TECHNOLOGY AND SOCIETY** IT
DECISIONS ABOUT USING TECHNOLOGY DT

A wide range of social conditions and forces influence how, when, or whether technologies get developed and implemented. Conversely, implemented technologies influence social conditions. These two complementary aspects, indicated by the labeled strands in this map, are not always distinct. Society attempts to control technology because of its profound social impacts, and some of the social conditions that influence technology grow out of technology itself.

Different curricula or instructional tacks could make use of the relationship between these benchmarks and those in the **INFLUENCES ON SOCIAL CHANGE** map in Chapter 7: HUMAN SOCIETY. Additionally, the **HARNESSING POWER**, **SPLITTING THE ATOM**, and **DISCOVERING GERMS** sections in *Science for All Americans* and *Benchmarks* Chapter 10: HISTORICAL PERSPECTIVES can provide a context for this map. Of course, the benchmarks presented here are also relevant to benchmarks about specific technologies in Chapter 8: THE DESIGNED WORLD.

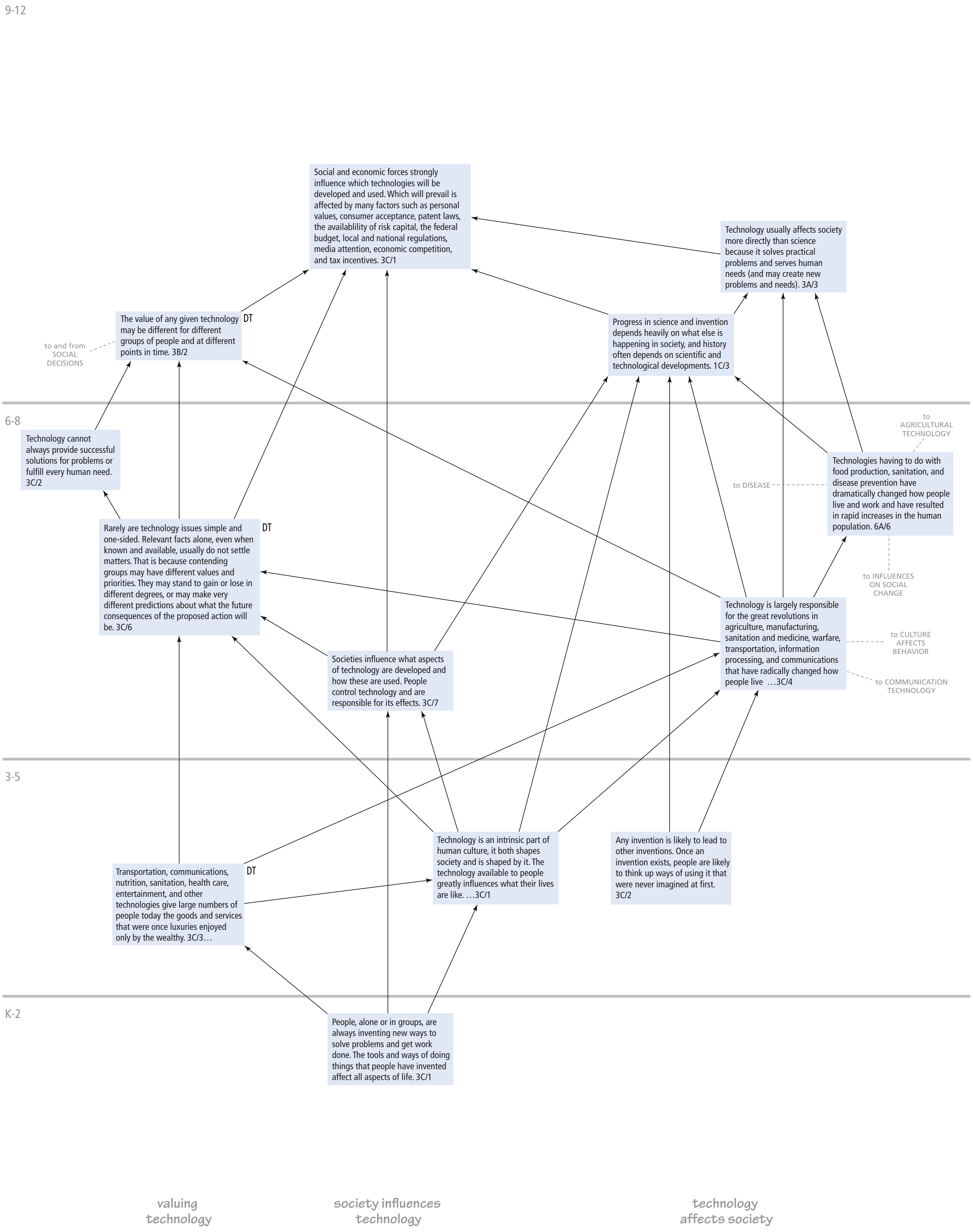
Related topics on specific technologies and on human society will be mapped for the next edition of *Atlas*. They include health technology, materials and manufacturing, and political and economic systems.

NOTES

The many connections between strands indicate their close relationship and dependence on one another. For example, the 3-5 benchmark "Transportation, communications, nutrition ..." is positioned in the valuing technology strand, but has several important connections to the technology affects society strand.

The 3-5 benchmark "Technology is an intrinsic part of human culture..." contributes to four later benchmarks. This benchmark is very general; students will likely learn it first in connection with simple examples and later expand their understanding of it to include the many different influences and their interaction.

No relevant research available in *Benchmarks*



Social and economic forces strongly influence which technologies will be developed and used. Which will prevail is affected by many factors such as personal values, consumer acceptance, patent laws, the availablility of risk capital, the federal budget, local and national regulations, media attention, economic competition, and tax incentives. 3C/1

Technology usually affects society more directly than science because it solves practical problems and serves human needs (and may create new problems and needs). 3A/3

The value of any given technology may be different for different groups of people and at different points in time. 3B/2 DT

Progress in science and invention depends heavily on what else is happening in society, and history often depends on scientific and technological developments. 1C/3

Technology cannot always provide successful solutions for problems or fulfill every human need. 3C/2

Technologies having to do with food production, sanitation, and disease prevention have dramatically changed how people live and work and have resulted in rapid increases in the human population. 6A/6

Rarely are technology issues simple and one-sided. Relevant facts alone, even when known and available, usually do not settle matters. That is because contending groups may have different values and priorities. They may stand to gain or lose in different degrees, or may make very different predictions about what the future consequences of the proposed action will be. 3C/6 DT

Technology is largely responsible for the great revolutions in agriculture, manufacturing, sanitation and medicine, warfare, transportation, information processing, and communications that have radically changed how people live …3C/4

Societies influence what aspects of technology are developed and how these are used. People control technology and are responsible for its effects. 3C/7

Technology is an intrinsic part of human culture, it both shapes society and is shaped by it. The technology available to people greatly influences what their lives are like. …3C/1

Any invention is likely to lead to other inventions. Once an invention exists, people are likely to think up ways of using it that were never imagined at first. 3C/2

Transportation, communications, nutrition, sanitation, health care, entertainment, and other technologies give large numbers of people today the goods and services that were once luxuries enjoyed only by the wealthy. 3C/3… DT

People, alone or in groups, are always inventing new ways to solve problems and get work done. The tools and ways of doing things that people have invented affect all aspects of life. 3C/1

ISSUES IN TECHNOLOGY:

DECISIONS ABOUT USING TECHNOLOGY

CLUSTER: **ISSUES IN TECHNOLOGY**

MAPS: **INTERACTION OF TECHNOLOGY AND SOCIETY** IT
DECISIONS ABOUT USING TECHNOLOGY DT

Understanding the complex and interrelated factors involved in making decisions about the use of technology requires that students develop ideas about costs and benefits, trade-offs, side-effects, and how people value technology. An additional subtlety is that judgements about costs and benefits and trade-offs are influenced by perception of risk and the different priorities of contending groups.

Relationships between this map and the specific technology topics in *Benchmarks* Chapter 8: THE DESIGNED WORLD could provide context in instruction for the benchmarks presented here. The potential effects of human inventions on ecosystems are obviously a major consideration in decisions about technology, but are not dealt with completely in this map. Environmental implications will be mapped in the next edition of *Atlas,* providing a bridge to many topics in life science (e.g., interdependence of life and flow of matter and energy in ecosystems).

NOTES

In strand maps, specific examples are usually placed before generalizations on the grounds that the examples will give students a foundation for understanding the generalizations. However, the 3-5 benchmark in the *trade-offs* strand about decisions in general precedes the 3-5 benchmark in the *costs and benefits* strand about the specific case of technology decisions. This is because the general case is more accessible due to the many complex factors in considering the use of technology in particular.

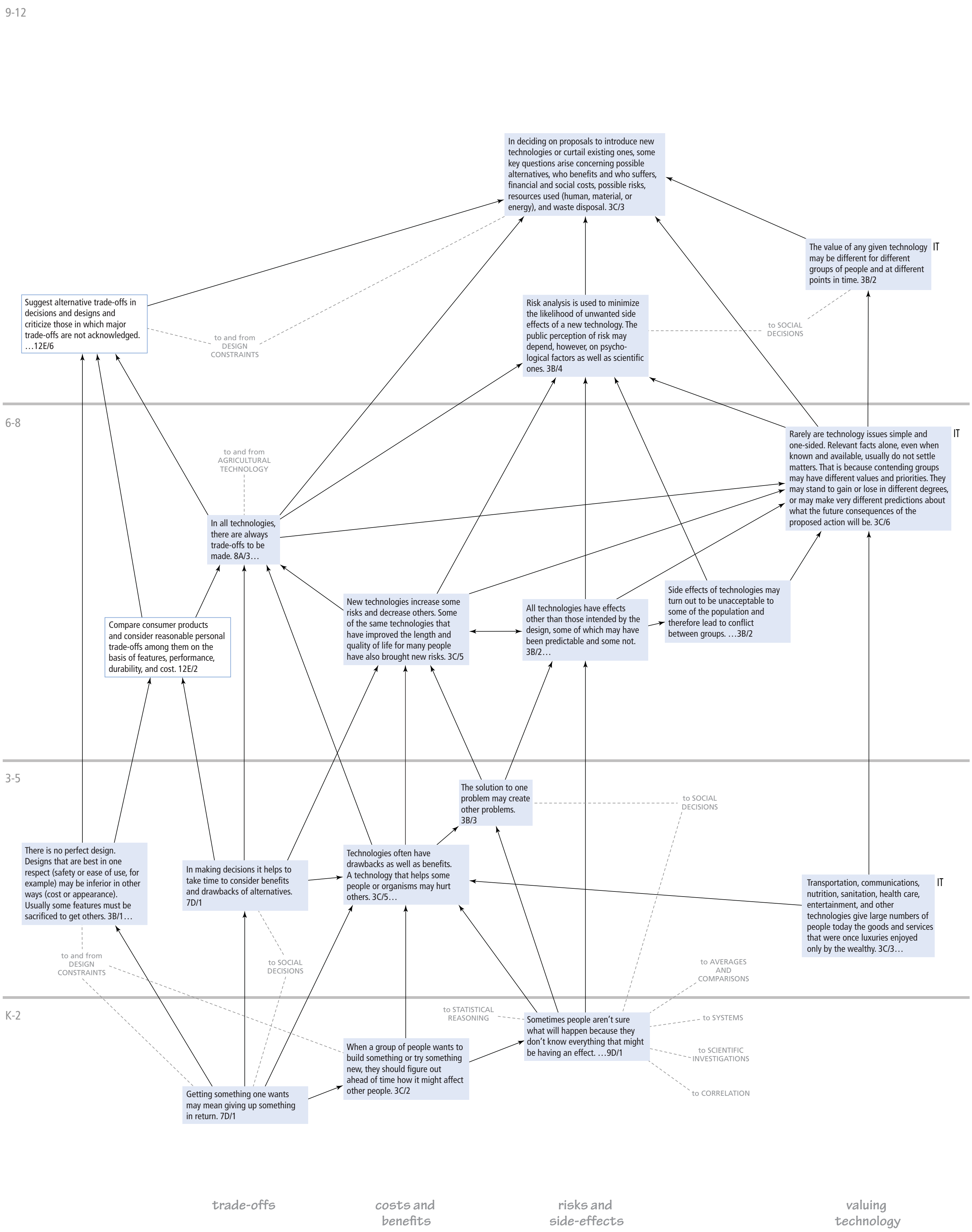
In the *costs and benefits* strand, the 6-8 benchmark "New technologies increase some…" does not simply repeat the 3-5 benchmark "Technologies often have drawbacks…." The 3-5 benchmark asks students to know that technologies can help some people and harm others. The 6-8 benchmark includes a more subtle idea: technologies may increase some kinds of risks and reduce others.

Trade-offs and consideration of costs and benefits are played out in a more limited way (during the design of a product) in the **DESIGN CONSTRAINTS** map, and in a more general way in the **SOCIAL DECISIONS** map in (Chapter 7). The benchmarks presented here also relate to topics about human society that have not yet been mapped, including social trade-offs and social conflict.

RESEARCH IN *BENCHMARKS*

Preliminary research gives some indication of two student perspectives on risk resulting from the failure of technological systems. In the first perspective, if the risk of failure involves the possibility of widespread harm, it is unacceptable; however, if the risk of failure is to oneself and voluntary, it is considered a part of life and hardly worthy of concern by others. In the second perspective, if the risk of failure involves harm to oneself and benefits to oneself, then it is of primary interest. Harm to others is simply ignored in this perspective (Fleming, 1986a, 1986b).

Some high-school students believe scientists and engineers are more capable of making decisions about public issues related to science and technology than the general public. Students believe that scientists and engineers know all the facts and are not influenced by personal motives and interests (Fleming, 1987; Aikenhead, 1987).



9-12

In deciding on proposals to introduce new technologies or curtail existing ones, some key questions arise concerning possible alternatives, who benefits and who suffers, financial and social costs, possible risks, resources used (human, material, or energy), and waste disposal. 3C/3

The value of any given technology may be different for different groups of people and at different points in time. 3B/2

Suggest alternative trade-offs in decisions and designs and criticize those in which major trade-offs are not acknowledged. …12E/6

Risk analysis is used to minimize the likelihood of unwanted side effects of a new technology. The public perception of risk may depend, however, on psychological factors as well as scientific ones. 3B/4

6-8

Rarely are technology issues simple and one-sided. Relevant facts alone, even when known and available, usually do not settle matters. That is because contending groups may have different values and priorities. They may stand to gain or lose in different degrees, or may make very different predictions about what the future consequences of the proposed action will be. 3C/6

In all technologies, there are always trade-offs to be made. 8A/3…

Side effects of technologies may turn out to be unacceptable to some of the population and therefore lead to conflict between groups. …3B/2

Compare consumer products and consider reasonable personal trade-offs among them on the basis of features, performance, durability, and cost. 12E/2

New technologies increase some risks and decrease others. Some of the same technologies that have improved the length and quality of life for many people have also brought new risks. 3C/5

All technologies have effects other than those intended by the design, some of which may have been predictable and some not. 3B/2…

3-5

The solution to one problem may create other problems. 3B/3

There is no perfect design. Designs that are best in one respect (safety or ease of use, for example) may be inferior in other ways (cost or appearance). Usually some features must be sacrificed to get others. 3B/1…

In making decisions it helps to take time to consider benefits and drawbacks of alternatives. 7D/1

Technologies often have drawbacks as well as benefits. A technology that helps some people or organisms may hurt others. 3C/5…

Transportation, communications, nutrition, sanitation, health care, entertainment, and other technologies give large numbers of people today the goods and services that were once luxuries enjoyed only by the wealthy. 3C/3…

K-2

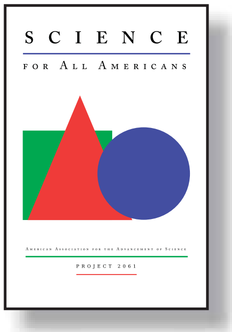
Sometimes people aren't sure what will happen because they don't know everything that might be having an effect. …9D/1

When a group of people wants to build something or try something new, they should figure out ahead of time how it might affect other people. 3C/2

Getting something one wants may mean giving up something in return. 7D/1

From Chapter 4:
The Physical Setting

The Earth



We live on a fairly small planet, the third from the sun in the only system of planets definitely known to exist (although similar systems are likely to be common in the universe). Like that of all planets and stars, the earth's shape is approximately spherical, the result of mutual gravitational attraction pulling its material toward a common center. Unlike the much larger outer planets, which are mostly gas, the earth is mostly rock, with three-fourths of its surface covered by a relatively thin layer of water and the entire planet enveloped by a thin blanket of air. Bulges in the water layer are raised on both sides of the planet by the gravitational tugs of the moon and sun, producing high tides about twice a day along ocean shores. Similar bulges are produced in the blanket of air as well.

Of all the diverse planets and moons in our solar system, only the earth appears to be capable of supporting life as we know it. The gravitational pull of the planet's mass is sufficient to hold onto an atmosphere. This thin envelope of gases evolved as a result of changing physical conditions on the earth's surface and the evolution of plant life, and it is an integral part of the global ecosystem. Altering the concentration of its natural component gases of the atmosphere, or adding new ones, can have serious consequences for the earth's life systems.

The distance of the earth from the sun ensures that energy reaches the planet at a rate sufficient to sustain life, and yet not so fast that water would boil away or that molecules necessary to life would not form. Water exists on the earth in liquid, solid, and gaseous forms—a rarity among the planets (the others are either closer to the sun and too hot or farther from the sun and too cold).

The motion of the earth and its position with regard to the sun and the moon have noticeable effects. The earth's one-year revolution around the sun, because of the tilt of the earth's axis, changes how directly sunlight falls on one part or another of the earth. This difference in heating different parts of the earth's surface produces seasonal variations in climate. The rotation of the planet on its axis every 24 hours produces the planet's night-and-day cycle—and (to observers on earth) makes it seem as though the sun, planets, stars, and moon are orbiting the earth. The combination of the earth's motion and the moon's own orbit around the earth, once in about 28 days, results in the phases of the moon (on the basis of the changing angle at which we see the sunlit side of the moon).

The earth has a variety of climatic patterns, which consist of different conditions of temperature, precipitation, humidity, wind, air pressure, and other atmospheric phenomena. These patterns result from an interplay of many factors. The basic energy source is the heating of land, ocean, and air by solar radiation. Transfer of heat energy at the interfaces of the atmosphere with the land and oceans produces layers at different temperatures in both the air and the oceans. These layers rise or sink or mix, giving rise to winds and ocean currents that carry heat energy between warm and cool regions. The earth's rotation curves the flow of winds and ocean currents, which are further deflected by the shape of the land.

The cycling of water in and out of the atmosphere plays an important part in determining climatic patterns—evaporating from the surface, rising and cooling, condensing into clouds and then into snow or rain, and falling again to the surface, where it collects in rivers, lakes, and porous layers of rock. There are also large areas on the earth's surface covered by thick ice (such as Antarctica), which interacts with the atmosphere and oceans in affecting worldwide variations in climate.

The earth's climates have changed radically and they are expected to continue changing, owing mostly to the effects of geological shifts such as the advance or retreat of glaciers over centuries of time or a series of huge volcanic eruptions in a short time. But even some relatively minor changes of atmospheric content or of ocean temperature, if sustained long enough, can have widespread effects on climate.

The earth has many resources of great importance to human life. Some are readily renewable, some are renewable only at great cost, and some are not renewable at all. The earth comprises a great variety of minerals, whose properties depend on the history of how they were formed as well as on the elements of which they are composed. Their abundance ranges from rare to almost unlimited. But the difficulty of extracting them from the environment is as important an issue as their abundance. A wide variety of minerals are sources for essential industrial materials, such as iron, aluminum, magnesium, and copper. Many of the best sources are being depleted, making it more and more difficult and expensive to obtain those minerals.

Fresh water is an essential resource for daily life and industrial processes. We obtain our water from rivers and lakes and from water that moves below the earth's surface. This groundwater, which is a major source for many people, takes a long time to accumulate in the quantities now being used. In some places it is being depleted at a very rapid rate. Moreover, many sources of fresh water cannot be used because they have been polluted.

Wind, tides, and solar radiation are continually available and can be harnessed to provide sources of energy. In principle, the oceans, atmosphere, topsoil, sea creatures, and trees are renewable resources. However, it can be enormously expensive to clean up polluted air and water, restore destroyed forests and fishing grounds, or restore or preserve eroded soils of poorly managed agricultural areas. Although the oceans and atmosphere are very large and have a great capacity to absorb and recycle materials naturally, they do have their limits. They have only a finite capacity to withstand change without generating major ecological alterations that may also have adverse effects on human activities.

Recommended Reading

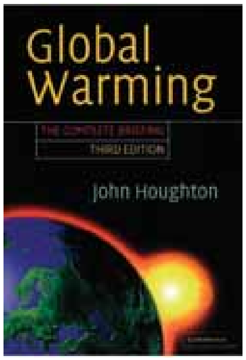
There are many well-written and authoritative books for a general audience that can help educators and others understand the science of climate change and its environmental and societal impacts. For each of the examples below, we have identified the most significant links between the book's content and specific chapters and sections in *Science for All Americans*. Additional highly recommended trade books on other topics covered in *Science for All Americans* can be found in *Resources for Science Literacy* online at http://www.project2061.org/publications/rsl/online/index.htm. For critical reviews of science books for all ages, visit *Science Books & Films* online at http://www.sbfonline.com/index.htm.

Global Warming: The Complete Briefing, Third Edition

by Sir John T. Houghton

Cambridge University Press, 2004, 351 pp. 0-521-52874-7, Index

Links to *Science for All Americans*: 1B, 3C, 4B, 11B, 11C



"Authoritative and well written, Houghton's briefing, *Global Warming*, should be required reading for many college courses on the environment. The book provides a sober, comprehensive look at global climate change, from basic climatology to the economics of reducing human-made contributions to global warming. Cochairman of the Scientific Assessment Working Group of the Intergovernmental Panel on Climate Change (IPCC), Houghton draws from a distinguished career in meteorology in this work.... The science presented is solid and detailed, with very many illustrative charts, graphs, and citations. Houghton understandably relies on numerous IPCC and (London-based) World Energy Council reports. Readers in the United States wishing to further examine climate stabilization options may find domestic analyses of energy strategies more relevant and more readily accessible."

—From a review of the Second Edition (1997) by John Morrill in Science Books & Films, 34/4 (May 1998), p. 100.

"All in all, the text and figures have improved on the previous edition...the book provides a clear explanation of the issues associated with global warming from a knowledgeable expert in the field."

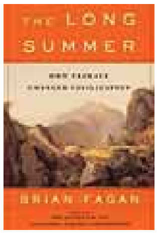
—From a review in the Journal of the British Astronomical Association

The Long Summer: How Climate Changed Civilization

by Brian Fagan

Basic Books, 2004, 248 pp. 0-465-02281-2, Index

Links to *Science for All Americans*: 1B, 3C, 4B, 11B, 11C



"In *The Long Summer: How Climate Changed Civilization*, Brian Fagan has written a grand tour of human history as influenced by climate. Covering the scope of human history over the past 20,000 years, Fagan draws upon a massive compilation of paleoecological and archaeological evidence not only to reconstruct past climates, but more importantly, to put those climates into the context of human history: exploration, settlement, and the rise and fall of civilizations great and small.... Fagan's thesis is that, in attempting to cope with normal fluctuations of climate, mankind has become increasingly vulnerable to long-term and threshold-type events. This book is highly recommended for college-level classes, as it presents a new perspective on human history, and for general audiences considering the implications and the challenges posed by human-induced global climate change."

—Reviewed by Dale Toweill in Science Books & Films, 40/3 (May-June 2004), p. 114.

See page 28 for additional suggestions for recommended reading.

WEATHER AND CLIMATE (4B)

The earth has a variety of climatic patterns, which consist of different conditions of temperature, precipitation, humidity, wind, air pressure, and other atmospheric phenomena. These result from a variety of factors. Climate and changes in climate have influenced in the past and will continue to influence what kinds of life forms are able to exist. Understanding the basic principles that contribute to maintaining and causing changes in weather and climate increases our ability to forecast and moderate the effects of weather and to make informed decisions about human activities that may contribute to climate change.

The map is organized around four strands—*temperature and winds, water cycle, atmosphere,* and *climate change*. The progression of understanding begins in the elementary grades with observations about heat transfer, changes in water from one state to another, and changes in weather over the course of a day and over the course of seasons. By middle school, the focus is on the water cycle, patterns of change in temperature, and the notion of climate change. In high school, seasons and winds and the water cycle are related to gravity and the earth's rotation, and climate change is related to natural causes and human activities.

Benchmarks in this map about temperature and winds draw on ideas about heat transfer and transformation in the **ENERGY TRANSFORMATIONS** map. Benchmarks in the *climate change* strand are also related to the **SCIENCE AND SOCIETY** map. The widespread use of climate models to improve our understanding of the earth's climate system and climate change suggests a connection to benchmarks in the **MODELS** map as well.

NOTES

The left-hand side of the *temperature and winds* strand presents a progression of understanding of seasons. The explanation of the seasons in terms of the tilt of the earth requires students to engage in fairly complex spatial reasoning. For this reason, although the idea is introduced at the 6-8 grade level in *Benchmarks*, the map places it (4B/H3) at the 9-12 level.

Benchmarks related to the heating of materials and the transfer of thermal energy lay the conceptual groundwork for understanding solar heating, global circulation, seasonal weather patterns and climate, and the effect of greenhouse gases. To understand how thermal energy moves in both oceanic and atmospheric systems, students need to know that convective currents are an essential mechanism that aids in that movement. In middle school, understanding of convection currents is linked to experiences with relevant phenomena. Understanding convection in terms of gravity, buoyant forces, and pressure is not expected until high school. It is not necessary for students to have a molecular comprehension of thermal energy to be able to understand atmospheric and oceanic circulation patterns and their role in climate.

Several lines of conceptual development converge in the new 9-12 benchmark that begins "Climatic conditions result from…." These include an understanding of temperature patterns over the earth, atmospheric and oceanic circulation patterns, and the water cycle. A double-headed arrow between this benchmark and another new benchmark (4B/H6) on climate change indicates that they are closely related but that neither is conceptually dependent on the other.

RESEARCH IN *BENCHMARKS*

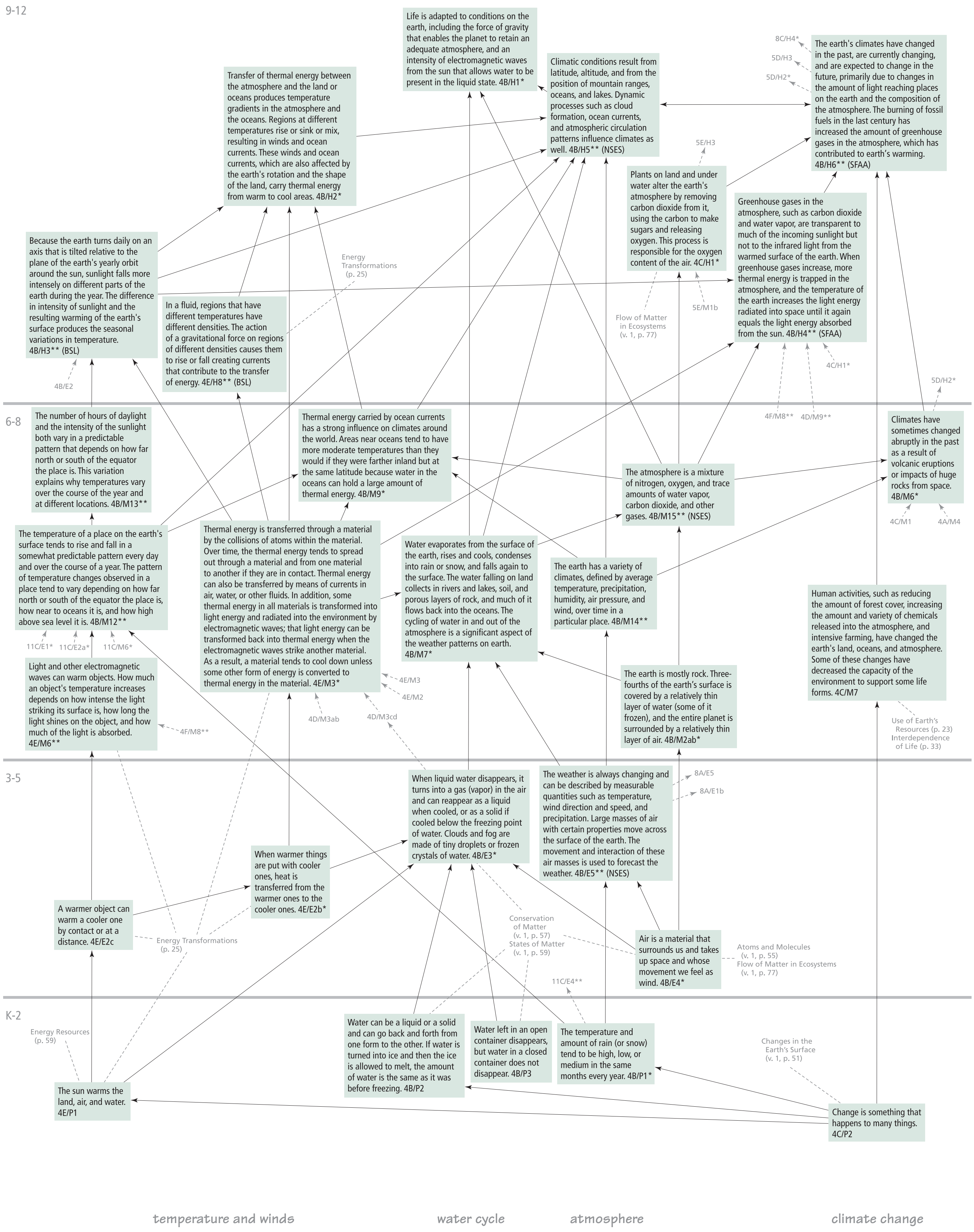
Students of all ages (including college students and adults) have difficulty understanding what causes the seasons. Students may not be able to understand explanations of the seasons before they reasonably understand the relative size, motion, and distance of the sun and the earth (Sadler, 1987; Vosniadou, 1991). Many students before and after instruction in earth science think that winter is colder than summer because the earth is farther from the sun in winter (Atwood & Atwood, 1996; Dove, 1998; Philips, 1991; Sadler, 1998). This idea is often related to the belief that the earth orbits the sun in an elongated elliptical path (Galili & Lavrik, 1998; Sadler, 1998). Other students, especially after instruction, think that the distance between the northern hemisphere and the sun changes because the earth leans toward the sun in the summer and away from the sun in winter (Galili & Lavrik, 1998; Sadler, 1998). Students' ideas about how light travels and about the earth-sun relationship, including the shape of the earth's orbit, the period of the earth's revolution around the sun, and the period of the earth's rotation around its axis, may interfere with students' understanding of the seasons (Galili & Lavrik, 1998; Salierno, Edelson, & Sherin, 2005). For example, some students believe that the side of the sun not facing the earth experiences winter, indicating a confusion between the daily rotation of the earth and its yearly revolution around the sun (Salierno, Edelson, & Sherin, 2005).

Although upper elementary students may identify air as existing even in static situations and recognize that it takes space, recognizing that air has weight may be challenging even for high-school students (Sere, 1985; Driver et al., 1994a; Krnel, Watson, & Glazar, 1998). Students of all ages (including college students) may believe that air exerts force or pressure only when it is moving and only downwards (Driver et al., 1994a; Sere, 1985; Henriques, 2002; Nelson, Aron, & Francek, 1992). Only a few middle-school students use the idea of pressure differences between regions of the atmosphere to account for wind; instead, they may account for winds in terms of visible moving objects or the movement of the earth (Driver et al., 1994a).

Before students understand that water is converted to an invisible form, they may initially believe that when water evaporates it ceases to exist, or that it changes location but remains a liquid, or that it is transformed into some other perceptible form (fog, steam, droplets, etc.) (Bar, 1989; Russell, Harlen, & Watt, 1989; Russell & Watt, 1990; Krnel, Watson, & Glazar, 1998). With special instruction, some students in 5th grade may be able to identify the air as the final location of evaporating water (Russell & Watt, 1990), but they must first accept air as a permanent substance (Bar, 1989). For many students, difficulty understanding the existence of water vapor in the atmosphere persists in middle school years (Lee et al., 1993; Johnson, 1998). Students can understand rainfall in terms of gravity once they attribute weight to little drops of water (typically in upper elementary grades), but the mechanism through which condensation occurs may not be understood until high school (Bar, 1989).

Students of all ages may confuse the ozone layer with the greenhouse effect, and may have a tendency to imagine that all environmentally friendly actions help to solve all environmental problems (for example, that the use of unleaded petrol reduces the risk of global warming) (Andersson & Wallin, 2000; Koulaidis & Christidou, 1998; Meadows & Wiesenmayer, 1999; Rye, Rubba, & Wiesenmayer, 1997). Students have difficulty linking relevant elements of knowledge when explaining the greenhouse effect and may confuse the natural greenhouse effect with the enhancement of that effect (Andersson & Wallin, 2000).

See **ENERGY RESOURCES** and **ENERGY TRANSFORMATIONS** for additional research.



Life is adapted to conditions on the earth, including the force of gravity that enables the planet to retain an adequate atmosphere, and an intensity of electromagnetic waves from the sun that allows water to be present in the liquid state. 4B/H1*

Transfer of thermal energy between the atmosphere and the land or oceans produces temperature gradients in the atmosphere and the oceans. Regions at different temperatures rise or sink or mix, resulting in winds and ocean currents. These winds and ocean currents, which are also affected by the earth's rotation and the shape of the land, carry thermal energy from warm to cool areas. 4B/H2*

Climatic conditions result from latitude, altitude, and from the position of mountain ranges, oceans, and lakes. Dynamic processes such as cloud formation, ocean currents, and atmospheric circulation patterns influence climates as well. 4B/H5** (NSES)

The earth's climates have changed in the past, are currently changing, and are expected to change in the future, primarily due to changes in the amount of light reaching places on the earth and the composition of the atmosphere. The burning of fossil fuels in the last century has increased the amount of greenhouse gases in the atmosphere, which has contributed to earth's warming. 4B/H6** (SFAA)

Plants on land and under water alter the earth's atmosphere by removing carbon dioxide from it, using the carbon to make sugars and releasing oxygen. This process is responsible for the oxygen content of the air. 4C/H1*

Greenhouse gases in the atmosphere, such as carbon dioxide and water vapor, are transparent to much of the incoming sunlight but not to the infrared light from the warmed surface of the earth. When greenhouse gases increase, more thermal energy is trapped in the atmosphere, and the temperature of the earth increases the light energy radiated into space until it again equals the light energy absorbed from the sun. 4B/H4** (SFAA)

Because the earth turns daily on an axis that is tilted relative to the plane of the earth's yearly orbit around the sun, sunlight falls more intensely on different parts of the earth during the year. The difference in intensity of sunlight and the resulting warming of the earth's surface produces the seasonal variations in temperature. 4B/H3** (BSL)

In a fluid, regions that have different temperatures have different densities. The action of a gravitational force on regions of different densities causes them to rise or fall creating currents that contribute to the transfer of energy. 4E/H8** (BSL)

The number of hours of daylight and the intensity of the sunlight both vary in a predictable pattern that depends on how far north or south of the equator the place is. This variation explains why temperatures vary over the course of the year and at different locations. 4B/M13**

Thermal energy carried by ocean currents has a strong influence on climates around the world. Areas near oceans tend to have more moderate temperatures than they would if they were farther inland but at the same latitude because water in the oceans can hold a large amount of thermal energy. 4B/M9*

The atmosphere is a mixture of nitrogen, oxygen, and trace amounts of water vapor, carbon dioxide, and other gases. 4B/M15** (NSES)

Climates have sometimes changed abruptly in the past as a result of volcanic eruptions or impacts of huge rocks from space. 4B/M6*

The temperature of a place on the earth's surface tends to rise and fall in a somewhat predictable pattern every day and over the course of a year. The pattern of temperature changes observed in a place tend to vary depending on how far north or south of the equator the place is, how near to oceans it is, and how high above sea level it is. 4B/M12**

Thermal energy is transferred through a material by the collisions of atoms within the material. Over time, the thermal energy tends to spread out through a material and from one material to another if they are in contact. Thermal energy can also be transferred by means of currents in air, water, or other fluids. In addition, some thermal energy in all materials is transformed into light energy and radiated into the environment by electromagnetic waves; that light energy can be transformed back into thermal energy when the electromagnetic waves strike another material. As a result, a material tends to cool down unless some other form of energy is converted to thermal energy in the material. 4E/M3*

Water evaporates from the surface of the earth, rises and cools, condenses into rain or snow, and falls again to the surface. The water falling on land collects in rivers and lakes, soil, and porous layers of rock, and much of it flows back into the oceans. The cycling of water in and out of the atmosphere is a significant aspect of the weather patterns on earth. 4B/M7*

The earth has a variety of climates, defined by average temperature, precipitation, humidity, air pressure, and wind, over time in a particular place. 4B/M14**

Human activities, such as reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming, have changed the earth's land, oceans, and atmosphere. Some of these changes have decreased the capacity of the environment to support some life forms. 4C/M7

Light and other electromagnetic waves can warm objects. How much an object's temperature increases depends on how intense the light striking its surface is, how long the light shines on the object, and how much of the light is absorbed. 4E/M6**

The earth is mostly rock. Three-fourths of the earth's surface is covered by a relatively thin layer of water (some of it frozen), and the entire planet is surrounded by a relatively thin layer of air. 4B/M2ab*

When liquid water disappears, it turns into a gas (vapor) in the air and can reappear as a liquid when cooled, or as a solid if cooled below the freezing point of water. Clouds and fog are made of tiny droplets or frozen crystals of water. 4B/E3*

The weather is always changing and can be described by measurable quantities such as temperature, wind direction and speed, and precipitation. Large masses of air with certain properties move across the surface of the earth. The movement and interaction of these air masses is used to forecast the weather. 4B/E5** (NSES)

When warmer things are put with cooler ones, heat is transferred from the warmer ones to the cooler ones. 4E/E2b*

A warmer object can warm a cooler one by contact or at a distance. 4E/E2c

Air is a material that surrounds us and takes up space and whose movement we feel as wind. 4B/E4*

Water can be a liquid or a solid and can go back and forth from one form to the other. If water is turned into ice and then the ice is allowed to melt, the amount of water is the same as it was before freezing. 4B/P2

Water left in an open container disappears, but water in a closed container does not disappear. 4B/P3

The temperature and amount of rain (or snow) tend to be high, low, or medium in the same months every year. 4B/P1*

The sun warms the land, air, and water. 4E/P1

Change is something that happens to many things. 4C/P2

USE OF EARTH'S RESOURCES (4B)

Of all the diverse planets and moons in our solar system, only the earth appears to be capable of supporting life as we know it. Water and air are essential resources; altering the quality of the water or the composition of the earth's atmosphere can have serious consequences for living systems. Informed citizens need to understand the implications of decisions about the use of Earth's resources.

The map is organized around four strands—*use of energy resources, needs of organisms for Earth's resources, human impact on the environment,* and *use of material resources*. In the elementary grades, the focus is on the survival needs of organisms and people's use of fuels. In middle school, the focus is on the use and trade-offs of different energy and material resources and on the dependence and impact of organisms (particularly humans) on their environment. In high school, the focus is on factors affecting the equilibrium of the synthesis and depletion of resources and the recycling of waste products resulting from resource use.

This map is closely related to both the **ENERGY RESOURCES** and **MATERIALS SCIENCE** maps.

NOTES

The *use of energy resources* strand focuses on the increased use and depletion of energy resources. Benchmarks in this strand also appear in the **ENERGY RESOURCES** map. Most of the benchmarks in the *use of material resources* strand also appear in the **MATERIALS SCIENCE** map, which addresses in more depth the problem of waste disposal and recycling.

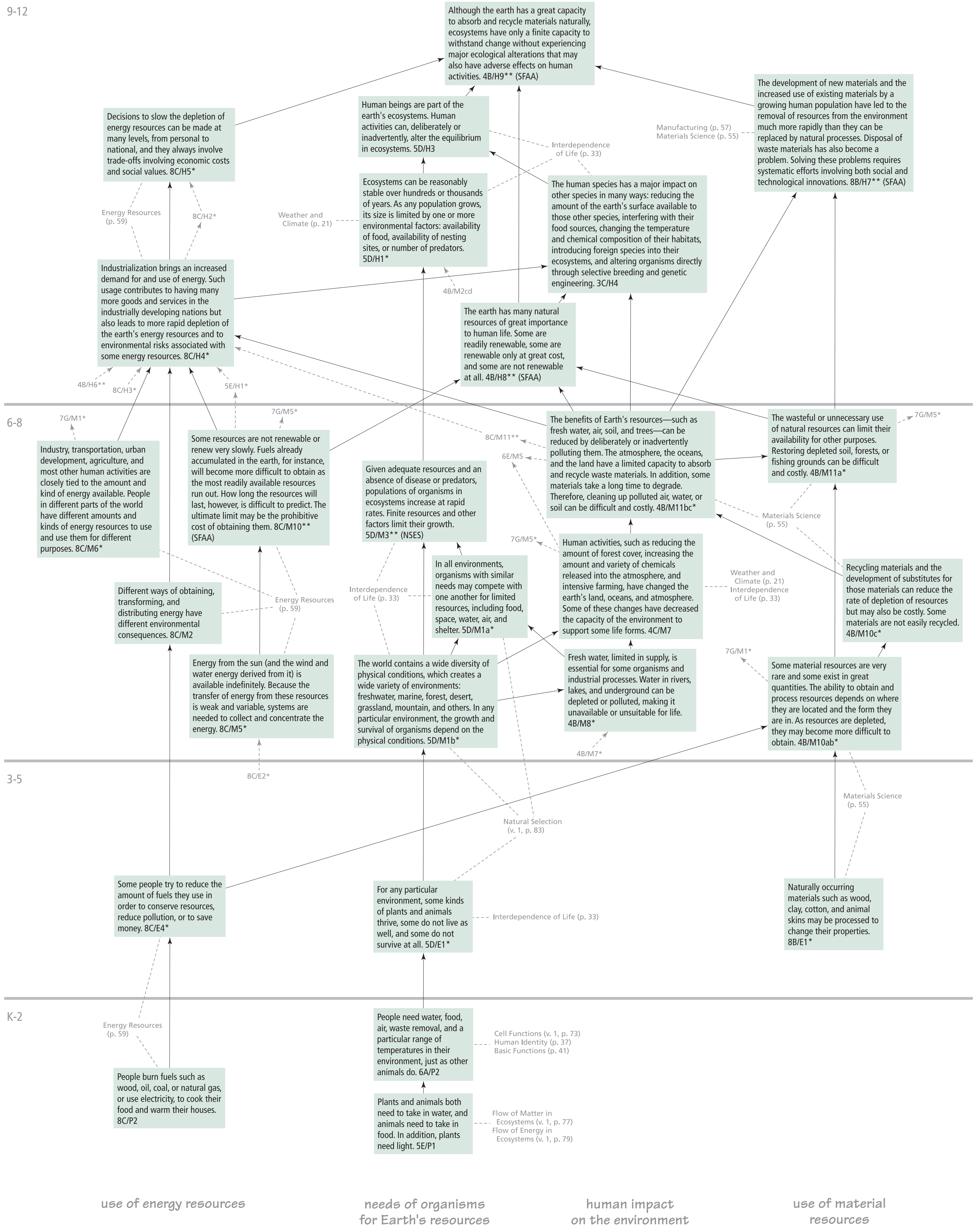
The *use of energy resources* and *use of material resources* strands include many similar key ideas: Some resources are renewable, some are not, and some are renewable at great cost; some resources take a very long time to accumulate; the growth of technology has led to increased use of resources; as resources are depleted, they may be more difficult and costly to obtain; and use of resources is associated with environmental risks.

The *needs of organisms for Earth's resources* strand addresses how organisms depend on their environment for resources, and shares several benchmarks with the **INTERDEPENDENCE OF LIFE** map. The *human impact on the environment* strand considers how humans affect the environment. The two strands converge on the 9-12 benchmark "Human beings are part of the earth's ecosystems…."

Students' understanding of the use of Earth's resources should be integrated with their growing knowledge of the processes that shape the earth (see the *Atlas 1* map **CHANGES IN THE EARTH'S SURFACE**). For example, knowing about the slow nature of the rock cycle would enable students to understand that mineral resources cannot be renewed for human use within a time span that is determined by the rate at which humans deplete them.

RESEARCH IN *BENCHMARKS*

No relevant research available in *Benchmarks*.



Although the earth has a great capacity to absorb and recycle materials naturally, ecosystems have only a finite capacity to withstand change without experiencing major ecological alterations that may also have adverse effects on human activities. 4B/H9** (SFAA)

The development of new materials and the increased use of existing materials by a growing human population have led to the removal of resources from the environment much more rapidly than they can be replaced by natural processes. Disposal of waste materials has also become a problem. Solving these problems requires systematic efforts involving both social and technological innovations. 8B/H7** (SFAA)

Decisions to slow the depletion of energy resources can be made at many levels, from personal to national, and they always involve trade-offs involving economic costs and social values. 8C/H5*

Human beings are part of the earth's ecosystems. Human activities can, deliberately or inadvertently, alter the equilibrium in ecosystems. 5D/H3

Ecosystems can be reasonably stable over hundreds or thousands of years. As any population grows, its size is limited by one or more environmental factors: availability of food, availability of nesting sites, or number of predators. 5D/H1*

The human species has a major impact on other species in many ways: reducing the amount of the earth's surface available to those other species, interfering with their food sources, changing the temperature and chemical composition of their habitats, introducing foreign species into their ecosystems, and altering organisms directly through selective breeding and genetic engineering. 3C/H4

Industrialization brings an increased demand for and use of energy. Such usage contributes to having many more goods and services in the industrially developing nations but also leads to more rapid depletion of the earth's energy resources and to environmental risks associated with some energy resources. 8C/H4*

The earth has many natural resources of great importance to human life. Some are readily renewable, some are renewable only at great cost, and some are not renewable at all. 4B/H8** (SFAA)

Industry, transportation, urban development, agriculture, and most other human activities are closely tied to the amount and kind of energy available. People in different parts of the world have different amounts and kinds of energy resources to use and use them for different purposes. 8C/M6*

Some resources are not renewable or renew very slowly. Fuels already accumulated in the earth, for instance, will become more difficult to obtain as the most readily available resources run out. How long the resources will last, however, is difficult to predict. The ultimate limit may be the prohibitive cost of obtaining them. 8C/M10** (SFAA)

Given adequate resources and an absence of disease or predators, populations of organisms in ecosystems increase at rapid rates. Finite resources and other factors limit their growth. 5D/M3** (NSES)

The benefits of Earth's resources—such as fresh water, air, soil, and trees—can be reduced by deliberately or inadvertently polluting them. The atmosphere, the oceans, and the land have a limited capacity to absorb and recycle waste materials. In addition, some materials take a long time to degrade. Therefore, cleaning up polluted air, water, or soil can be difficult and costly. 4B/M11bc*

The wasteful or unnecessary use of natural resources can limit their availability for other purposes. Restoring depleted soil, forests, or fishing grounds can be difficult and costly. 4B/M11a*

In all environments, organisms with similar needs may compete with one another for limited resources, including food, space, water, air, and shelter. 5D/M1a*

Human activities, such as reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming, have changed the earth's land, oceans, and atmosphere. Some of these changes have decreased the capacity of the environment to support some life forms. 4C/M7

Recycling materials and the development of substitutes for those materials can reduce the rate of depletion of resources but may also be costly. Some materials are not easily recycled. 4B/M10c*

Different ways of obtaining, transforming, and distributing energy have different environmental consequences. 8C/M2

Energy from the sun (and the wind and water energy derived from it) is available indefinitely. Because the transfer of energy from these resources is weak and variable, systems are needed to collect and concentrate the energy. 8C/M5*

The world contains a wide diversity of physical conditions, which creates a wide variety of environments: freshwater, marine, forest, desert, grassland, mountain, and others. In any particular environment, the growth and survival of organisms depend on the physical conditions. 5D/M1b*

Fresh water, limited in supply, is essential for some organisms and industrial processes. Water in rivers, lakes, and underground can be depleted or polluted, making it unavailable or unsuitable for life. 4B/M8*

Some material resources are very rare and some exist in great quantities. The ability to obtain and process resources depends on where they are located and the form they are in. As resources are depleted, they may become more difficult to obtain. 4B/M10ab*

Some people try to reduce the amount of fuels they use in order to conserve resources, reduce pollution, or to save money. 8C/E4*

For any particular environment, some kinds of plants and animals thrive, some do not live as well, and some do not survive at all. 5D/E1*

Naturally occurring materials such as wood, clay, cotton, and animal skins may be processed to change their properties. 8B/E1*

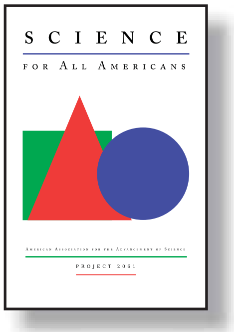
People need water, food, air, waste removal, and a particular range of temperatures in their environment, just as other animals do. 6A/P2

People burn fuels such as wood, oil, coal, or natural gas, or use electricity, to cook their food and warm their houses. 8C/P2

Plants and animals both need to take in water, and animals need to take in food. In addition, plants need light. 5E/P1

From Chapter 8:
The Designed World

ENERGY SOURCES AND USE



Energy Sources

Industry, transportation, urban development, agriculture, and most other human activities are closely tied to the amount and kind of energy available. Energy is required for technological processes: taking apart, putting together, moving around, communicating, and getting raw materials, and then working them and recycling them.

Different sources of energy and ways of using them have different costs, implications, and risks. Some of the resources—direct sunlight, wind, and water—will continue to be available indefinitely. Plant fuels—wood and grasses—are self renewing, but only at a limited rate and only if we plant as much as we harvest. Fuels already accumulated in the earth—coal, oil and natural gas, and uranium—will become more difficult to obtain as the most readily available sources run out. When scarcity threatens, new technology may make it possible to use the remaining sources better by digging deeper, processing lower concentration ores, or mining the ocean bed. Just when they will run out completely, however, is difficult to predict. The ultimate limit may be prohibitive cost rather than complete disappearance—a question of when the energy required to obtain the resources becomes greater than the energy those resources will provide.

Sunlight is the ultimate source of most of the energy we use. It becomes available to us in several ways: The energy of sunlight is captured directly in plants, and it heats the air, land, and water to cause wind and rain. But the flux of energy is fairly weak, and large collection systems are necessary to concentrate energy for most technological uses: Hydroelectric energy technology uses rainwater concentrated in rivers by runoff from vast land areas; windmills use the flow of air produced by the heating of large land and ocean surfaces; and electricity generated from wind power and directly from sunlight falling on light-sensitive surfaces requires very large collection systems. Small-scale energy production for household use can be achieved in part by using windmills and direct solar heating, but cost-efficient technology for the large-scale use of windmills and solar heating has not yet been developed.

For much of history, burning wood was the most common source of intense energy for cooking, for heating dwellings, and for running machines. Most of the energy used today is derived from burning fossil fuels, which have stored sunlight energy that plants collected over millions of years. Coal was the most widely used fossil fuel until recently. But in the last century, oil and its associated natural gas have become preferred because of their ease of collection, multiple uses in industry, and ability to be concentrated into a readily portable source of energy for vehicles such as cars, trucks, trains, and airplanes. All burning of fossil fuels, unfortunately, dumps into the atmosphere waste products that may threaten health and life; the mining of coal underground is extremely hazardous to the health and safety of miners, and can leave the earth scarred; and oil spills can endanger marine life. Returning to the burning of wood is not a satisfactory alternative, for that too adds so-called greenhouse gases to the atmosphere; and overcutting trees for fuel depletes the forests needed to maintain healthy ecosystems both locally and worldwide.

But there are other sources of energy. One is the fission of the nuclei of heavy elements, which—compared to the burning of fossil fuels—releases an immense quantity of energy in relation to the mass of material used. In nuclear reactors, the energy generated is used mostly to boil water into steam, which drives electric generators. The required uranium is in large, although ultimately limited, supply. The waste products of fission, however, are highly radioactive and remain so for thousands of years. The technical problem of reasonably safe disposal of these fission products is compounded by public fear of radioactivity and worry about the sabotage of nuclear power plants and the theft of nuclear materials to make weapons. Controlled nuclear fusion reactions are a potentially much greater source of energy, but the technology has not yet proved feasible. Fusion reactions would use fuel materials that are safer in themselves, although there would still be a problem of disposing of worn-out construction materials made radioactive by the process. And as always with new technology, there may be some unanticipated risks.

Energy Use

Energy must be distributed from its source to where it is to be used. For much of human history, energy had to be used on site—at the windmill or water mill, or close to the forest. In time, improvement in transportation made it possible for fossil fuels to be burned far from where they were mined, and intensive manufacturing could spread much more widely. In this century, it has been common to use energy sources to generate electricity, which can deliver energy almost instantly along wires far from the source. Electricity, moreover, can conveniently be transformed into and from other kinds of energy.

As important as the amount of energy available is its quality: the extent to which it can be concentrated and the convenience with which it can be used. A central factor in technological change has been how hot a fire could be made. The discovery of new fuels, the design of better ovens and furnaces, and the forced delivery of air or pure oxygen have progressively increased the temperature available for firing clay and glass, smelting metal ores, and purifying and working metals. Lasers are a new tool for focusing radiation energy with great intensity and control, and they are being developed for a growing number of applications—from making computer chips and performing eye surgery to communicating by satellite.

During any useful transformation of energy from one form to another, there is inevitably some dissipation of energy into the environment. Except for the energy bound in the structure of manufactured materials, most of our uses of energy result in all of it eventually dissipating away, slightly warming the environment and ultimately radiating into space. In this practical sense, energy gets "used up," even though it is still around somewhere.

People have invented ingenious ways of deliberately bringing about energy transformations that are useful to them. These ways range from the simple acts of throwing rocks (which transforms biochemical energy into motion) and starting fires (chemical energy into heat and light), to using such complex devices as steam engines (heat energy into motion), electric generators (motion into electrical energy), nuclear fission reactors (nuclear energy into heat), and solar converters (radiation energy into electrical energy). In the operation of these devices, as in all phenomena, the useful energy output—that is, what is available for further change—is always less than the energy input, with the difference usually appearing as heat. One goal in the design of such devices is to make them as efficient as possible—that is, to maximize the useful output for a given input.

Consistent with the general differences in the global distribution of wealth and development, energy is used at highly unequal rates in different parts of the world. Industrialized nations use tremendous amounts of energy for chemical and mechanical processes in factories, creating synthetic materials, producing fertilizer for agriculture, powering industrial and personal transportation, heating and cooling buildings, lighting, and communications. The demand for energy at a still greater rate is likely as the world's population grows and more nations industrialize. Along with large-scale use, there is large-scale waste (for example, vehicles with more power than their function warrants and buildings insufficiently insulated against heat transfer). But other factors, especially an increase in the efficiency of energy use, can help reduce the demand for additional energy.

Depletion of energy sources can be slowed by both technical and social means. Technical means include maximizing the usefulness that we realize from a given input of energy by means of good design of the transformation device, by means of insulation where we want to restrict heat flow (for example, insulating hot-water tanks), or by doing something with the heat as it leaks out. Social means include government, which may restrict low-priority uses of energy or may establish requirements for efficiency (such as in automobile engines) or for insulation (as in house construction). Individuals also may make energy efficiency a consideration in their own choice and use of technology (for example, turning out lights and driving high-efficiency cars)—either to conserve energy as a matter of principle or to reduce their personal long-term expenses. As always, there are trade-offs. For example, better-insulated houses stay warmer in winter and cooler in summer, but restrict ventilation and thus may increase the indoor accumulation of pollutants.

From Chapter 5: The Living Environment

Interdependence of Life

Every species is linked, directly or indirectly, with a multitude of others in an ecosystem. Plants provide food, shelter, and nesting sites for other organisms. For their part, many plants depend upon animals for help in reproduction (bees pollinate flowers, for instance) and for certain nutrients (such as minerals in animal waste products). All animals are part of food webs that include plants and animals of other species (and sometimes the same species). The predator/prey relationship is common, with its offensive tools for predators—teeth, beaks, claws, venom, etc.—and its defensive tools for prey—camouflage to hide, speed to escape, shields or spines to ward off, irritating substances to repel. Some species come to depend very closely on others (for instance, pandas or koalas can eat only certain species of trees). Some species have become so adapted to each other that neither could survive without the other (for example, the wasps that nest only in figs and are the only insect that can pollinate them).

There are also other relationships between organisms. Parasites get nourishment from their host organisms, sometimes with bad consequences for the hosts. Scavengers and decomposers feed only on dead animals and plants. And some organisms have mutually beneficial relationships—for example, the bees that sip nectar from flowers and incidentally carry pollen from one flower to the next, or the bacteria that live in our intestines and incidentally synthesize some vitamins and protect the intestinal lining from germs.

But the interaction of living organisms does not take place on a passive environmental stage. Ecosystems are shaped by the nonliving environment of land and water—solar radiation, rainfall, mineral concentrations, temperature, and topography. The world contains a wide diversity of physical conditions, which creates a wide variety of environments: freshwater and oceanic, forest, desert, grassland, tundra, mountain, and many others. In all these environments, organisms use vital earth resources, each seeking its share in specific ways that are limited by other organisms. In every part of the habitable environment, different organisms vie for food, space, light, heat, water, air, and shelter. The linked and fluctuating interactions of life forms and environment compose a total ecosystem; understanding any one part of it well requires knowledge of how that part interacts with the others.

The interdependence of organisms in an ecosystem often results in approximate stability over hundreds or thousands of years. As one species proliferates, it is held in check by one or more environmental factors: depletion of food or nesting sites, increased loss to predators, or invasion by parasites. If a natural disaster such as flood or fire occurs, the damaged ecosystem is likely to recover in a succession of stages that eventually results in a system similar to the original one.

Like many complex systems, ecosystems tend to show cyclic fluctuations around a state of approximate equilibrium. In the long run, however, ecosystems inevitably change when climate changes or when very different new species appear as a result of migration or evolution (or are introduced deliberately or inadvertently by humans).

ENERGY RESOURCES (8C)

Industry, transportation, urban development, agriculture, and most other human activities are closely tied to the amount and kind of energy available. Energy is required for technological processes and needs to be distributed from its source to where it is to be used. Energy sources and ways of using them have different costs, implications and risks. Moreover, the increasing world demand for energy raises national and global issues and the need for an informed public to address them.

The map is organized around three strands—*resources, efficient use,* and *societal and environmental implications*. In the elementary grades the focus is on energy resources and basic ideas about heat transfer. In middle school the emphasis shifts to the transformation and distribution of various energy resources and their environmental consequences. In high school the focus is on trade-offs of various energy resources, the efficiency of energy transformations, and the inevitable dissipation of thermal energy into the environment. At each level, benchmarks about energy are connected to benchmarks about technology and societal implications of energy use.

This map is closely related to the **ENERGY TRANSFORMATIONS** and **INDUSTRIAL REVOLUTION** maps. It also illustrates general principles about the nature of technology in **THE INTERACTION OF TECHNOLOGY AND SOCIETY** and **DECISIONS ABOUT USING TECHNOLOGY** maps in *Atlas 1* and the **SCIENCE AND SOCIETY** and **TECHNOLOGY AND SCIENCE** maps in this volume and can serve as a context for learning benchmarks on these maps.

NOTES

The *resources* strand moves from ideas about the variety of energy resources available to ideas about whether different resources are renewable or not and why. The benchmark "Sunlight is the ultimate source…" is positioned at the 3-5 grade level in *Benchmarks* but has been delayed until the 9-12 level in the map. This change in grade level placement recognizes that understanding how the energy in fossil fuels comes from energy captured by plants long ago requires students to have a more sophisticated knowledge of matter and energy transformations in ecosystems and of processes that shape the earth.

In the *efficient use* strand, the new grades 9-12 benchmark "The useful energy output of a device…" is to be interpreted broadly and intends for students to understand the concept of designing devices to maximize the efficiency of transformation. A prerequisite to understanding the concept of "useful energy" is the idea expressed in benchmark 4E/H3 that less can be done with energy that is spread out.

Two new middle-school benchmarks in the *efficient use* strand come from *Science for All Americans*. The benchmark "Energy is required for technological processes…" describes a variety of processes that use energy and provides the background for appreciating the increased demand and use of energy in industrialized societies. Another new benchmark 8C/M8 expects students to become familiar with a variety of energy-transforming devices and consider what their inputs and outputs are in preparation for discussing the devices' efficiency.

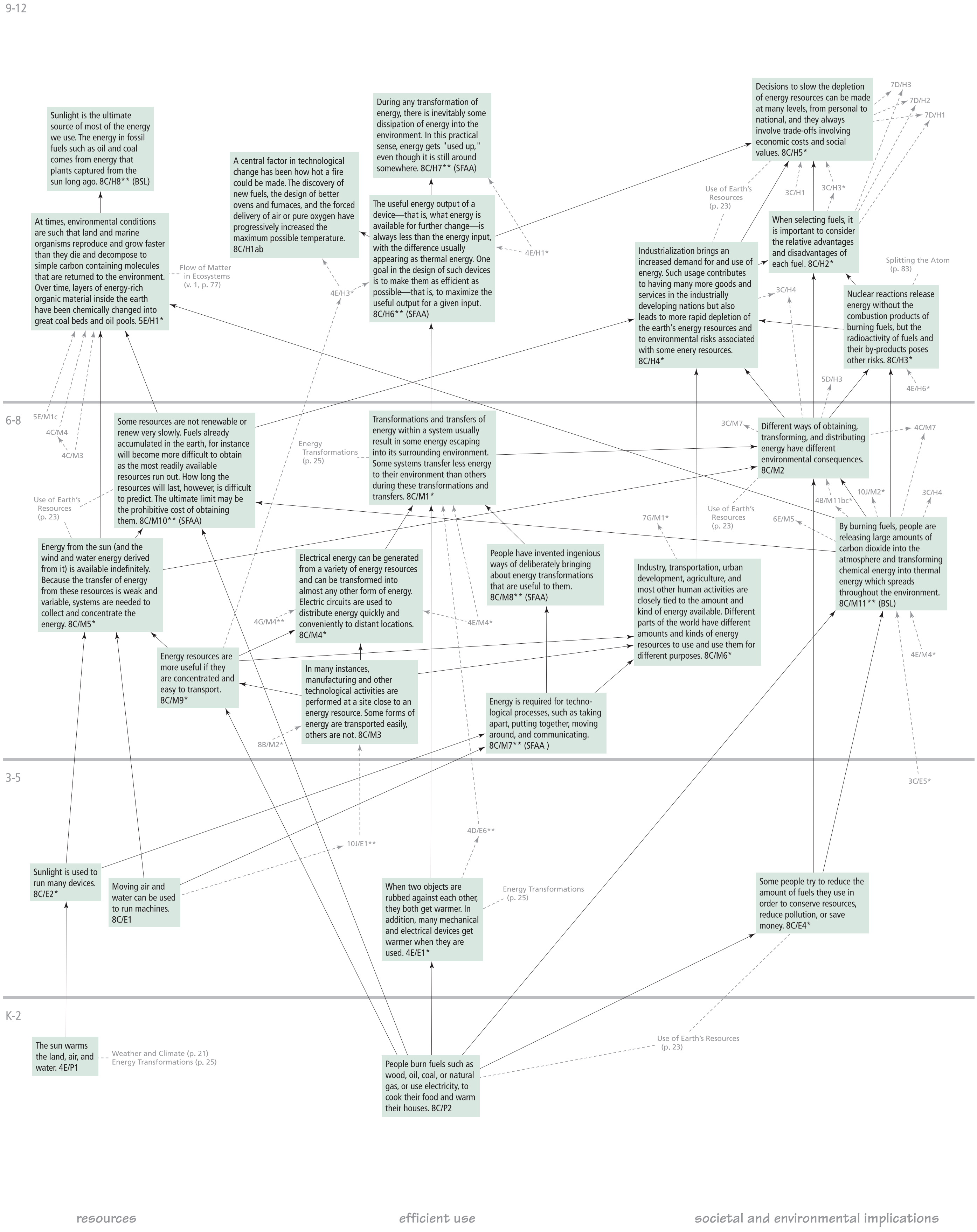
Energy use is always associated with costs and benefits. Hence, the high-school benchmark "Decisions to slow the depletion of energy resources…" is linked to a number of benchmarks related to considering costs and benefits of using technologies, the complexities of decision making, and social trade-offs.

RESEARCH IN *BENCHMARKS*

Students may identify the transfer of energy to the environment with pollution or waste materials being thrown to the environment (Amettler & Pinto, 2002). Students are not likely to be aware of the heating of the environment which accounts for the energy dissipated (Driver et al., 1994b). Students who have developed an awareness of heat transfer to the environment as a component of most energy transformations may assume that such a transfer results in energy "being lost." They do not think that energy has become spread out and is not as useful as energy which is "concentrated" in one place (Driver et al., 1994b).

Middle-school students do not always explain the process of heating and cooling in terms of heat transfer (Tiberghien, 1983; Tomasini & Balandi, 1987). Some students think that "cold" is being transferred from a colder to a warmer object, others that both "heat" and "cold" are transferred at the same time. Middle- and high-school students often do not explain heat conduction phenomena as interactions (Kesidou, Duit, & Glynn, 1995; Tiberghien, 1985). For example, students sometimes think that, depending on its properties, an object which is at the same temperature with its surroundings can cool down spontaneously. Even after instruction, students don't always give up their naive notion that some substances (for example, flour, sugar, or air) cannot heat up (Tiberghien, 1985) or that metals get hot quickly because "they attract heat," "suck heat in," or "hold heat well" (Erickson, 1985; Lewis & Linn, 1994). Middle-school students believe different materials in the same surroundings have different temperatures because they feel different (for example, metal feels colder than wood). As a result, they may not recognize the universal tendency to temperature equalization (Tomasini & Balandi, 1987; Lewis & Linn, 1994). Helping most students develop scientific ideas in this domain appears to be possible only with long-term interventions that focus on connecting scientific ideas about rate of heat transfer, insulation/conduction, and thermal equilibrium with each other and with ideas students hold based on everyday experiences (Clark & Linn, 2003; Clark & Jorde, 2004; Clark, 2006).

See **ENERGY TRANSFORMATIONS** for additional research.



Sunlight is the ultimate source of most of the energy we use. The energy in fossil fuels such as oil and coal comes from energy that plants captured from the sun long ago. 8C/H8** (BSL)

At times, environmental conditions are such that land and marine organisms reproduce and grow faster than they die and decompose to simple carbon containing molecules that are returned to the environment. Over time, layers of energy-rich organic material inside the earth have been chemically changed into great coal beds and oil pools. 5E/H1*

A central factor in technological change has been how hot a fire could be made. The discovery of new fuels, the design of better ovens and furnaces, and the forced delivery of air or pure oxygen have progressively increased the maximum possible temperature. 8C/H1ab

During any transformation of energy, there is inevitably some dissipation of energy into the environment. In this practical sense, energy gets "used up," even though it is still around somewhere. 8C/H7** (SFAA)

The useful energy output of a device—that is, what energy is available for further change—is always less than the energy input, with the difference usually appearing as thermal energy. One goal in the design of such devices is to make them as efficient as possible—that is, to maximize the useful output for a given input. 8C/H6** (SFAA)

Decisions to slow the depletion of energy resources can be made at many levels, from personal to national, and they always involve trade-offs involving economic costs and social values. 8C/H5*

Industrialization brings an increased demand for and use of energy. Such usage contributes to having many more goods and services in the industrially developing nations but also leads to more rapid depletion of the earth's energy resources and to environmental risks associated with some enery resources. 8C/H4*

When selecting fuels, it is important to consider the relative advantages and disadvantages of each fuel. 8C/H2*

Nuclear reactions release energy without the combustion products of burning fuels, but the radioactivity of fuels and their by-products poses other risks. 8C/H3*

Some resources are not renewable or renew very slowly. Fuels already accumulated in the earth, for instance will become more difficult to obtain as the most readily available resources run out. How long the resources will last, however, is difficult to predict. The ultimate limit may be the prohibitive cost of obtaining them. 8C/M10** (SFAA)

Transformations and transfers of energy within a system usually result in some energy escaping into its surrounding environment. Some systems transfer less energy to their environment than others during these transformations and transfers. 8C/M1*

Different ways of obtaining, transforming, and distributing energy have different environmental consequences. 8C/M2

Energy from the sun (and the wind and water energy derived from it) is available indefinitely. Because the transfer of energy from these resources is weak and variable, systems are needed to collect and concentrate the energy. 8C/M5*

Electrical energy can be generated from a variety of energy resources and can be transformed into almost any other form of energy. Electric circuits are used to distribute energy quickly and conveniently to distant locations. 8C/M4*

People have invented ingenious ways of deliberately bringing about energy transformations that are useful to them. 8C/M8** (SFAA)

Industry, transportation, urban development, agriculture, and most other human activities are closely tied to the amount and kind of energy available. Different parts of the world have different amounts and kinds of energy resources to use and use them for different purposes. 8C/M6*

By burning fuels, people are releasing large amounts of carbon dioxide into the atmosphere and transforming chemical energy into thermal energy which spreads throughout the environment. 8C/M11** (BSL)

Energy resources are more useful if they are concentrated and easy to transport. 8C/M9*

In many instances, manufacturing and other technological activities are performed at a site close to an energy resource. Some forms of energy are transported easily, others are not. 8C/M3

Energy is required for technological processes, such as taking apart, putting together, moving around, and communicating. 8C/M7** (SFAA)

Sunlight is used to run many devices. 8C/E2*

Moving air and water can be used to run machines. 8C/E1

When two objects are rubbed against each other, they both get warmer. In addition, many mechanical and electrical devices get warmer when they are used. 4E/E1*

Some people try to reduce the amount of fuels they use in order to conserve resources, reduce pollution, or save money. 8C/E4*

The sun warms the land, air, and water. 4E/P1

People burn fuels such as wood, oil, coal, or natural gas, or use electricity, to cook their food and warm their houses. 8C/P2

INTERDEPENDENCE OF LIFE (5D)

Every species is linked, directly or indirectly, with a multitude of others in an ecosystem. Ecosystems are shaped by both the nonliving environment and by its inhabitants, including humans. Hence, benchmarks on this map are closely related to benchmarks on the **FLOW OF MATTER IN ECOSYSTEMS** map in *Atlas 1* and to benchmarks on the **USE OF EARTH'S RESOURCES** map.

The map is organized around four strands—*interactions among organisms, dynamic nature of ecosystems, dependence of organisms on their environment,* and *human impact*. The learning progression begins in the elementary grades with an emphasis on the needs of organisms and how they are met in different environments. In middle school, the emphasis is on understanding how organisms (including humans) interact with one another and with the environment in a wide variety of ecosystems. In high school, students' knowledge about the interdependence of organisms in ecosystems and the environment is linked to more abstract ideas about stability and change in systems.

NOTES

Students may not regard food as a scarce resource for animals and, hence, may not consider competition among species for food resources. Therefore, the grades 6-8 benchmark "In all environments, organisms with similar needs…" was modified to include the idea that resources for which animals compete are limited. A new benchmark (5D/M3) was added to the map to extend students' understanding of the implications of finite resources for populations of organisms.

Students' knowledge of the variety of environments and changes in environmental conditions on Earth needs to be integrated with their growing understanding of earth science, in particular with benchmarks related to climate in the **WEATHER AND CLIMATE** map. As students become more familiar with the characteristics of systems in general, they can begin to recognize some of those characteristics—such as interdependence of parts, stability, and change—as they appear in ecosystems.

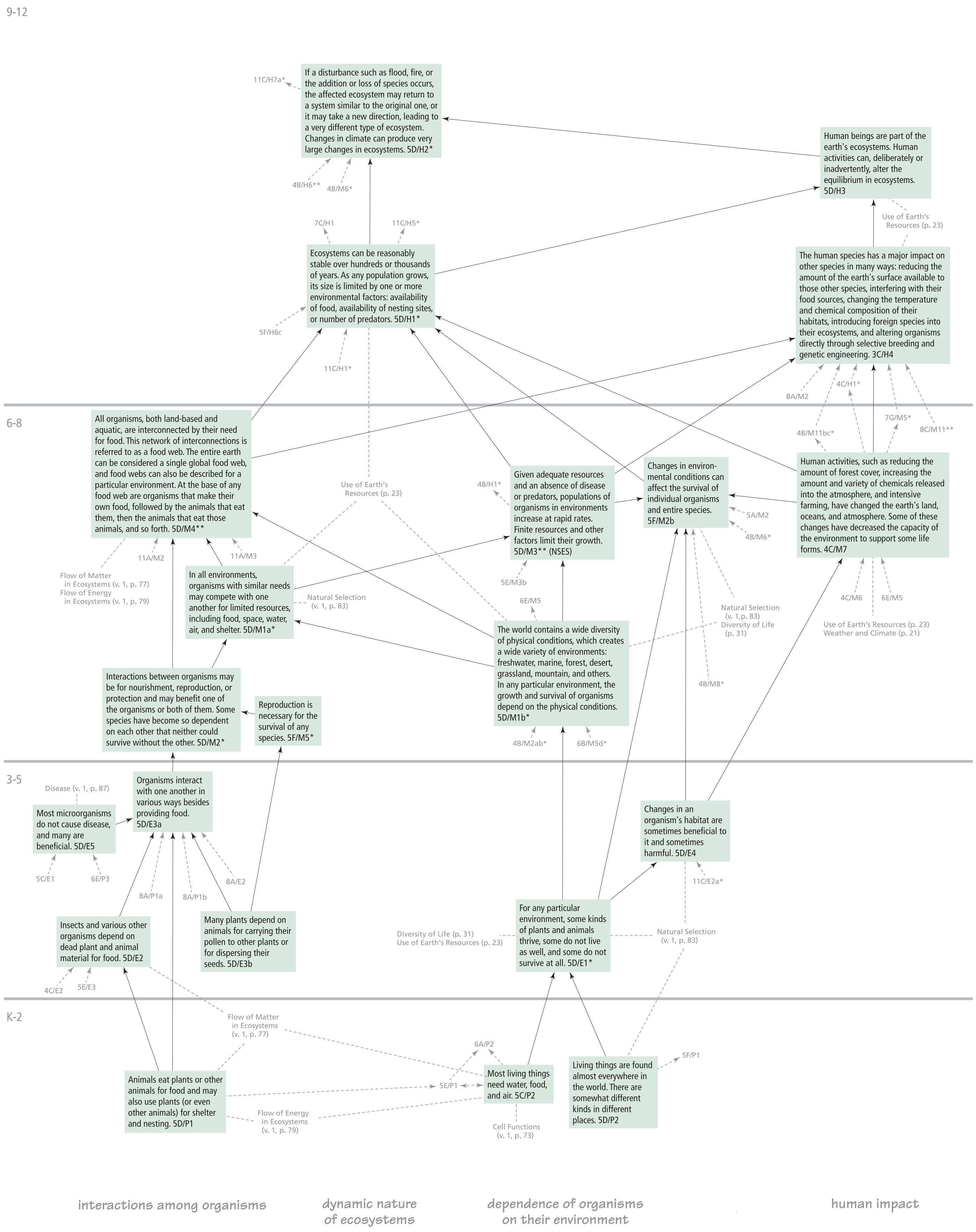
Ethical choices and the implications of various uses of the environment are not explicitly addressed in this map. However, the map can provide contexts for learning about the effects of science on society, ethics in research, and the incompleteness of scientific answers as presented on the **SCIENCE AND SOCIETY** map and the **SCIENTIFIC WORLD VIEW** map.

RESEARCH IN *BENCHMARKS*

Lower elementary-school students can understand simple food links involving two organisms. Yet they often think of organisms as independent of each other but dependent on people to supply them with food and shelter. Upper elementary-school students may not believe food is a scarce resource in ecosystems, thinking that organisms can change their food at will according to the availability of particular sources (Leach et al., 1992). Students of all ages think that some populations of organisms are numerous in order to fulfill a demand for food by another population (Leach et al., 1992).

Middle-school and high-school students may believe that organisms are able to effect changes in bodily structure to exploit particular habitats or that they respond to a changed environment by seeking a more favorable environment (Jungwirth, 1975; Clough & Wood-Robinson, 1985a). It has been suggested that the language about adaptation used by teachers or textbooks to make biology more accessible to students may cause or reinforce these beliefs (Jungwirth, 1975).

Some middle-school students think dead organisms simply rot away. They do not realize that the matter from the dead organism is converted into other materials in the environment. Some middle-school students see decay as a gradual, inevitable consequence of time without need of decomposing agents (Smith & Anderson, 1986). Some high-school students believe that matter is conserved during decay, but do not know where it goes (Leach et al., 1992).



9-12

If a disturbance such as flood, fire, or the addition or loss of species occurs, the affected ecosystem may return to a system similar to the original one, or it may take a new direction, leading to a very different type of ecosystem. Changes in climate can produce very large changes in ecosystems. 5D/H2*

Human beings are part of the earth's ecosystems. Human activities can, deliberately or inadvertently, alter the equilibrium in ecosystems. 5D/H3

Ecosystems can be reasonably stable over hundreds or thousands of years. As any population grows, its size is limited by one or more environmental factors: availability of food, availability of nesting sites, or number of predators. 5D/H1*

The human species has a major impact on other species in many ways: reducing the amount of the earth's surface available to those other species, interfering with their food sources, changing the temperature and chemical composition of their habitats, introducing foreign species into their ecosystems, and altering organisms directly through selective breeding and genetic engineering. 3C/H4

6-8

All organisms, both land-based and aquatic, are interconnected by their need for food. This network of interconnections is referred to as a food web. The entire earth can be considered a single global food web, and food webs can also be described for a particular environment. At the base of any food web are organisms that make their own food, followed by the animals that eat them, then the animals that eat those animals, and so forth. 5D/M4**

Given adequate resources and an absence of disease or predators, populations of organisms in environments increase at rapid rates. Finite resources and other factors limit their growth. 5D/M3** (NSES)

Changes in environmental conditions can affect the survival of individual organisms and entire species. 5F/M2b

Human activities, such as reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming, have changed the earth's land, oceans, and atmosphere. Some of these changes have decreased the capacity of the environment to support some life forms. 4C/M7

In all environments, organisms with similar needs may compete with one another for limited resources, including food, space, water, air, and shelter. 5D/M1a*

The world contains a wide diversity of physical conditions, which creates a wide variety of environments: freshwater, marine, forest, desert, grassland, mountain, and others. In any particular environment, the growth and survival of organisms depend on the physical conditions. 5D/M1b*

Interactions between organisms may be for nourishment, reproduction, or protection and may benefit one of the organisms or both of them. Some species have become so dependent on each other that neither could survive without the other. 5D/M2*

Reproduction is necessary for the survival of any species. 5F/M5*

3-5

Most microorganisms do not cause disease, and many are beneficial. 5D/E5

Organisms interact with one another in various ways besides providing food. 5D/E3a

Changes in an organism's habitat are sometimes beneficial to it and sometimes harmful. 5D/E4

Insects and various other organisms depend on dead plant and animal material for food. 5D/E2

Many plants depend on animals for carrying their pollen to other plants or for dispersing their seeds. 5D/E3b

For any particular environment, some kinds of plants and animals thrive, some do not live as well, and some do not survive at all. 5D/E1*

K-2

Animals eat plants or other animals for food and may also use plants (or even other animals) for shelter and nesting. 5D/P1

Most living things need water, food, and air. 5C/P2

Living things are found almost everywhere in the world. There are somewhat different kinds in different places. 5D/P2

Recommended Reading

There are many well-written and authoritative books for a general audience that can help educators and others understand the science of climate change and its environmental and societal impacts. For each of the examples below, we have identified the most significant links between the book's content and specific chapters and sections in *Science for All Americans*. Additional highly recommended trade books on other topics covered in *Science for All Americans* can be found in *Resources for Science Literacy* online at **http://www.project2061.org/publications/rsl/online/index.htm**. For critical reviews of science books for all ages, visit *Science Books & Films* online at **http://www.sbfonline.com/index.htm**.

Global Warming: Causes, Effects, and the Future

by Mark Maslin

Voyageur Press, 2002, 72 pp. 0-89658-587-5, Index

Links to *Science for All Americans*: 1B, 3C, 4B, 11C

"Mark Maslin presents a no-punches-pulled look at global warming in this small volume, defining the processes, presenting the evidence, addressing skeptics, and identifying the potential risks to human society. Although the scientific evidence for global warming is simplified (and perhaps overemphasized by presentation of only the clearest of data and processes), the range of scientific evidence (from atmospheric mechanics and carbon sequestration to societal change) is fairly and broadly identified. Narrative dealing with critical processes is accompanied by clear illustrations to ease understanding. Photographs are abundant and well selected to accompany key points. This volume, with its no-nonsense approach and broad treatment, will provide an excellent and stimulating introduction for students desiring to learn more about the science underlying the processes driving global climate warming."

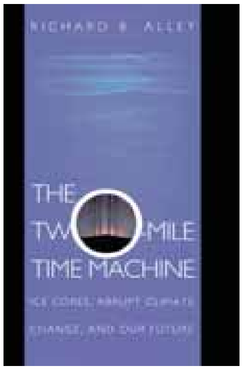
—From a review by Dale Toweill in Science Books & Films, 38/6 (November-December 2002), p. 549.

The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future

by Richard B. Alley

Princeton University Press, 2000, 229 pp. 0-691-00493-5, Index

Links to *Science for All Americans*: 1B, 3C, 4B, 11C



"Books in which scientists write about their professional experience and describe in lay terms the stuff that makes them excited about science rarely disappoint. Richard Alley's *The Two Mile Time Machine* is no exception. It describes a fascinating journey into the geologic past and the history of the Earth's climate. . . . Alley ends his entertaining book by polishing his crystal ball, envisioning what the future climate will be, and what we might do about it."

—From a review by J.A. Rial, American Scientist, 89/2 (March-April 2001).

"A fascinating first-hand story. . . . [A]n engaging narrative about the processes of obtaining, analyzing, and interpreting the ice cores. . . . Scientists, students, and the general public all need to know the present state of our incomplete understanding of the global climate system. This book provides an excellent foundation."

—From a review by Al Bartlett in American Journal of Physics, 70/2 (February 2002), pp. 190-191.

Web Sites for Climate Change Resources

There is an abundance of information and materials available online for science educators and communicators. The following Web sites provide access to a variety of authoritative resources from government, academic, and scientific organizations.

AAAS Global Climate-Change Resources

To provide scientific leadership on the issue of global climate change, AAAS has developed this site where educators, students, and other members of the public can access materials and background information on AAAS efforts.

http://www.aaas.org/climate

National Oceanic & Atmospheric Administration (NOAA), National Climate Data Center

This site draws on the findings of the 2001 report by the Intergovernmental Panel on Climate Change, and the National Research Council's 2001 report *Climate Change Science: An Analysis of Some Key Questions*, as well as NOAA's own data resources to answer some frequently asked questions about global warming.

http://www.ncdc.noaa.gov/oa/climate/globalwarming.html

National Center for Atmospheric Research

Two sites, operated by the University Corporation for Atmospheric Research, provide a wealth of information on topics related to weather and climate and to climate change. The sites offer a variety of Web links for scientists, educators, students, or enthusiasts. Specific topics include the Earth's past and future, the greenhouse effect and global warming, El Niño & La Niña, and how scientists study the dynamic forces in the atmosphere that change our weather and climate.

http://www.ucar.edu/research/climate/

http://www.eo.ucar.edu/basics/index.html

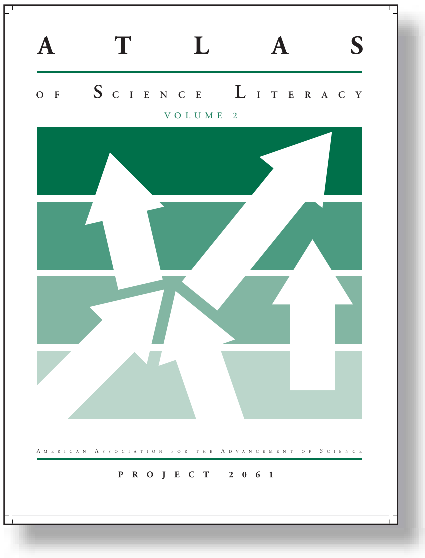
Marian Koshland Science Museum of the National Academy of Sciences

Based on the Museum's Global Warming Facts & Our Future interactive exhibit, this Web site features online activities, resources for teachers, Web links, and other resources designed to help visitors explore the latest scientific information on the causes, impacts, and responses to global climate change.

http://www.koshland-science-museum.org/exhibitgcc/index.jsp

New for 2007

Atlas of Science Literacy, Volume 2



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