Project 2061:
Education for a Changing Future

The Return of Halley's Comet as a Metaphor for Long-term Reform

2061

1985

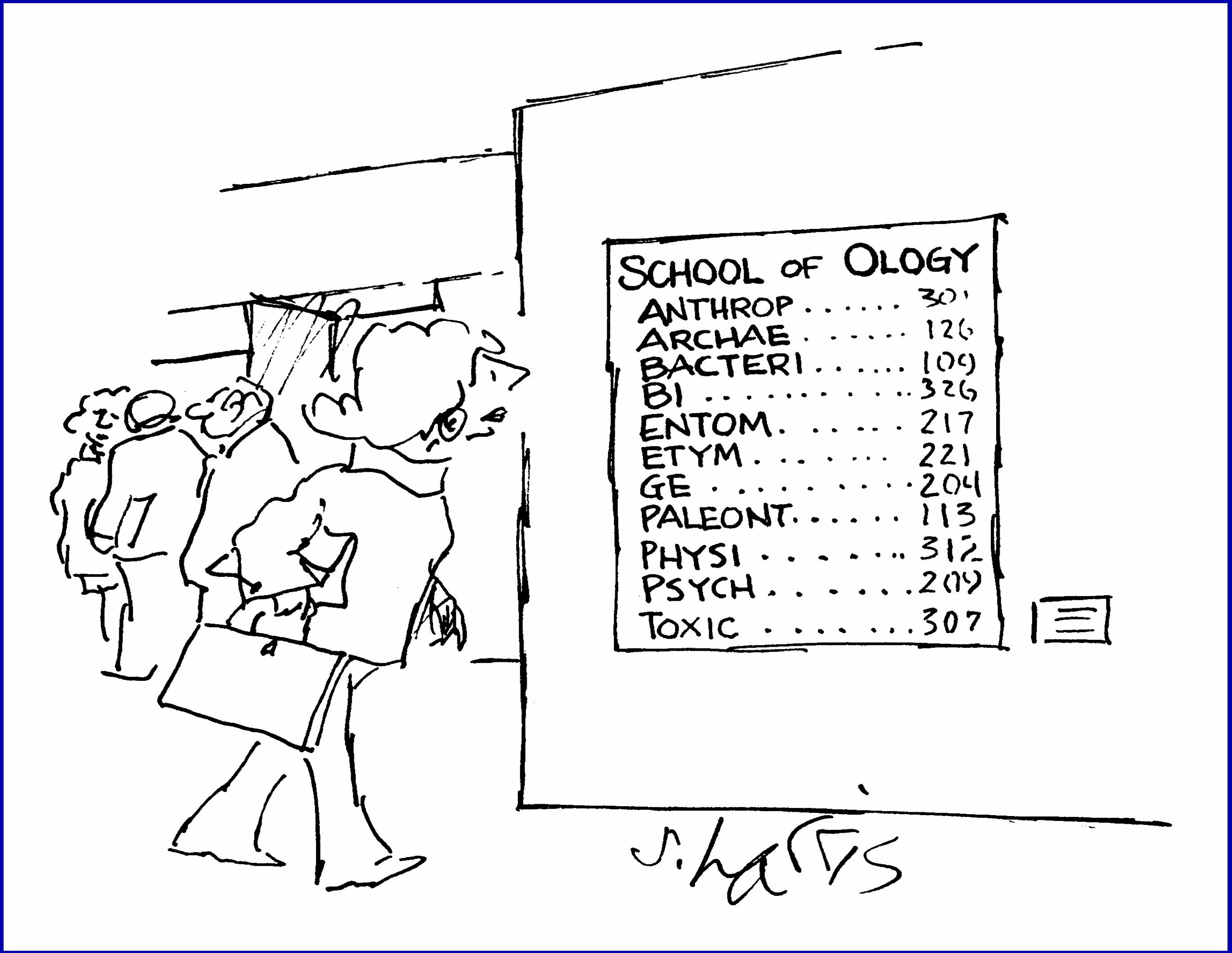
1910

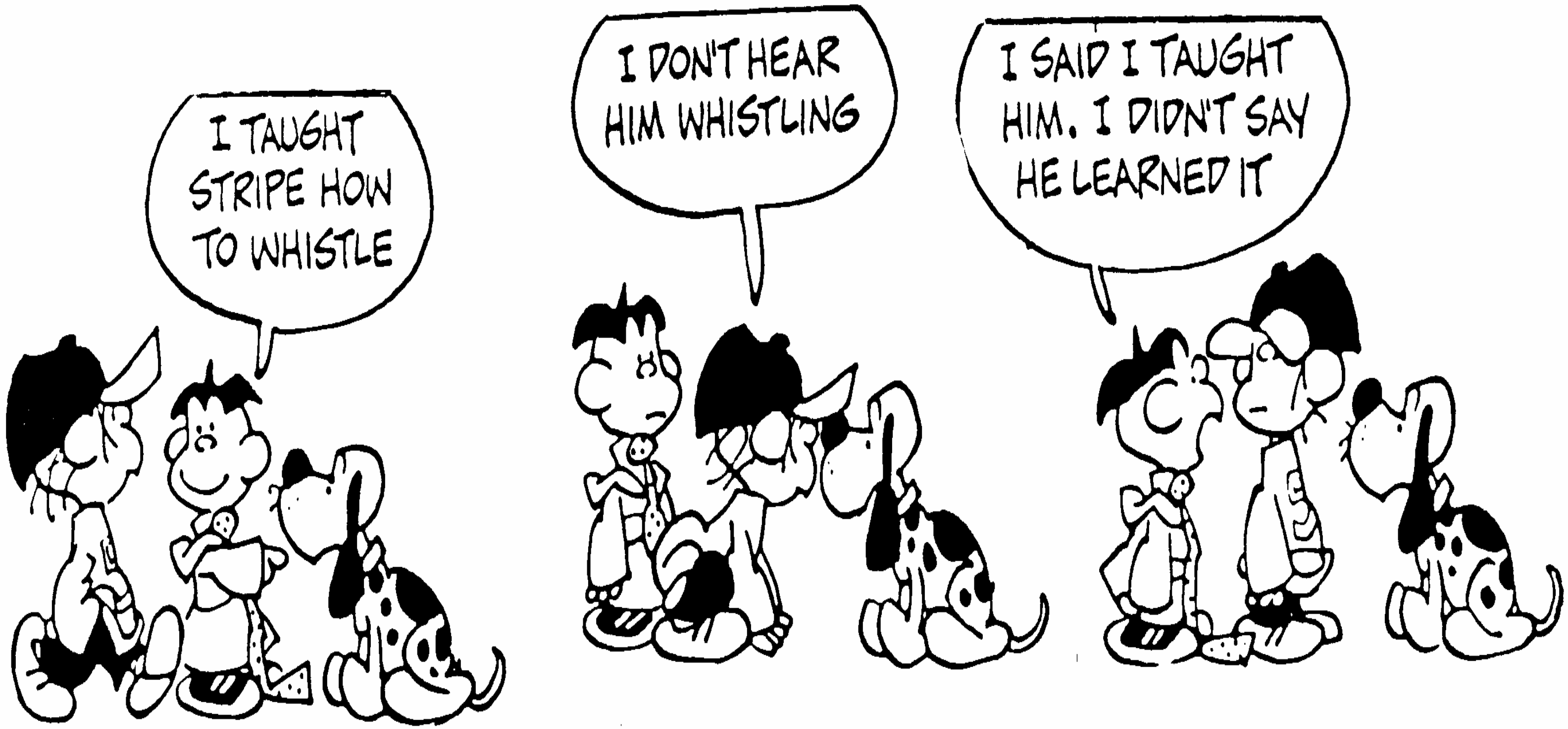
1834

1758

1682

Our Mission is to Increase the Quality of Science Literacy of All


SCHOOL OF OLOGY
ANTHROP 301
ARCHAE 126
BACTERI 109
BI 326
ENTOM 217
ETYM 221
GE 204
PALEONT 113
PHYSI 312
PSYCH 209
TOXIC 307
S. Harris

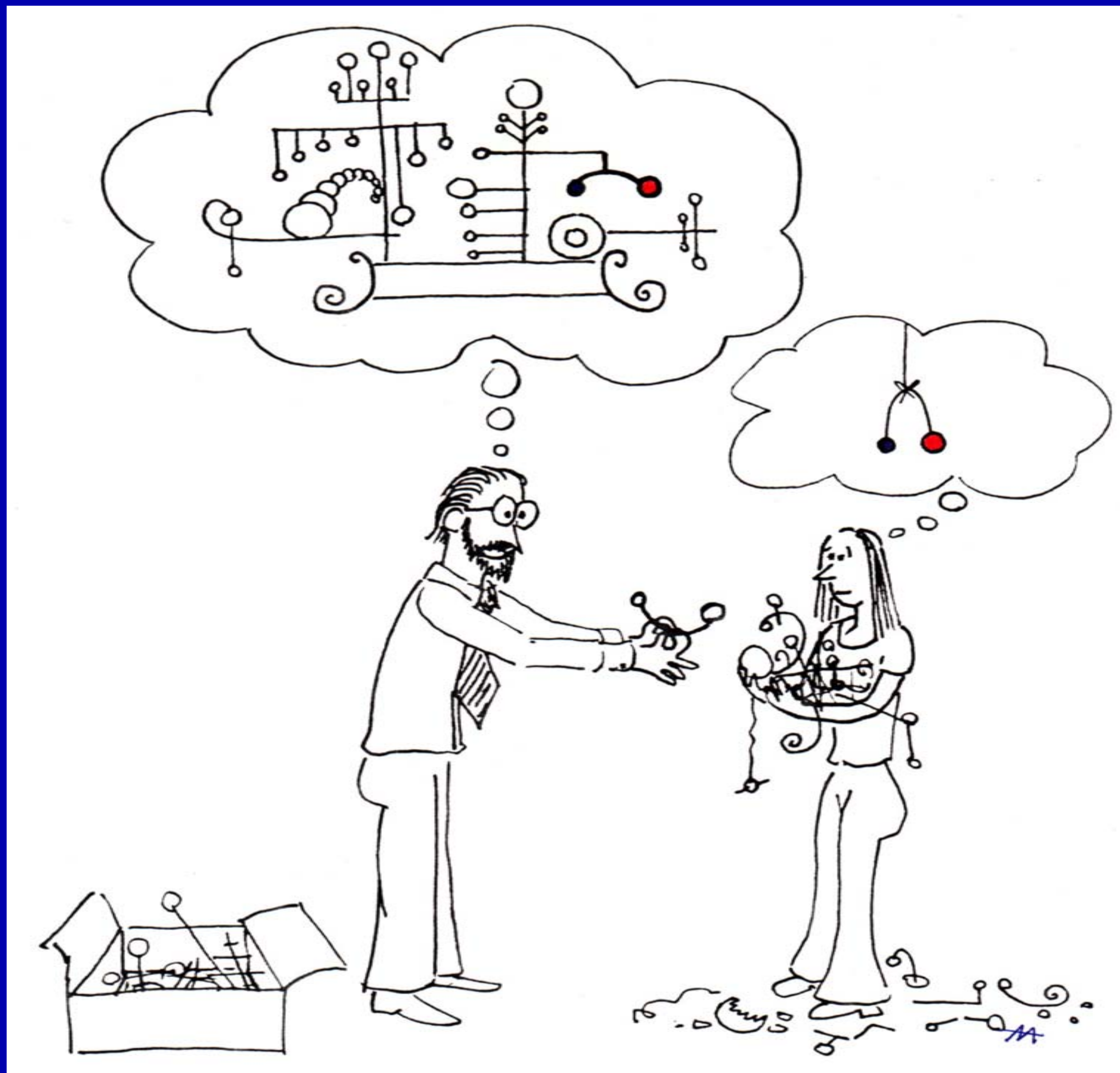

I TAUGHT STRIPE HOW TO WHISTLE
I DON'T HEAR HIM WHISTLING
I SAID I TAUGHT HIM. I DIDN'T SAY HE LEARNED IT

Project 2061 AAAS

How well do US college graduates understand important science ideas?

1. A seed grows into a large tree. Where did the mass of the tree come from?
2. What if I told you that the mass comes mainly from the carbon dioxide in the air?

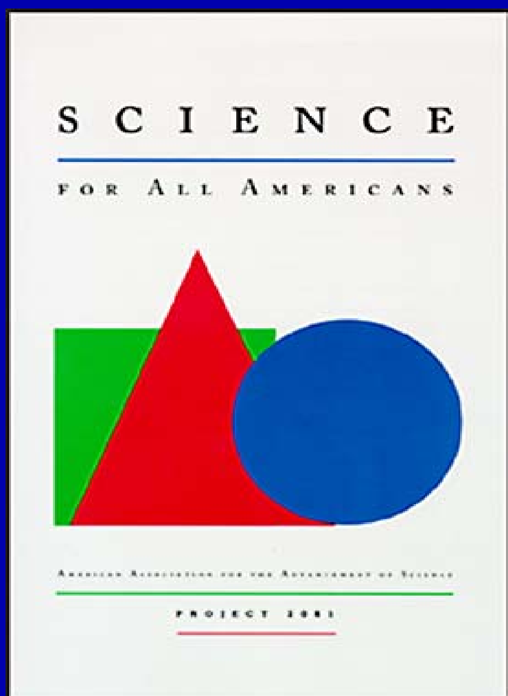
Project 2061 AAAS



Project 2061 AAAS

Develop, clarify, and disseminate learning goals for K-12 education in science, mathematics, and technology.

Characterizing Adult Literacy in Science Mathematics, and Technology



THE NATURE OF SCIENCE
THE NATURE OF MATHEMATICS
THE NATURE OF TECHNOLOGY
THE PHYSICAL SETTING
THE LIVING ENVIRONMENT
THE HUMAN ORGANISM
HUMAN SOCIETY
THE DESIGNED WORLD
THE MATHEMATICAL WORLD
HISTORICAL PERSPECTIVES
COMMON THEMES
HABITS OF MIND

from Chapter 1: THE NATURE OF SCIENCE

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…

from Chapter 4: THE PHYSICAL SETTING

Energy Transformations

Energy appears in many forms, including radiation, the motion of bodies, excited states of atoms, and strain within and between molecules. All of these forms are in an important sense equivalent, in that one form can change into another. Most of what goes on in the universe—such as the collapsing and exploding of stars, biological growth and decay, the operation of machines and computers—involves one form of energy being transformed into another…

from **Chapter 5: THE LIVING ENVIRONMENT**

Flow of Matter and Energy

However complex the workings of living organisms, they share with all other natural systems the same physical principles of the conservation and transformation of matter and energy. Over long spans of time, matter and energy are transformed among living things, and between them and the physical environment. In these grand-scale cycles, the total amount of matter and energy remains constant, even though their form and location undergo continual change.

Almost all life on earth is ultimately maintained by transformations of energy from the sun. Plants capture the sun's energy and use it to synthesize complex, energy-rich molecules (chiefly sugars) from molecules of carbon dioxide and water. These synthesized molecules then serve, directly or indirectly, as the source of energy for the plants themselves and ultimately for all animals and decomposer organisms…

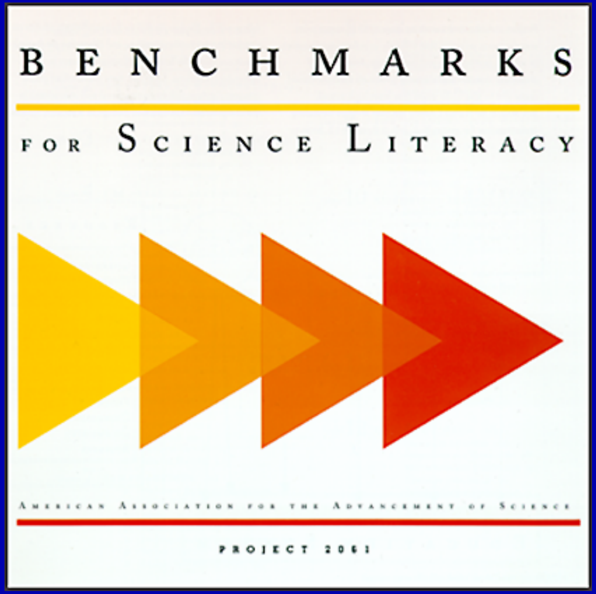
from Chapter 11: COMMON THEMES

Systems

…Drawing the boundary of a system well can make the difference between understanding and not understanding what is going on. The conservation of mass during burning, for instance, was not recognized for a long time because the gases produced were not included in the system whose weight was measured…

Thinking of everything within some boundary as being a system suggests the need to look for certain kinds of influence and behavior. For example, we may consider a system's inputs and outputs. Air and fuel go into an engine; exhaust, heat, and mechanical work come out. Information, sound energy, and electrical energy go into a telephone system; information, sound energy, and heat come out. And we look for what goes into and comes out of any part of the system--the outputs of some parts being inputs for others. For example, the fruit and oxygen that are outputs of plants in an ecosystem are inputs for some animals in the system; the carbon dioxide and droppings that are the output of animals may serve as inputs for the plants…

K-12 steps toward science literacy



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from **Chapter 5: THE LIVING ENVIRONMENT**

Flow of Matter and Energy

K-2: Most plants and animals need to take in water and air. In addition, animals need to take in food and plants need light.

3-5: From food, people and other organisms obtain fuel and materials for body repair and growth.

6-8: All organisms need food as a source of molecules that provide chemical energy and building materials…

9-12: The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. As energy is transformed in living systems, some energy is stored in newly made structures but much is dissipated into the environment as heat. Therefore, continual input of energy from sunlight keeps the process going.

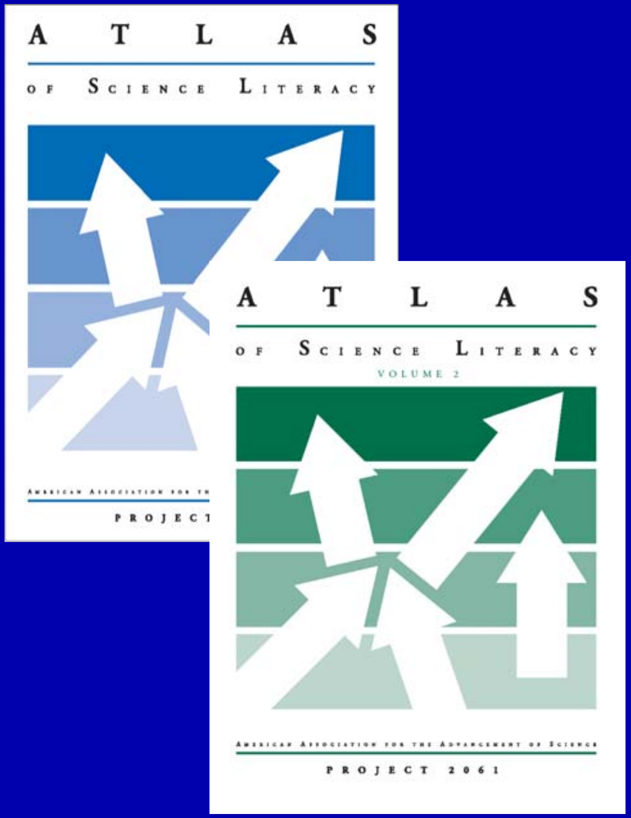
Learning Research Informed the Substance and Grade-Level Placement of Benchmarks

Chapter 15: THE RESEARCH BASE

…Students of all ages...see food as [any] substance (water, air, minerals, etc.) that organisms take directly in from their environment (Anderson, Sheldon, & Dubay, 1990; Simpson & Arnold, 1985). In addition, some students of all ages think food is a requirement for growth, rather than a source of matter for growth. They have little knowledge about food being transformed and made part of a growing organism's body (Smith & Anderson, 1986; Leach et al., 1992).

Middle-school and high-school students have difficulty thinking of the human body as a chemical system and have little knowledge about the elements composing the living body (Stavy, Eisen, & Yaakobi, 1987)…Students see these substances as fundamentally different and not transformable into each other (Smith & Anderson, 1986).

K-12 Connections among steps



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ATLAS OF SCIENCE LITERACY, VOLUME 1 AND VOLUME 2

COMBINED TABLE OF CONTENTS

Titles and page numbers printed in green indicate maps in Volume 2; those printed in gray indicate maps in Volume 1.

ENERGY TRANSFORMATIONS (4E)

Most of what goes on in the universe—such as the collapsing and exploding of stars, biological growth and decay, the operation of machines and computers—involves transforming one form of energy into another. Understanding basic ideas about energy transformation, including its conservation and dissipation, is needed for making sense of a wide variety of phenomena and for making informed decisions involving energy use.

The map is organized around three strands—forms of energy, conservation, and dissipation. The progression of understanding begins in elementary grades with observable patterns of phenomena involving heat transfer; moves in middle school to descriptions of energy forms, transformation, and transfer; and culminates in high school with energy conservation and dissipation as thermal energy. While there are really only two forms of energy—kinetic and potential—students typically encounter energy forms with more varied labels. Hence, the strand on forms of energy begins in middle school with a more diverse list of forms and reconciles them in high school into kinetic or potential.

Ideas about energy conservation on this map relate to the more general idea of conservation developed in the CONSTANCY map, and ideas about energy transformation contribute to understanding ideas about energy transformation in living systems on the FLOW OF ENERGY IN ECOSYSTEMS map in Atlas 1. Ideas about heat transfer contribute to understanding ideas about temperature and winds on the WEATHER AND CLIMATE map, and ideas about energy released in nuclear reactions contribute to understanding the history of ideas on the RELATIVITY and SPLITTING THE ATOM maps. Benchmarks in this map also contribute to and are supported by benchmarks in the ENERGY RESOURCES map.

NOTES

In the forms of energy strand a new high-school benchmark "Many forms of energy…" synthesizes distinctions between kinetic energy (which concerns the motion of objects in a system) and potential energy (which concerns the relative position of interacting objects in a system).

The conservation strand begins with the precursor idea of accounting, keeping track of where things come from and where they go. The idea of energy conservation is introduced first qualitatively in benchmark 4E/M1. The second part of the benchmark was added to help address a common student misconception about energy loss. The high-school benchmark 4E/H1 expresses concretely the idea of energy conservation quantitatively: If we can keep track of how much energy of each kind increases and decreases, we find that whenever the energy in one place diminishes, the energy in other places increases by just the same amount. A new high-school benchmark "If no energy is transferred into or out of a system…" expresses the same idea more abstractly.

Describing processes in terms of energy transformation, transfer, and conservation in any meaningful way requires first defining the system under consideration. A new benchmark 11A/M5, shown as an off-map connection, expects students to know that a system is "defined by placing boundaries around collections of interrelated things," and since systems often interact with their environment, students should also know that "it is important to keep track of what enters or leaves the system."

RESEARCH IN BENCHMARKS

Even after some years of physics instruction, students do not distinguish well between heat and temperature when they explain thermal phenomena (Kesidou & Duit, 1993; Tiberghien, 1983; Wiser, 1986, 1988). Their belief that temperature is the measure of heat is particularly resistant to change. Long-term teaching interventions are required for upper middle-school students to start differentiating between heat and temperature (Linn & Songer, 1991; Clark & Linn, 2003).

Few middle- and high-school students understand the molecular basis of heat conduction even after instruction (Wiser, 1986; Kesidou & Duit, 1993; Driver et al., 1994). For example, students attribute to particles properties such as "hotness" and "coldness" or believe that heat is produced by particles rubbing against each other (Driver et al., 1994; Kesidou, Duit, & Glynn, 1995).

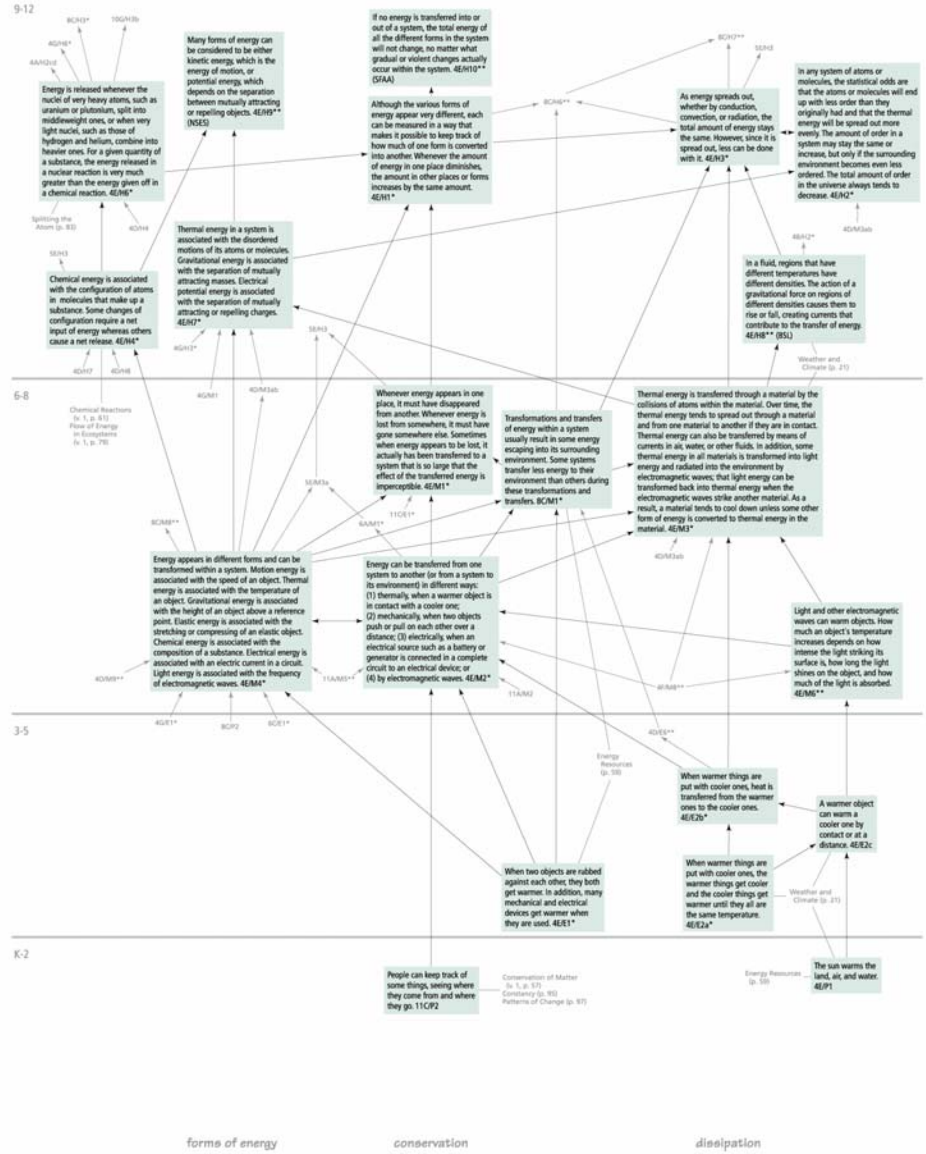
During instruction, upper elementary-school students use ideas that give heat an active drive or intent to explain observations of convection currents. They also draw parallels between evaporation and the water cycle and convection, sometimes explicitly explaining the upwards motion of convection currents as evaporation (Jones, Carter, & Rua, 2000).

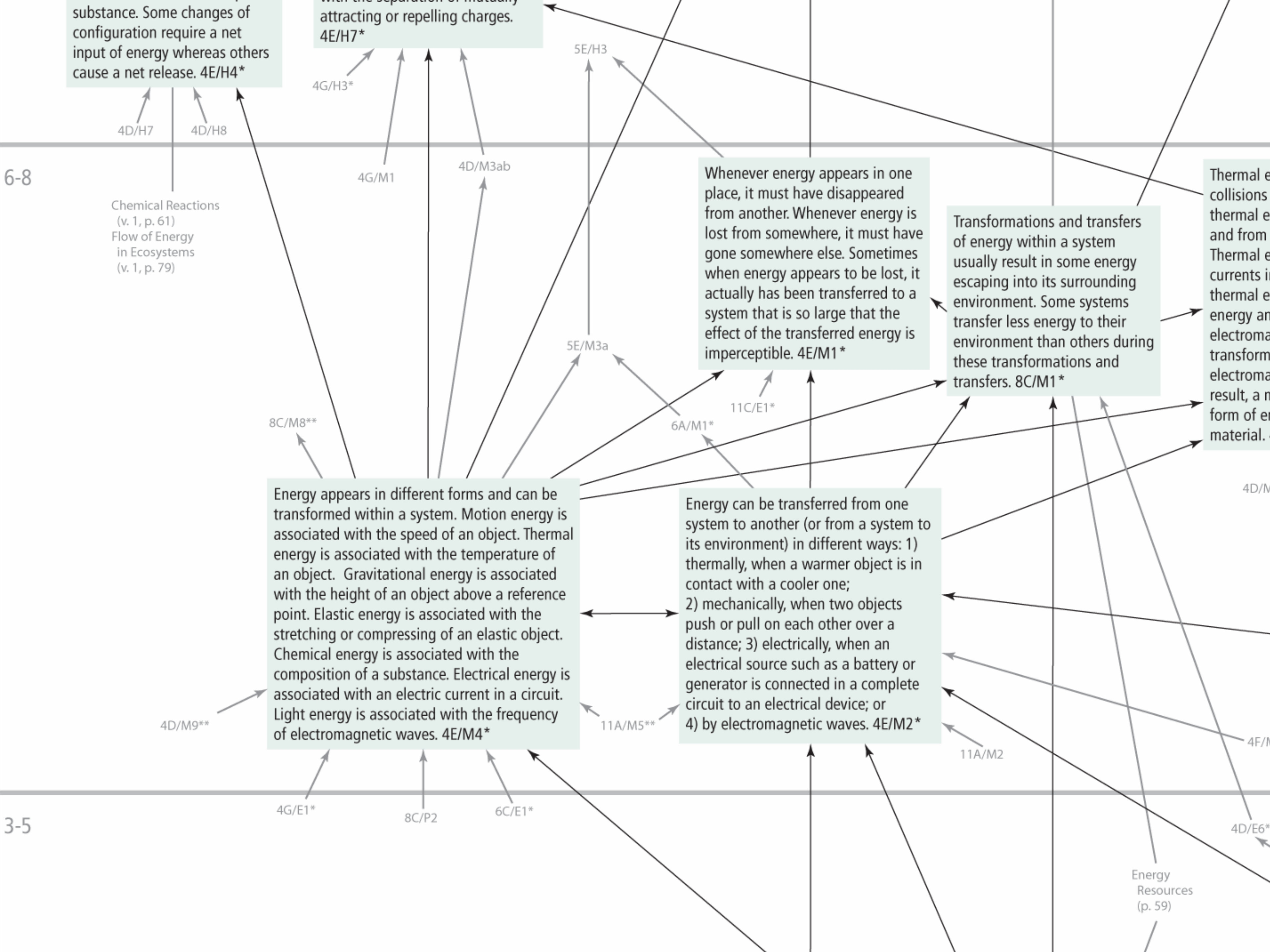
Students rarely think energy is measurable and quantifiable (Solomon, 1985; Watts, 1983a). Students' alternative conceptualizations of energy influence their interpretations of textbook representations of energy (Stylianidou, Ormerod, & Ogborn, 2002).

Middle- and high-school students tend to think that energy transformations involve only one form of energy at a time (Brook & Wells, 1988). Although they develop some skill in identifying different forms of energy, in most cases their descriptions of energy-change focus only on forms which have perceivable effects (Brook & Driver, 1986). The transformation of motion to heat seems to be difficult for students to accept, especially in cases with no temperature increase (Brook & Driver, 1986; Kesidou & Duit, 1993). Finally, it may not be clear to students that some forms of energy, such as light, sound, and chemical energy, can be used to make things happen (Carr & Kirkwood, 1988).

The idea of energy conservation seems counterintuitive to middle- and high-school students who hold on to the everyday use of the term energy, but teaching heat dissipation ideas at the same time as energy conservation ideas may help alleviate this difficulty (Solomon, 1983). Even after instruction, however, students do not seem to appreciate that energy conservation is a useful way to explain phenomena (Brook & Driver, 1984). A key difficulty students have in understanding conservation appears to derive from not considering the appropriate system and environment (Ametller & Pinto, 2002). In addition, middle- and high-school students tend to use their conceptualizations of energy to interpret energy conservation ideas (Brook & Driver, 1986; Kesidou & Duit, 1993; Solomon, 1985). For example, some students interpret the idea that "energy is not created or destroyed" to mean that energy is stored up in the system and can even be released again in its original form (Solomon, 1985). Or, students may believe that no energy remains at the end of a process, but may say that "energy is not lost" because an effect was caused during the process (for example, a weight was lifted) (Duit & Haeussler, 1994). Although teaching approaches which accommodate students' difficulties about energy appear to be more successful than traditional science instruction, the main deficiencies outlined above remain despite these approaches (Brook & Driver, 1986; Brook & Wells, 1988).

See **ENERGY RESOURCES** for additional research.





substance. Some changes of configuration require a net input of energy whereas others cause a net release. 4E/H4*
attracting or repelling charges. 4E/H7*
4G/H3*
5E/H3
4D/H7
4D/H8
6-8
4G/M1
4D/M3ab
Chemical Reactions (v. 1, p. 61)
Flow of Energy in Ecosystems (v. 1, p. 79)
Whenever energy appears in one place, it must have disappeared from another. Whenever energy is lost from somewhere, it must have gone somewhere else. Sometimes when energy appears to be lost, it actually has been transferred to a system that is so large that the effect of the transferred energy is imperceptible. 4E/M1*
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*
5E/M3a
11C/E1*
6A/M1*
8C/M8**
Energy appears in different forms and can be transformed within a system. Motion energy is associated with the speed of an object. Thermal energy is associated with the temperature of an object. Gravitational energy is associated with the height of an object above a reference point. Elastic energy is associated with the stretching or compressing of an elastic object. Chemical energy is associated with the composition of a substance. Electrical energy is associated with an electric current in a circuit. Light energy is associated with the frequency of electromagnetic waves. 4E/M4*
Energy can be transferred from one system to another (or from a system to its environment) in different ways: 1) thermally, when a warmer object is in contact with a cooler one; 2) mechanically, when two objects push or pull on each other over a distance; 3) electrically, when an electrical source such as a battery or generator is connected in a complete circuit to an electrical device; or 4) by electromagnetic waves. 4E/M2*
4D/M9**
11A/M5**
11A/M2
4G/E1*
8C/P2
6C/E1*
3-5
4D/E6*
Energy Resources (p. 59)

9-12

8C/H3*

10G/H3b

4G/H6*

4A/H2cd

Many forms of energy can be considered to be either kinetic energy, which is the energy of motion, or potential energy, which depends on the separation between mutually attracting or repelling objects. 4E/H9** (NSES)

If no energy is transferred into or out of a system, the total energy of all the different forms in the system will not change, no matter what gradual or violent changes actually occur within the system. 4E/H10** (SFAA)

Energy is released whenever the nuclei of very heavy atoms, such as uranium or plutonium, split into middleweight ones, or when very light nuclei, such as those of hydrogen and helium, combine into heavier ones. For a given quantity of a substance, the energy released in a nuclear reaction is very much greater than the energy given off in a chemical reaction. 4E/H6*

Although the various forms of energy appear very different, each can be measured in a way that makes it possible to keep track of how much of one form is converted into another. Whenever the amount of energy in one place diminishes, the amount in other places or forms increases by the same amount. 4E/H1*

Splitting the Atom (p. 83)

4D/H4

5E/H3

Thermal energy in a system is associated with the disordered motions of its atoms or molecules. Gravitational energy is associated with the separation of mutually attracting masses. Electrical potential energy is associated with the separation of mutually attracting or repelling charges. 4E/H7*

Chemical energy is associated with the configuration of atoms in molecules that make up a substance. Some changes of configuration require a net input of energy whereas others cause a net release. 4E/H4*

5E/H3

4G/H3*

4D/H7

4D/H8

6-8

4G/M1

4D/M3ab

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4D/M9**

11A/M5**

11A/M2

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attracting or repelling charges. 4E/H7*

5E/H3

The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. As energy is transformed in living systems, some energy is stored in newly made structures but much is dissipated into the environment as heat. Therefore, continual input of energy from sunlight keeps the process going.

4G/H3*

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4) by electromagnetic waves. 4E/M2*

4D/M9**

11A/M5**

11A/M2

Systems are defined by placing boundaries around collections of interrelated things to make them easier to study. Regardless of where the boundaries are placed, a system still interacts with its surrounding environment. Therefore, when studying a system, it is important to keep track of what enters or leaves the system.

3-5

Thinking about things as systems means looking for how every part relates to others. The output from one part of a system (which can include material, energy, or information) can become the input to other parts. Such feedback can serve to control what goes on in the system as a whole.

Energy Resources (p. 59)

Semiconducting materials differ greatly in how well they conduct electrons, depending on the exact composition of the material. 4G/H4d*

At very low temperatures, some materials become superconductors and offer no resistance to the flow of electrons. 4G/H4c*

purposes

11D/H2*

Groups of atoms and molecules can form structures that can be measured in billionths of a meter. The properties of structures at this scale (known as the nanoscale) and materials composed of such structures, can be very different than the properties at the macroscopic scale because of the increase in the ratio of surface area to volume and changes in the relative strengths of different forces at different scales. Increased knowledge of the properties of materials at the nanoscale provides a basis for the development of new materials and new uses of existing materials. 8B/H6**

ctricity and
agnetism
. 27)

4G/H4ab*

Objects made up of a small number of atoms may exhibit different properties than macroscopic objects made up of the same kinds of atoms. 8B/H5**

Atoms may link together in
well-defined molecules, or

Some materials, such as
plastics, are synthesized
chemical reactions that

THE PHYSICAL SETTING

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*

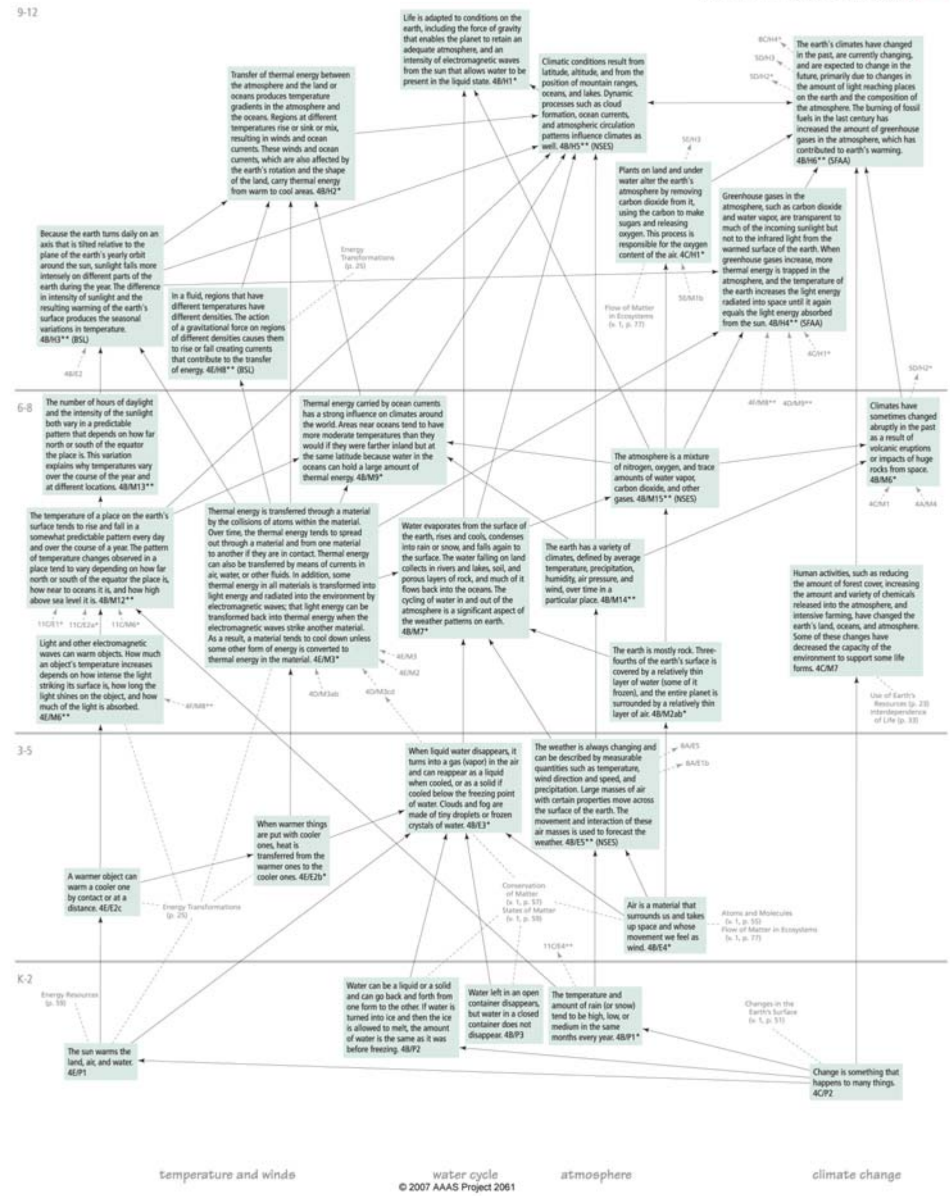
Students of all ages (including college students and adults) have difficulty understanding what causes the seasons. Students may not be able to understand explanations of the seasons before they reasonably understand the relative size, motion, and distance of the sun and the earth (Sadler, 1987; Vosniadou, 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.



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places it (4B/H3)

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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).

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*

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)

8C/H4* 5D/H3 5D/H2*

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*

5E/H3

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)

Energy Transformations (p. 25)

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)

Flow of Matter in Ecosystems (v. 1, p. 77)

5E/M1b

4C/H1*

4B/E2

5D/H2*

4F/M8** 4D/M9**

6-8

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.

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 ...

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.

In solids, the atoms or molecules are closely locked in position and can only vibrate. In liquids, they have higher energy, are more loosely connected, and can slide past one another; some molecules may get enough energy to escape into a gas. In gases, the atoms or molecules have still more energy and are free of one another except during occasional collisions.

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*

4C/M1 4A/M4

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 it is, how near to oceans it is, and how high above sea level it is. 4B/M12**

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.

Energy can be transferred from one system to another (or from a system to its environment) in different ways: 1) thermally, when a warmer object is in contact with a cooler one; 2) mechanically, when two objects push or pull on each other over a dstance; 3) electrically, when an electrical source such as a battery or generator is connected in a complete circuit to an electrical device; or 4) by electromagnetic waves.

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

11C/E1* 11C/E2a* 11C/M6*

Atoms and molecules are perpetually in motion. Increased temperature means greater average energy of motion, so most substances expand when heated.

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**

... 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*

4E/M3 4E/M2 4D/M3ab 4D/M3cd 4F/M8**

... frozen), and the entire planet is surrounded by a relatively thin layer of air. 4B/M2ab*

Use of Earth's Resources (p. 23)
Interdependence of Life (p. 33)

dapted to conditions on the
ncluding the force of gravity
ables the planet to retain an
te atmosphere, and an
y of electromagnetic waves
e sun that allows water to be
in the liquid state. 4B/H1*

The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. As energy is transformed in living systems, some energy is stored in newly made structures but much is dissipated into the environment as heat. Therefore, continual input of energy from sunlight keeps the process going.

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)

5E/H3

8C/H4*

5D/H3

5D/H2*

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*

Plants use the energy from light to make sugars from carbon dioxide and water.

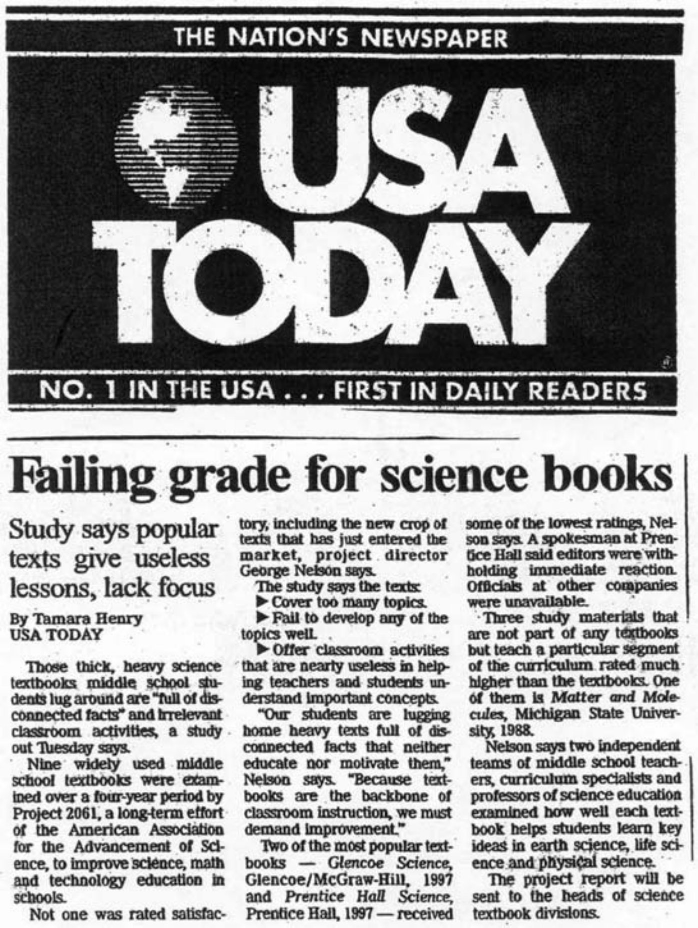
Greenhouse gases in the atmosphere, such as carbon dioxide and water vapor, are transparent to much of the incoming sunlight but not to the infrared light from the warmed surface of the earth. When greenhouse gases increase, more thermal energy is trapped in the atmosphere, and the temperature of the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

5E/M1b

Flow of Matter in Ecosystems (v. 1, p. 77)

4C/H1*

Existing textbooks provide little help



THE NATION'S NEWSPAPER

USA TODAY

NO. 1 IN THE USA . . . FIRST IN DAILY READERS

Failing grade for science books

Study says popular texts give useless lessons, lack focus

By Tamara Henry
USA TODAY

Those thick, heavy science textbooks middle school students lug around are "full of disconnected facts" and irrelevant classroom activities, a study out Tuesday says.

Nine widely used middle school textbooks were examined over a four-year period by Project 2061, a long-term effort of the American Association for the Advancement of Science, to improve science, math and technology education in schools.

Not one was rated satisfactory, including the new crop of texts that has just entered the market, project director George Nelson says.

The study says the texts:

▶ Cover too many topics.

▶ Fail to develop any of the topics well.

▶ Offer classroom activities that are nearly useless in helping teachers and students understand important concepts.

"Our students are lugging home heavy texts full of disconnected facts that neither educate nor motivate them," Nelson says. "Because textbooks are the backbone of classroom instruction, we must demand improvement."

Two of the most popular textbooks — *Glencoe Science*, Glencoe/McGraw-Hill, 1997 and *Prentice Hall Science*, Prentice Hall, 1997 — received some of the lowest ratings, Nelson says. A spokesman at Prentice Hall said editors were withholding immediate reaction. Officials at other companies were unavailable.

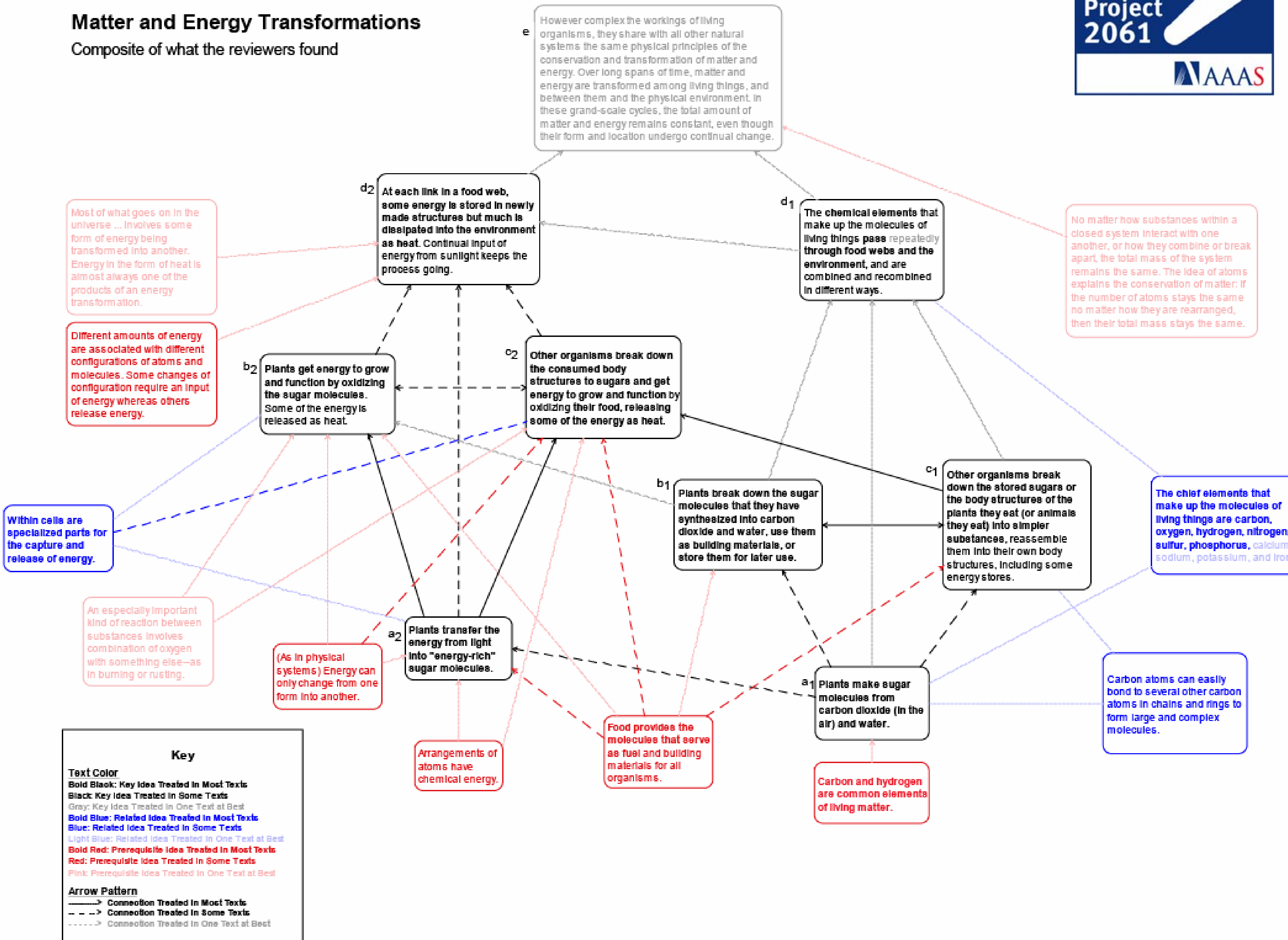
Three study materials that are not part of any textbooks but teach a particular segment of the curriculum rated much higher than the textbooks. One of them is *Matter and Molecules*, Michigan State University, 1988.

Nelson says two independent teams of middle school teachers, curriculum specialists and professors of science education examined how well each textbook helps students learn key ideas in earth science, life science and physical science.

The project report will be sent to the heads of science textbook divisions.

Matter and Energy Transformations

Composite of what the reviewers found



Topic: Matter and energy transformations

Project 2061 Instructional Analysis of Biology Textbooks

Project 2061 AAAS

Instructional Categories	Biology Miller · Levine *Prentice Hall*	Biology: A Community Context *South-Western Educational Publishing*	Biology: Principles & Explorations *Holt, Rinehart and Winston*	Biology: The Dynamics of Life *Glencoe, McGraw-Hill*	Biology: Visualizing Life *Holt, Rinehart and Winston*	BSCS Biology: A Human Approach *Kendall Hunt*	BSCS Biology: An Ecological Approach *Kendall Hunt*	Heath Biology *D.C. Heath and Company*	Insights in Biology *Kendall Hunt*	Modern Biology *Holt, Rinehart and Winston*
I. PROVIDING A SENSE OF PURPOSE										
Conveying unit purpose	Fair	Good	Poor	Poor	Poor	Excellent	Fair	Poor	Fair	Poor
Conveying lesson purpose	Poor	Fair	Poor	Poor	Poor	Satisfactory	Poor	Poor	Satisfactory	Poor
Justifying lesson sequence	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
II. TAKING ACCOUNT OF STUDENT IDEAS										
Attending to prerequisite knowledge and skills	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Alerting teacher to commonly held student ideas	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Assisting teacher in identifying own students' ideas	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Fair	Poor
Addressing commonly held ideas	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
III. ENGAGING STUDENTS WITH RELEVANT PHENOMENA										
Providing variety of phenomena	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Providing vivid experiences	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
IV. DEVELOPING AND USING SCIENTIFIC IDEAS										
Introducing terms meaningfully	Poor	Poor	Poor	Poor	Poor	Poor	Fair	Poor	Satisfactory	Poor
Representing ideas effectively	Poor	Poor	Poor	Poor	Poor	Fair	Poor	Poor	Poor	Fair
Demonstrating use of knowledge	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Providing practice	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
V. PROMOTING STUDENT THINKING ABOUT PHENOMENA, EXPERIENCES, AND KNOWLEDGE										
Encouraging students to explain their ideas	Poor	Poor	Poor	Poor	Poor	Fair	Poor	Poor	Fair	Poor
Guiding student interpretation and reasoning	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Fair	Poor
Encouraging students to reflect on their own learning	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
VI. ASSESSING PROGRESS										
Aligning assessment to goals	Poor	Poor	Poor	Poor	Poor	Satisfactory	Fair	N/A	Poor	Poor
Testing for understanding	Poor	Poor	Poor	Poor	Poor	Satisfactory	Fair	N/A	Poor	Poor
Using assessment to inform instruction	Poor	Poor	Poor	Poor	Poor	Poor	Poor	N/A	Poor	Poor

= Excellent (3); = Good (2.5-2.9); = Satisfactory (2-2.4); = Fair (1.5-1.9); = Poor (0-1.4)

We Found that Textbooks Rarely

- Present the set of key ideas coherently
- Take account of commonly held student ideas
- Engage students with phenomena to illustrate the key science ideas or their explanatory power
- Include effective representations to clarify the key science ideas
- Scaffold students efforts to make sense of the phenomena and representations
- Provide assessments to effectively monitor students' progress

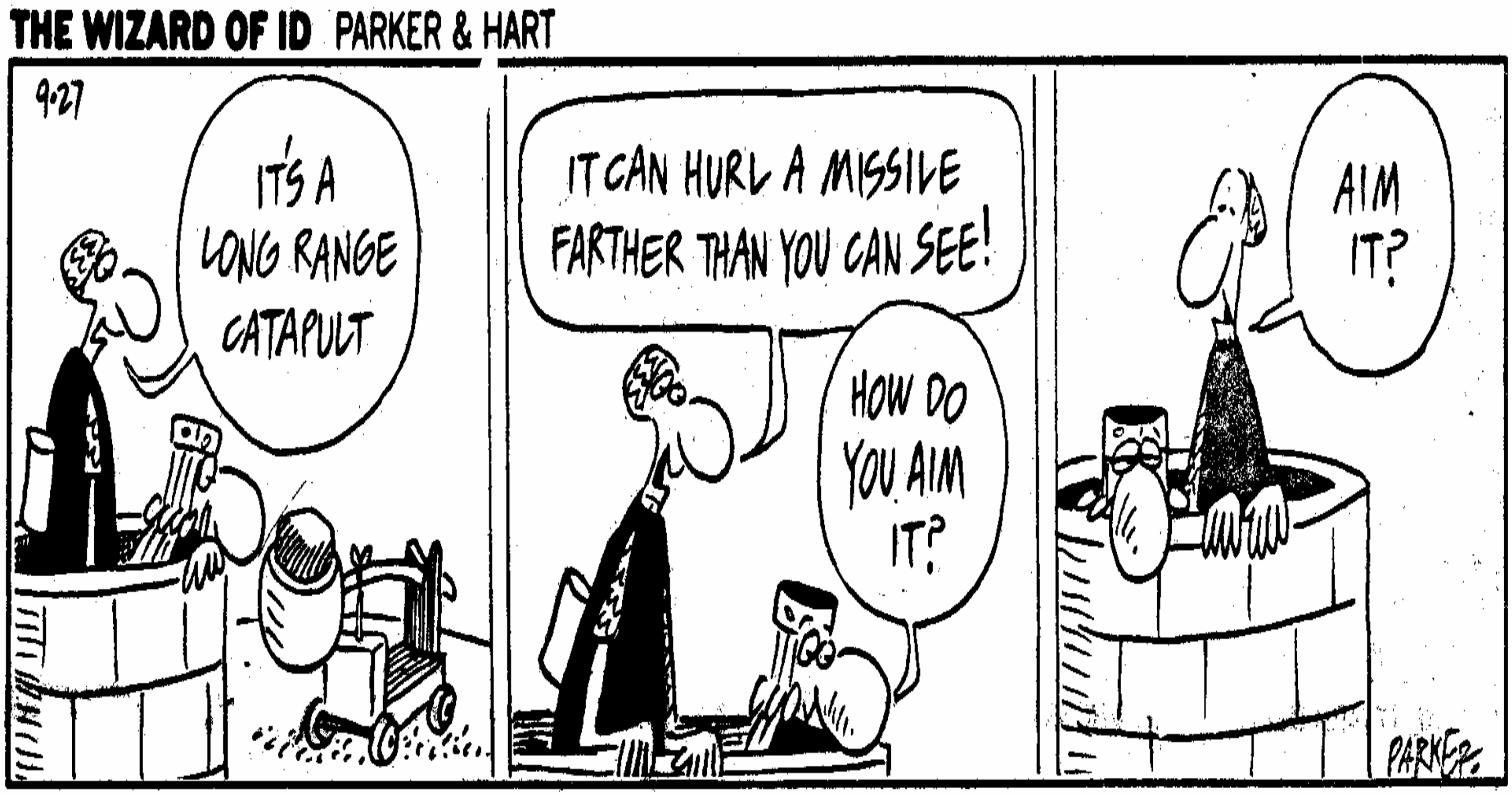
http://www.project2061.org/publications/textbook/default.htm

Foster the development and use of effective goals-based curriculum and assessment materials

Tools and Resources for Materials R&D

- Clarifications of benchmark ideas
- Descriptions of common student misconceptions
- Assessment items
- Descriptions of phenomena and representations
- Web-based interfaces

Project 2061
AAAS



Clarifying Benchmark Ideas

Benchmark to be clarified:

Atoms and molecules are perpetually in motion. Increased temperature means greater average energy of motion, so most substances expand when heated. In solids, the atoms are closely locked in position and can only vibrate. In liquids, the atoms or molecules have higher energy, are more loosely connected, and can slide past one another; some molecules may get enough energy to escape into a gas. In gases, the atoms or molecules have still more energy and are free of one another except during occasional collisions (4D/M3).

Key Idea for Thermal Expansion and Contraction

For any single state of matter, changes in temperature typically change the average distance between atoms or molecules. Most substances or mixtures of substances expand when heated and contract when cooled (based on benchmark 4D/M3b, *Benchmarks for Science Literacy*, p. 78).

Draft Boundaries for Assessment

- Students should know that as the temperature of a substance increases, the average distance between the atoms/molecules of the substance typically increases, causing the substance to expand.
- Students should also know that as the temperature of a substance decreases the average distance between the atoms/molecules typically decreases, causing the substance to contract.
- Students are expected to know that this expansion or contraction can happen to solids, liquids, and gases.
- They are expected to know that expansion or contraction due to changes in temperature can also happen to mixtures of substances.
- They are also expected to know that the number of atoms and the mass of the atoms do not change with changes in temperature.

Excerpts from Misconceptions List

- Some students are unfamiliar with the non-molecular aspects of physical changes in matter, e.g., thermal expansion and contraction, compression and expansion of gases, dissolving, changes in state such as melting, condensation. (Berkheimer, et al, 1988)
- Some students think that the mass of atoms/molecules of a substance *increases* when the temperature *increases* and *decreases* when the temperature *decreases* (AAAS Pilot testing, 2006).
- The size of atoms/molecules of a substance *decreases* when the temperature *increases* and *increases* when the temperature *decreases* (AAAS Pilot testing, 2006).
- The number of atoms/molecules of a substance *increases* when the temperature *increases* and *decreases* when the temperature *decreases* (AAAS Pilot testing, 2006).

Iron Frying Pan Item (Atomic/Molecular only version)

After cooking breakfast, a cook places a hot iron frying pan on the counter to cool. What happens as the iron pan cools?

A. The iron atoms get heavier.

B. The iron atoms decrease in size.

C. The number of iron atoms increases.

D. The distance between iron atoms decreases.

Iron Frying Pan Item (Macro + Molecular Version)

After cooking breakfast, a cook places a hot iron frying pan on the counter to cool. What happens as the iron pan cools?

A. Even though you cannot see it, the pan gets a tiny bit smaller because the iron atoms decrease in size.

B. Even though you cannot see it, the pan gets a tiny bit smaller because the distance between iron atoms decreases.*

C. Even though you cannot feel it, the pan gets a tiny bit heavier because the iron atoms increase in mass.

D. Even though you cannot feel it, the pan gets a tiny bit heavier because the number of iron atoms increases.

Results of Pilot Testing (n = 30)

Item Type	% Correct Responses
Atomic/Molecular Only	56%
Macro + Molecular	13%

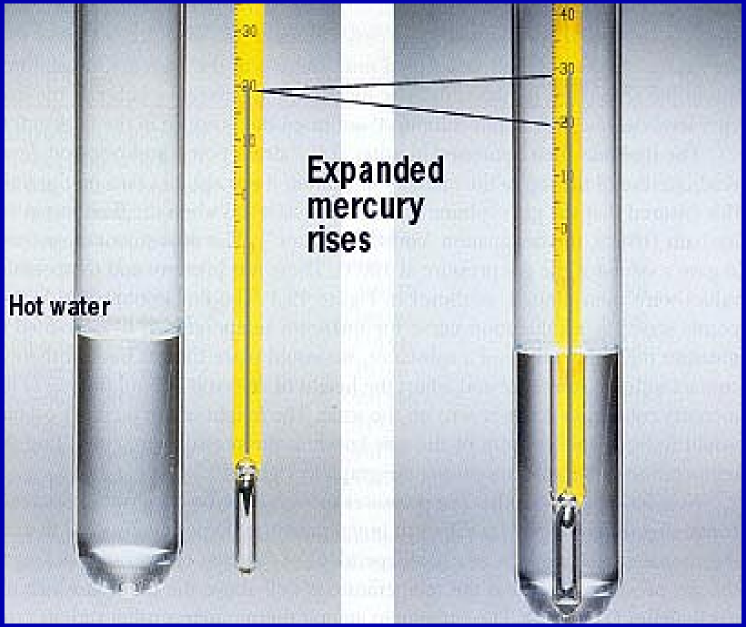
Sample Phenomenon to Illustrate Key Idea: Thermal Expansion of a Solid

- Students observe that a metal ball that fits through a metal ring will no longer fit through the ring after the ball is heated.
- Students need to interpret the “lack of fitting” as an indication of the thermal expansion of the metal ball.
- To help students reconcile this phenomenon with their everyday observations that macroscopic substances don’t appear to expand or contract, students need to appreciate that the ball-and-ring device is capable of detecting small changes that their eyes may not detect.

http://www.sciencekit.com/category.asp_Q_c_E_429628

Sample Phenomenon to Illustrate Key Idea: Thermal Expansion of a Liquid

- Students observe that the level of liquid mercury rises as a thermometer is heated.
- Students need to interpret the height increase of the liquid mercury as an indication of its thermal expansion.
- To help students reconcile this phenomenon with their everyday observations that macroscopic substances don't appear to expand, students need to appreciate that the tiny diameter of the thermometer makes it easier to detect the change.



http://sol.sci.uop.edu/~jfalward/temperatureandexpansion/temperatureandexpansion.html

Clarifying Benchmark Ideas

Benchmark to be clarified:

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 a place has tends to vary depending on how far north or south of the equator it is, how near to oceans it is, and how high above sea level it is. (4B/M12**)

Key Ideas in Benchmark 4B/M12**

- **Key Idea A (Daily Temperature Cycles):** The temperature of any location on the Earth's surface tends to rise and fall in a somewhat predictable pattern over the course of a day.
- **Key Idea B (Yearly Temperature Cycles):** The temperature of any location on the Earth's surface tends to rise and fall in a somewhat predictable cycle over the course of a year.
- **Key Idea C (Factors Affecting Variation in Cycles):** The yearly temperature cycle of a location depends on how far north or south of the equator it is, how high it is, and how near to oceans it is.

Draft Boundaries for Assessment (Daily Temperature Cycles)

- Students should know that over any particular day, the temperature changes. It is higher at some times and lower at other times.
- Students should also know that while no two days follow the exact same cycle of rising and falling, most days follow a similar pattern of having the lowest temperature a few hours before sunrise, and then getting warmer over the course of the day until late afternoon, at which point the temperature begins to fall.
- Students are not expected to know why this pattern takes place. They are only expected to know what the pattern is.
- Students are expected to know that there are days that do not follow this pattern. For example, the high temperature of the day could be just after midnight or the low temperature could be in the middle of the afternoon.

Clarifying Benchmark Ideas

Benchmark to be clarified:

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**)

Key Ideas in Benchmark 4B/M13**

- Key Idea A: (Yearly Amount of Day Light Cycles) The number of hours of daytime or nighttime in a place on the Earth's surface varies in a predictable pattern over the course of a year that depends upon how far north or south of the equator the place is.
- Key Idea B (Yearly Cycles of Sun's Path): The path the sun appears to take across the sky when viewed from a particular place on the surface of the Earth shifts higher and lower over the course of the year. The path also appears higher or lower from different places on the surface of the Earth depending on how far north or south of the equator the place is.
- Key Idea C (Sun's Height Affects its Intensity): The intensity of sunlight striking a place on the surface of the Earth varies depending on how high the sun is in the sky. Therefore the intensity depends upon what time of day it is, what time of year it is, and on how far north or south of the equator the place is.
- Key Idea D (Effect of Sunlight on Temperature): The temperature of a location on the surface of the Earth depends upon the number of hours of sunlight and the intensity of that sunlight.

Clarifying Benchmark Ideas

Benchmark to be clarified:

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 heating of the Earth's surface produces the seasonal variations in temperature. (4B/H3**)

Key Ideas in Benchmark 4B/H3**

- Key Idea A (Constant Direction of Axis of Earth's Orbit): The axis of the Earth's rotation is tilted relative to the plane of the Earth's yearly orbit around the sun. As the Earth orbits the sun, the axis remains pointed to the same place in space.
- Key Idea B (Earth's Orientation affects Amount of Daylight): The difference in how much of the day is daytime and how much is nighttime at a place on the surface of the Earth depends upon where the Earth is in its yearly orbit around the sun and how far the place is from the equator.
- Key Idea C (Sunlight on a Spherical Earth): Because the Earth is a sphere, at any particular time, light from the sun strikes different parts of the Earth at different angles and therefore the intensity of light striking the surface of the Earth is different in different places.
- Key Idea D (Earth's Orientation Affects Intensity of Light): The intensity of sunlight striking a place on the surface of the Earth depends upon where the Earth is in its yearly orbit around the sun and how far the place is from the equator. These variations of intensity as the Earth orbits the sun explain the seasonal variations in temperatures at different places on the surface of the Earth.
- Key Idea E (Tilted Axis During Orbit Causes Seasons): The seasonal variations in temperatures at different places on the surface of the Earth are explained by the differential heating of the Earth's surface as it rotates on an axis that is tilted relative to the plane of its orbit around the sun.

Sample Misconceptions from Research (Related to Multiple Key Ideas)

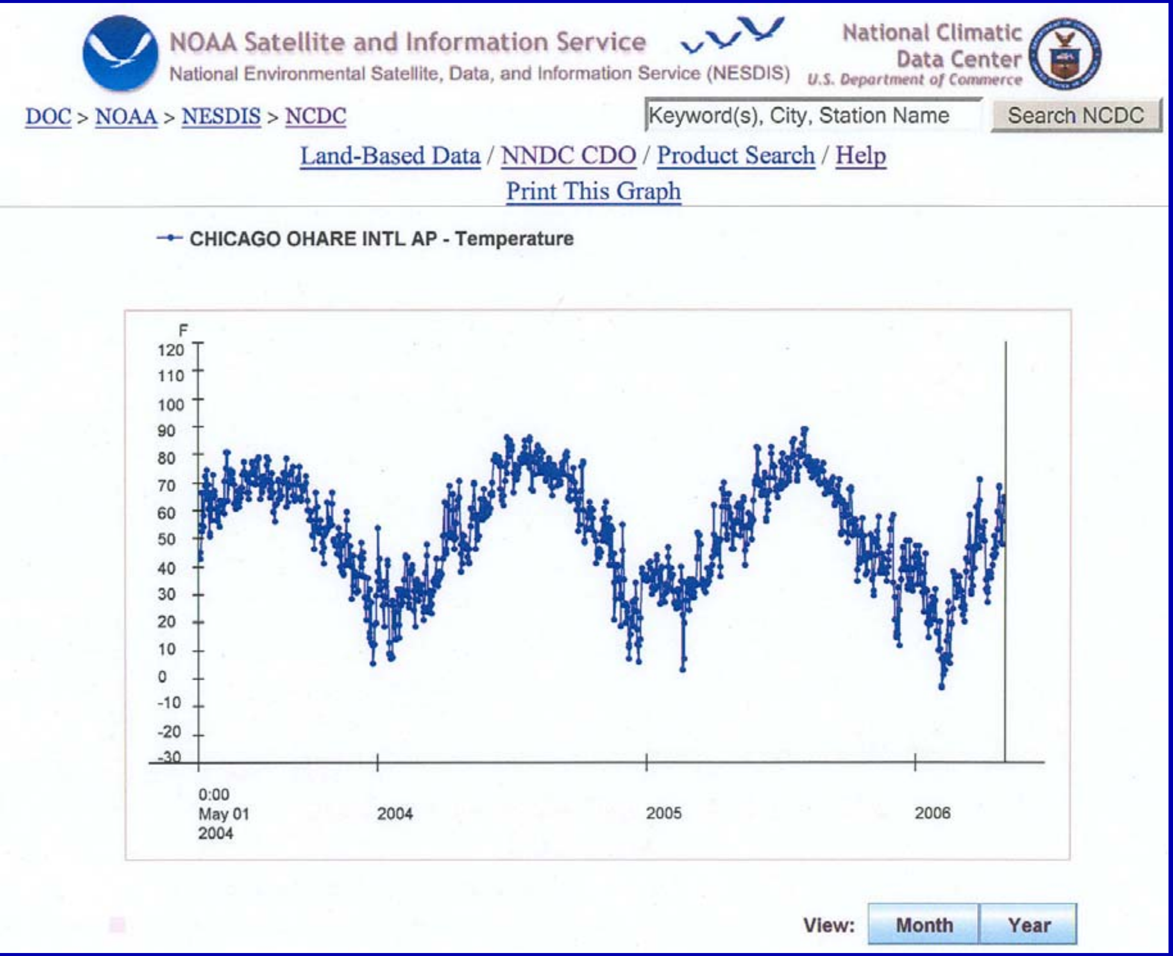
- The sun is further away from the earth in winter than in summer. (19/49 pre-service teachers)
- The direction of the earth's tilt changes as the earth revolves around the sun. (7/49 pre-service teachers)
- Seasons are caused by the rotation of the earth on its axis. (4/49 pre-service teachers)
- The pole of the hemisphere having summer is pointed directly towards the sun. (4/49 pre-service teachers)

Atwood, R.K. and V.A. Atwood, 1996: Preservice Elementary Teachers' Conceptions of the Causes of Seasons, J. Res. Sci. Teaching, 33, pp.553-563.

Draft Boundaries for Assessment (Yearly Temperature Cycles)

- Students should that the temperature in any one place tends to be higher during some parts of the year and lower during other parts of the year.
- They should know that the daily high and low temperatures in any one place tend to rise and fall in a fairly predictable yearly cycle.
- Students should also know that while no two years follow the exact same cycle of rising and falling, most years follow a similar pattern of having the lowest daily temperature in the winter and the highest daily temperature in the summer.
- Students are not expected to know why this pattern takes place. They are only expected to know what the pattern is.

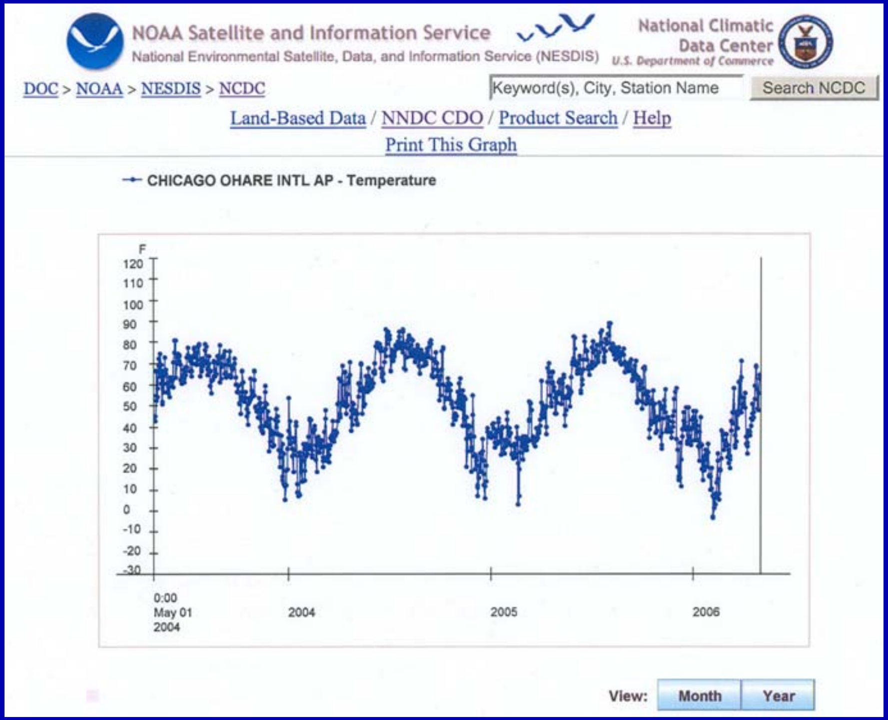
Sample Phenomenon: Yearly Temperature Cycle

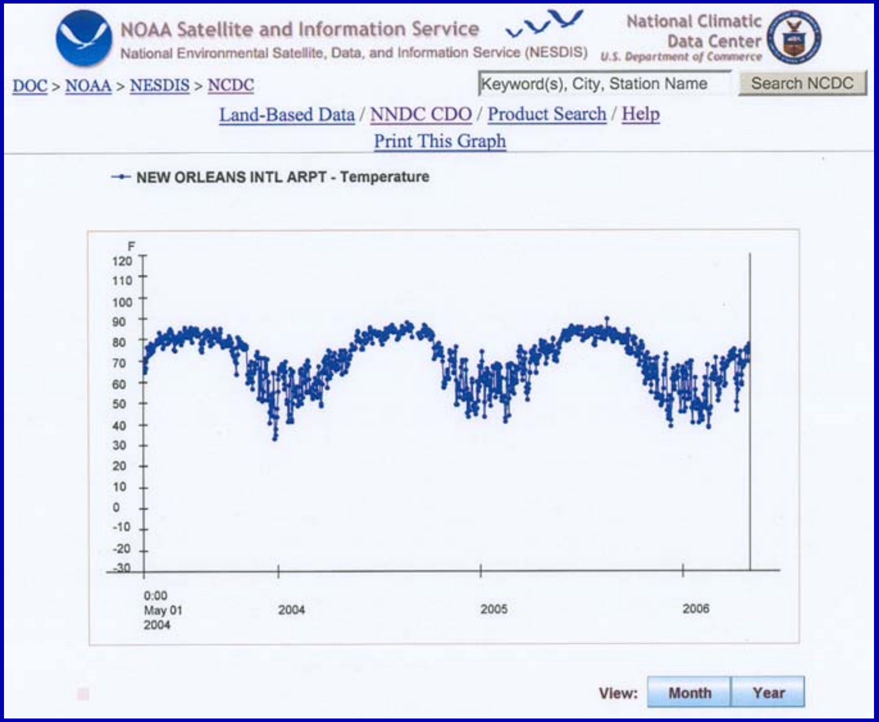


Excerpt from Draft Boundaries (Factors Affecting Variation in Cycles)

- Students should know that places nearer to the equator are in general warmer than places farther from the equator. They should also know that the range of higher and lower temperatures is in general less extreme near the equator and more extreme farther from the equator.

Sample Phenomenon: Effect of Distance from Equator on Yearly Temperature Cycle





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Communicating and Learning About Global Climate Change

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

Project 2061 AAAS

Maps Relevant to Climate Change

- WEATHER AND CLIMATE
- USE OF EARTH'S RESOURCES
- ENERGY RESOURCES
- INTERDEPENDENCE OF LIFE
- SCIENTIFIC INVESTIGATIONS
- INTERACTION OF TECHNOLOGY AND SOCIETY
- DECISIONS ABOUT USING TECHNOLOGY
- PATTERNS OF CHANGE

How might we work together to ensure a science literate citizenry when Halley's Comet returns?

2061

1985

1910

1834

1758

1682