Evolution on the Front Line:

An Abbreviated Guide for Teaching Evolution, from Project 2061 at AAAS

Project 2061 AAAS

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.

Contacts:

- **Dr. Jo Ellen Roseman**
  Director, Project 2061
  202 326 6752
  jroseman@aaas.org
- **Dr. George DeBoer**
  Deputy Director, Project 2061
  202 326 6624
  gdeboer@aaas.org

For more information, visit our Web site:
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.

For more information, visit our Web site:
www.aaas.org

Designed by AAAS Publication Services.

About this Guide

Dear Colleague,

At Project 2061, the national science education reform initiative of AAAS, we recognize the important role that teachers play in helping their students gain the knowledge and skills that are necessary for science literacy. An understanding of how life on Earth evolved is central to biology, and today's students need a solid grounding in these ideas if they are to become science-literate adults. Moreover, students need an understanding of the nature of science—the kinds of knowledge it produces, its assumptions and methods, its demand for evidence and logical reasoning, its ability to explain and predict—in order to make sense of discussions related to creationism and intelligent design.

To support your efforts to convey core evolution concepts to your students, we are pleased to provide you with this abbreviated guide to relevant Project 2061 resources. Launched by AAAS in 1985, Project 2061 has been at the forefront of science education reform, defining adult science literacy; setting goals for K-12 student learning; conducting research on many aspects of curriculum, instruction, and assessment; and providing professional development for educators. This guide consists of excerpts from several of Project 2061's tools and is designed to help you answer the following questions:

Page 2: What do adults need to know about evolution and the nature of science and why is this knowledge important?

These excerpts from *Science for All Americans* describe the concept of evolution as one of the unifying principles for understanding life on earth and explains the basic mechanisms of natural selection. They also focus on the process of scientific inquiry and the nature of the knowledge it produces. For some additional reading on these topics (and on all of the topics covered in *Science for All Americans)*, see p. 6 for selections from our online list of trade books that have been highly rated by AAAS's *Science Books & Films.*

Page 7: What do students need to learn about evolution and the nature of science and when should they learn it?

For each grade level, *Benchmarks for Science Literacy* lays out the specific ideas that students should know about evolution and about how science itself works, along with comments on instructional issues that may arise.

Page 14: How do students build a coherent understanding of evolution and the nature of science as they progress from one grade level to the next?

A set of conceptual strand maps excerpted from the *Atlas of Science Literacy* displays how ideas that contribute to students' understanding of biological evolution, natural selection and the use of evidence and reasoning in scientific inquiry develop over time.

Page 23: How well do textbooks deal with the topic of evolution and the nature of science?

In *High School Biology Textbooks: A Benchmarks-Based Evaluation,* a study of nine of the most widely used biology textbooks, Project 2061 reviewers found that while most texts presented many of the ideas related to evolution, few presented the necessary connections among ideas or treated ideas related to the nature of science. The ideas the reviewers looked for and what they actually found are displayed in this excerpt.

Also, to help you respond to some of the most frequently asked questions about teaching evolution, see page 22 for suggestions from AAAS. Many more Project 2061 resources are available in print and online. For additional details about the resources described here and other Project 2061 tools for science teaching and learning, please visit our Web site at www.Project2061.org.

We hope this guide will be helpful. We commend you for your efforts on behalf of science literacy.

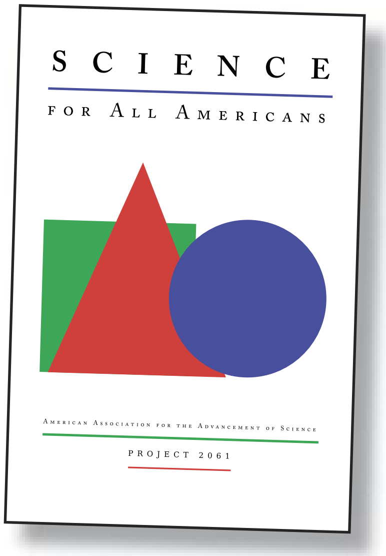
Sincerely,

Jo Ellen Roseman

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

The following excerpts are from *Science for All Americans*

Defines what every high school graduate should know and be able to do in science, mathematics, and technology. It also lays out some principles for effective science teaching and learning.



From Chapter 5: The Living Environment

Evolution of Life

The earth's present-day life forms appear to have evolved from common ancestors reaching back to the simplest one-cell organisms almost four billion years ago. Modern ideas of evolution provide a scientific explanation for three main sets of observable facts about life on earth: the enormous number of different life forms we see about us, the systematic similarities in anatomy and molecular chemistry we see within that diversity, and the sequence of changes in fossils found in successive layers of rock that have been formed over more than a billion years.

Since the beginning of the fossil record, many new life forms have appeared, and most old forms have disappeared. The many traceable sequences of changing anatomical forms, inferred from ages of rock layers, convince scientists that the accumulation of differences from one generation to the next has led eventually to species as different from one another as bacteria are from elephants. The molecular evidence substantiates the anatomical evidence from fossils and provides additional detail about the sequence in which various lines of descent branched off from one another.

Although details of the history of life on earth are still being pieced together from the combined geological, anatomical, and molecular evidence, the main features of that history are generally agreed upon. At the very beginning, simple molecules may have formed complex molecules that eventually formed into cells capable of self-replication. Life on earth has existed for three billion years. Prior to that, simple molecules may have formed complex organic molecules that eventually formed into cells capable of self-replication. During the first two billion years of life, only microorganisms existed—some of them apparently quite similar to bacteria and algae that exist today. With the development of cells with nuclei about a billion years ago, there was a great increase in the rate of evolution of increasingly complex, multicelled organisms. The rate of evolution of new species has been uneven since then, perhaps reflecting the varying rates of change in the physical environment.

A central concept of the theory of evolution is natural selection, which arises from three well-established observations: (1) There is some variation in heritable characteristics within every species of organism, (2) some of these characteristics will give individuals an advantage over others in surviving to maturity and reproducing, and (3) those individuals will be likely to have more offspring, which will themselves be more likely than others to survive and reproduce. The likely result is that over successive generations, the proportion of individuals that have inherited advantage-giving characteristics will tend to increase.

Selectable characteristics can include details of biochemistry, such as the molecular structure of hormones or digestive enzymes, and anatomical features that are ultimately produced in the development of the organism, such as bone size or fur length. They can also include more subtle features determined by anatomy, such as acuity of vision or pumping efficiency of the heart. By biochemical or anatomical means, selectable characteristics may also influence behavior, such as weaving a certain shape of web, preferring certain characteristics in a mate, or being disposed to care for offspring.

New heritable characteristics can result from new combinations of parents' genes or from mutations of them. Except for mutation of the DNA in an organism's sex cells, the characteristics that result from occurrences during the organism's lifetime cannot be biologically passed on to the next generation. Thus, for example, changes in an individual caused by use or disuse of a structure or function, or by changes in its environment, cannot be promulgated by natural selection.

By its very nature, natural selection is likely to lead to organisms with characteristics that are well adapted to survival in particular environments. Yet chance alone, especially in small populations, can result in the spread of inherited characteristics that have no inherent survival or reproductive advantage or disadvantage. Moreover, when an environment changes (in this sense, other organisms are also part of the environment), the advantage or disadvantage of characteristics can change. So natural selection does not necessarily result in long-term progress in a set direction.

The continuing operation of natural selection on new characteristics and in changing environments, over and over again for millions of years, has produced a succession of diverse new species. Evolution is not a ladder in which the lower forms are all replaced by superior forms, with humans finally emerging at the top as the most advanced species. Rather, it is like a bush: Many branches emerged long ago; some of those branches have died out; some have survived with apparently little or no change over time; and some have repeatedly branched, sometimes giving rise to more complex organisms.

The modern concept of evolution provides a unifying principle for understanding the history of life on earth, relationships among all living things, and the dependence of life on the physical environment. While it is still far from clear how evolution works in every detail, the concept is so well established that it provides a framework for organizing most of biological knowledge into a coherent picture.

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 for All Americans is available in print from Oxford University Press at 1-800-451-7556 or online at **www.project2061.org/publications/sfaa/online**

Recommended trade books from *Resources for Science Literacy: Professional Development*

Provides educators with a variety of information—including highly recommended trade books—to help improve their science knowledge and teaching skills.

Resources for Science Literacy: Professional Development is available online at **http://www.project2061.org/publications/rsl/online/index.htm**

The Beak of the Finch: A Story of Evolution in Our Time

by Jonathan Weiner

(Illus.), Alfred A. Knopf Inc., 1994, x+332pp.
0-679-40003-6, Index

Recent polls suggest that approximately 50% of Americans do not believe in evolution. Most people, even trained scientists, would refer to evolution as the "theory" of evolution. Darwin never used the word "evolution" in *The Origin of Species.* All of this can be explained by the understanding that the process takes place over a long period of time and cannot be observed or tested. Evolution must be believed by logic alone. This book clearly and elegantly shows the modern-day reality of the visible action of evolution as observable fact. The text is based on numerous scientific publications by professors Peter and Rosemary Grant and their associates. Weiner takes us through the steps of these two researchers in over a decade of daily observations and measurements on perhaps the most famous birds in the world, Darwin's finches. Darwin himself was the first to describe and marvel over this diverse, yet similar, group of closely related birds that inhabit the Galapagos Islands in a patchwork of species and adaptations. Darwin was also the first to note how seemingly minute variations in the beaks of different species coincided with very different behaviors and distributions on the islands. The Grants have taken Darwin's and others' observations many steps further. They began by taking dozens of measurements on every bird on one island of the Galapagos (Daphne Major) and following every individual and every one of its progeny through a decade that included both a major drought and a veritable flood: climatic extremes. What they found first was that the population of various finches on Daphne Major are not static. The seasonal differences swing wildly about and are directly related to changes in rainfall, food availability, and other factors. Detailed studies show that seemingly minute differences of only a single millimeter in the depth of a finch's beak can strongly influence that bird's survival, breeding potential, and contribution to the gene pool. The researchers were able to observe conditions that favored both greater separation of species (i.e., greater distinction) and the fusion of species (when conditions favor the survival of hybrids). And, unlike Darwin's wildest dreams, the Grants actually measured factors that might easily suggest the origin of new species. Their students who were working with blood samples were able to pinpoint DNA chains that corresponded with changes in the birds' structure and changes in climate. At high noon, the sun is so bright we cannot see the stars, but they are always there. And so it is with evolution, it is always moving and changing the players in each species even if very slowly, but it is there and it can be seen and measured. Today, the prime agents of change are humans, and our selection pressure on a wide range of plants and animals may unalterably force this world into a new phase of evolution. The author relates all of these factors to the readers through various other examples of plants, animals, and humans in a highly readable manner.

—Reviewed by James W. Waddick in Science Books & Films, *30/9 (December 1994), pp. 263-4.*

Blueprints: Solving the Mystery of Evolution

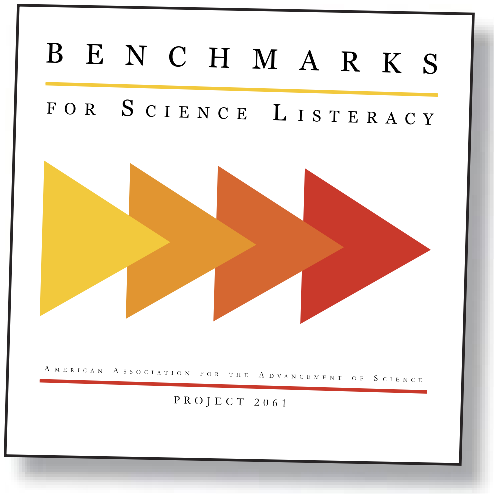
by Maitland A. Edey and Donald C. Johanson

Little Brown & Company, Inc., ©1989, x+418pp.
0-140-1326-51, Index

This book by the authors of the 1981 work, *Lucy: The Beginnings of Humankind* (NY: Simon & Schuster, 1981) is excellent. The scope is broad–namely, the history of general evolutionary theory. It is scholarly, comprehensively researched, and exceedingly lucid. The bulk of the work summarizes the history of theories of heredity up to the cracking of the genetic code in the 1960s. This is preceded by a discourse on Darwiniana and followed by a brief review of theories of the origin of life. The text concludes with a long chapter on human evolution (updating, in a sense, *Lucy*) and a philosophical touch. The style is slightly recursive, with the authors sometimes addressing the reader and sometimes addressing each other. Edey and Johanson successfully communicate their ideas to a lay audience, with little obvious sacrifice in content. While this book may not have the broad appeal of *Lucy,* it will interest a general audience. It should also prove useful in introductory anthropology classes.

—Reviewed by Jonathan Marks in Science Books & Films, *25/4 (March/April 1990), pp. 204.*

The following excerpts are from *Benchmarks for Science Literacy*



Recommends what all students should know and be able to do in science, mathematics, and technology by the end of grades 2, 5, 8, and 12.

From Chapter 5: The Living Environment

Evolution of Life

In the twentieth century, no scientific theory has been more difficult for people to accept than biological evolution by natural selection. It goes against some people's strongly held beliefs about when and how the world and the living things in it were created. It hints that human beings had lesser creatures as ancestors, and it flies in the face of what people can plainly see—namely that generation after generation, life forms don't change; roses stay roses, worms stay worms. New traits arising by chance alone is a strange idea, unsatisfying to many and offensive to some. And its broad applicability is not appreciated by students, most of whom know little of the vast amount of biological knowledge that evolution by natural selection attempts to explain.

It is important to distinguish between evolution, the historical changes in life forms that are well substantiated and generally accepted as fact by scientists, and natural selection, the proposed mechanism for these changes. Students should first be familiar with the evidence of evolution so that they will have an informed basis for judging different explanations. This familiarity depends on knowledge from the life and physical sciences: knowledge of phenomena occurring at several different levels of biological organization and over very long time spans, and of how fossils form and how their ages are determined. Students may very well wonder why the fossil record has so many seeming holes in it. If so, the opportunity should be seized to show the value of mathematics. The probability of specimens of any species of organisms surviving is small—soft body parts are eaten or decomposed, and hard parts are crushed or dissolved. The probability of finding a specimen is small because most are buried or otherwise inexcavable. Mathematics holds that the probability of acquiring a specimen of an extinct species is extremely small—the product of the two probabilities.

Before natural selection is proposed as a mechanism for evolution, students must recognize the diversity and apparent relatedness of species. Students take years to acquire sufficient knowledge of living organisms and the fossil record. Natural selection should be offered as an explanation for familiar phenomena and then revisited as new phenomena are explored. To appreciate how natural selection can account for evolution, students have to understand the important distinction between the selection of an individual with a certain trait and the changing proportions of that trait in populations. Their being able to grasp this distinction requires some understanding of the mathematics of proportions and opportunities for them to reflect on the individual-versus-population distinction in other contexts.

Controversy is an important aspect of the scientific process. Students should realize that although virtually all scientists accept the general concept of evolution of species, scientists do have different opinions on how fast and by what mechanisms evolution proceeds. A separate issue altogether is how life itself began, a detailed mechanism for which has not yet emerged.

Kindergarten through Grade 2

Students should begin to build a knowledge base about biological diversity. Student curiosity about fossils and dinosaurs can be harnessed to consider life forms that no longer exist. But the distinction between extinct creatures and those that still live elsewhere will not be clear for some time. "Long ago" has very limited meaning at this age level. Even as students make observations of organisms in their own environments, they can extend their experiences with other environments through film.

By the end of the 2nd grade, students should know that

- Different plants and animals have external features that help them thrive in different kinds of places.
- Some kinds of organisms that once lived on earth have completely disappeared, although they were something like others that are alive today.

Grades 3 through 5

Students can begin to look for ways in which organisms in one habitat differ from those in another and consider how some of those differences are helpful to survival. The focus should be on the consequences of different features of organisms for their survival and reproduction. The study of fossils that preserve plant and animal structures is one approach to looking at characteristics of organisms. Evidence for the similarity within diversity of existing organisms can draw upon students' expanding knowledge of anatomical similarities and differences.

By the end of the 5th grade, students should know that

- Individuals of the same kind differ in their characteristics, and sometimes the differences give individuals an advantage in surviving and reproducing.
- Fossils can be compared to one another and to living organisms according to their similarities and differences. Some organisms that lived long ago are similar to existing organisms, but some are quite different.

Grades 6 through 8

During middle school, several lines of evidence are further developed. The fossil evidence can be expanded beyond extinctions and survivals to the notion of evolutionary history. Sedimentation of rock can be brought in to show relative age. However, actual age, which requires an understanding of isotopic dating techniques, should wait until high school, when students learn about the structure of atoms. Breeding experiments can illustrate the heritability of traits and the effects of selection. It was familiarity with selective breeding that stimulated Darwin's thinking that differences between successive generations can naturally accumulate.

By the end of the 8th grade, students should know that

- Small differences between parents and offspring can accumulate (through selective breeding) in successive generations so that descendants are very different from their ancestors.
- Individual organisms with certain traits are more likely than others to survive and have offspring. Changes in environmental conditions can affect the survival of individual organisms and entire species.
- Many thousands of layers of sedimentary rock provide evidence for the long history of the earth and for the long history of changing life forms whose remains are found in the rocks. More recently deposited rock layers are more likely to contain fossils resembling existing species.

Grades 9 through 12

Knowing what evolutionary change is and how it played out over geological time, students can now turn to its mechanism. They need to shift from thinking in terms of selection of individuals with a trait to changing proportions of a trait in populations. Familiarity with artificial selection, coming from studies of pedigrees and their own experiments, can be applied to natural systems, in which selection occurs because of environmental conditions. Students' understanding of radioactivity makes it possible for them to comprehend isotopic dating techniques used to determine the actual age of fossils and hence to appreciate that sufficient time may have elapsed for successive changes to have accumulated. Knowledge of DNA contributes to the evidence for life having evolved from common ancestors and provides a plausible mechanism for the origin of new traits.

History should not be overlooked. Learning about Darwin and what led him to the concept of evolution illustrates the interacting roles of evidence and theory in scientific inquiry. Moreover, the concept of evolution provided a framework for organizing new as well as "old" biological knowledge into a coherent picture of life forms.

Finally there is the matter of public response. Opposition has come and continues to come from people whose interpretation of religious writings conflicts with the story of evolution. Schools need not avoid the issue altogether. Perhaps science courses can acknowledge the disagreement and concentrate on frankly presenting the scientific view. Even if students eventually choose not to believe the scientific story, they should be well informed about what the story is.

By the end of the 12th grade, students should know that

- The basic idea of biological evolution is that the earth's present-day species developed from earlier, distinctly different species.
- Molecular evidence substantiates the anatomical evidence for evolution and provides additional detail about the sequence in which various lines of descent branched off from one another.
- Natural selection provides the following mechanism for evolution: Some variation in heritable characteristics exists within every species, some of these characteristics give individuals an advantage over others in surviving and reproducing, and the advantaged offspring, in turn, are more likely than others to survive and reproduce. The proportion of individuals that have advantageous characteristics will increase.
- Heritable characteristics can be observed at molecular and whole-organism levels—in structure, chemistry, or behavior. These characteristics strongly influence what capabilities an organism will have and how it will react, and therefore influence how likely it is to survive and reproduce.
- New heritable characteristics can result from new combinations of existing genes or from mutations of genes in reproductive cells. Changes in other cells of an organism cannot be passed on to the next generation.
- Natural selection leads to organisms that are well suited for survival in particular environments. Chance alone can result in the persistence of some heritable characteristics having no survival or reproductive advantage or disadvantage for the organism. When an environment changes, the survival value of some inherited characteristics may change.

- The theory of natural selection provides a scientific explanation for the history of life on earth as depicted in the fossil record and in the similarities evident within the diversity of existing organisms.
- Life on earth is thought to have begun as simple, one-celled organisms about 4 billion years ago. During the first 2 billion years, only single-cell microorganisms existed, but once cells with nuclei developed about a billion years ago, increasingly complex multicellular organisms evolved.
- Evolution builds on what already exists, so the more variety there is, the more there can be in the future. But evolution does not necessitate long-term progress in some set direction. Evolutionary changes appear to be like the growth of a bush: Some branches survive from the beginning with little or no change, many die out altogether, and others branch repeatedly, sometimes giving rise to more complex organisms.

From Chapter 1: The Nature of Science

The Scientific World View

A scientific world view is not something that working scientists spend a lot of time discussing. They just do science. But underlying their work are several beliefs that are not always held by nonscientists. One is that by working together over time, people can in fact figure out how the world works. Another is that the universe is a unified system and knowledge gained from studying one part of it can often be applied to other parts. Still another is that knowledge is both stable and subject to change.

Little is gained by presenting these beliefs to students as dogma. For one thing, such beliefs are subtle. The first one cited above says only that scientists believe that the world can be understood, not that it ever will be so completely understood that science can shut down once and for all, the job done. Indeed, in finding answers to one set of questions about how the world works, scientists inevitably unearth new questions, so the quest will likely continue as long as human curiosity survives. Also, the human capacity for generating trustworthy knowledge about nature has limits. Scientific investigations often fail to find convincing answers to the questions they pursue. The claim that science will find answers always carries the implied disclaimers, "in many cases" and "in the very long run."

The belief that knowledge gained by studying one part of the universe can be applied to other parts is often confirmed but turns out to be true only part of the time. It happens, for example, that the behavior of a given organism is sometimes different when observed in a laboratory instead of its natural environment. Thus, a belief in the unity of the universe does not eliminate the need to show how far the findings in one situation can be extended.

The notion that scientific knowledge is always subject to modification can be difficult for students to grasp. It seems to oppose the certainty and truth popularly accorded to science, and runs counter to the yearning for certainty that is characteristic of most cultures, perhaps especially so among youth. Moreover, the picture of change in science is not simple. As new questions arise, new theories are proposed, new instruments are invented, and new techniques are developed. In response, new experiments are conducted, new specimens collected, new observations made, and new analyses performed. Some of the findings challenge existing theories, leading to their modification or to the invention, on very rare occasions, of entirely new theories—which, in turn, leads to new experiments, new observations…and so on.

But that ferment of change occurs mostly at the cutting edge of research. In fact, it is important not to overdo the "science always changes" theme, since the main body of scientific knowledge is very stable and grows by being corrected slowly and having its boundaries extended gradually. Scientists themselves accept the notion that scientific knowledge is always open to improvement and can never be declared absolutely certain.

Kindergarten through Grade 2

From their very first day in school, students should be actively engaged in learning to view the world scientifically. That means encouraging them to ask questions about nature and to seek answers, collect things, count and measure things, make qualitative observations, organize collections and observations, discuss findings, etc. Getting into the spirit of science and liking science are what count most. Awareness of the scientific world view can come later.

Anticipating an eventual understanding of the scientific world view, these early science experiences can be designed to bring out one aspect of the belief in the unity of nature: consistency. Students should sometimes repeat observations and investigations in the classroom, and then, when possible, do so again in the school yard and at home. For instance, students could be asked to compare what happens in different places when an egg is cooked, or how moving objects are affected when pushed or pulled, or what a seed looks like when it starts to grow. These activities should serve to stimulate curiosity and engage students in taking an interest in their environment and the workings of nature.

By the end of the 2nd grade, students should know that:

- When a science investigation is done the way it was done before, we expect to get a very similar result.
- Science investigations generally work the same way in different places.

Grades 3 through 5

As children continue to investigate the world, the consistency premise can be strengthened by putting more emphasis on explaining inconsistency. When students observe differences in the way things behave or get different results in repeated investigations, they should suspect that something differs from trial to trial and try to find out what. Sometimes the difference results from methods, sometimes from the way the world is. The point is that different findings can lead to interesting new questions to be investigated.

This emphasis on scientific engagement calls for frequent hands-on activities. But that is not to say that students must, or even can, "discover" everything by direct experience. Stories about people making discoveries and inventions can be used to illustrate the kinds of convictions about the world and what can be learned from it that are shared by the varied people who do science.

By the end of the 5th grade, students should know that:

- Results of similar scientific investigations seldom turn out exactly the same. Sometimes this is because of unexpected differences in the things being investigated, sometimes because of unrealized differences in the methods used or in the circumstances in which the investigation is carried out, and sometimes just because of uncertainties in observations. It is not always easy to tell which.

Grades 6 through 8

Most early adolescents have a more immediate interest in nature than in the philosophy of science. They should continue to be engaged in doing science and encouraged to reflect on the science they are engaged in, with the assumption that they will later acquire a more mature reflection on science as a world view.

Early adolescence, however, is not too early to begin to deal with the question of the durability of scientific knowledge, and particularly its susceptibility to change. Both incremental changes and more radical changes in scientific knowledge should be taken up. Radical changes in science sometimes result from the appearance of new information, and sometimes from the invention of better theories (for example, germ theory and geologic time, as discussed in Chapter 10: Historical Perspectives).

By the end of the 8th grade, students should know that:

- 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. Even with similar results, scientists may wait until an investigation has been repeated many times before accepting the results as correct.
- Scientific knowledge is subject to modification as new information challenges prevailing theories and as a new theory leads to looking at old observations in a new way.
- Some scientific knowledge is very old and yet is still applicable today.
- Some matters cannot be examined usefully in a scientific way. Among them are matters that by their nature cannot be tested objectively and those that are essentially matters of morality. Science can sometimes be used to inform ethical decisions by identifying the likely consequences of particular actions but cannot be used to establish that some action is either moral or immoral.

Grades 9 through 12

Aspects of the scientific world view can be illustrated in the upper grades both by the study of historical episodes in science and by reflecting on developments in current science. Case studies provide opportunities to examine such matters as the theoretical and practical limitations of science, the differences in the character of the knowledge the different sciences generate, and the tension between the certainty of accepted science and the breakthroughs that upset this certainty.

By the end of the 12th grade, students should know that:

- Scientists assume that the universe is a vast single system in which the basic rules are the same everywhere. The rules may range from very simple to extremely complex, but scientists operate on the belief that the rules can be discovered by careful, systematic study.
- From time to time, major shifts occur in the scientific view of how the world works. More often, however, the changes that take place in the body of scientific knowledge are small modifications of prior knowledge. Change and continuity are persistent features of science.
- No matter how well one theory fits observations, a new theory might fit them just as well or better, or might fit a wider range of observations. In science, the testing, revising, and occasional discarding of theories, new and old, never ends. This ongoing process leads to an increasingly better understanding of how things work in the world but not to absolute truth. Evidence for the value of this approach is given by the improving ability of scientists to offer reliable explanations and make accurate predictions.

Scientific Inquiry

Scientific inquiry is more complex than popular conceptions would have it. It is, for instance, a more subtle and demanding process than the naive idea of "making a great many careful observations and then organizing them." It is far more flexible than the rigid sequence of steps commonly depicted in textbooks as "the scientific method." It is much more than just "doing experiments," and it is not confined to laboratories. More imagination and inventiveness are involved in scientific inquiry than many people realize, yet sooner or later strict logic and empirical evidence must have their day. Individual investigators working alone sometimes make great discoveries, but the steady advancement of science depends on the enterprise as a whole. And so on.

If students themselves participate in scientific investigations that progressively approximate good science, then the picture they come away with will likely be reasonably accurate. But that will require recasting typical school laboratory work. The usual high-school science "experiment" is unlike the real thing: The question to be investigated is decided by the teacher, not the investigators; what apparatus to use, what data to collect, and how to organize the data are also decided by the teacher (or the lab manual); time is not made available for repetitions or, when things are not working out, for revising the experiment; the results are not presented to other investigators for criticism; and, to top it off, the correct answer is known ahead of time.

Of course, the student laboratory can be designed to help students learn about the nature of scientific inquiry. As a first step, it would help simply to reduce the number of experiments undertaken (making time available to probe questions more deeply) and eliminate many of their mechanical, recipe-following aspects. In making this change, however, it should be kept in mind that well-conceived school laboratory experiences serve other important purposes as well. For example, they provide opportunities for students to become familiar with the phenomena that the science concepts being studied try to account for.

Another, more ambitious step is to introduce some student investigations that more closely approximate sound science. Such investigations should become more ambitious and more sophisticated. Before graduating from high school, students working individually or in teams should design and carry out at least one major investigation. They should frame the question, design the approach, estimate the time and costs involved, calibrate the instruments, conduct trial runs, write a report, and finally, respond to criticism.

Such investigations, whether individual or group, might take weeks or months to conduct. They might happen in and out of school time and be broken up by periods when, for technical reasons, work cannot go forward. But the total time invested will probably be no more than the sum of all those weekly one-period labs that contribute little to student understanding of scientific inquiry.

Kindergarten through Grade 2

Students should be actively involved in exploring phenomena that interest them both in and out of class. These investigations should be fun and exciting, opening the door to even more things to explore. An important part of students' exploration is telling others what they see, what they think, and what it makes them wonder about. Children should have lots of time to talk about what they observe and to compare their observations with those of others. A premium should be placed on careful expression, a necessity in science, but students at this level should not be expected to come up with scientifically accurate explanations for their observations. Theory can wait.

By the end of the 2nd grade, students should know that:

- 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.
- Tools such as thermometers, magnifiers, rulers, or balances often give more information about things than can be obtained by just observing things without their help.
- Describing things as accurately as possible is important in science because it enables people to compare their observations with those of others.
- When people give different descriptions of the same thing, it is usually a good idea to make some fresh observations instead of just arguing about who is right.

Grades 3 through 5

Children's strategies for finding out more and more about their surroundings improve as they gain experience in conducting simple investigations of their own and working in small groups. They should be encouraged to observe more and more carefully, measure things with increasing accuracy (where the nature of the investigations involves measurement), record data clearly in logs and journals, and communicate their results in charts and simple graphs as well as in prose. Time should be provided to let students run enough trials to be confident of their results. Investigations should often be followed up with presentations to the entire class to emphasize the importance of clear communication in science. Class discussions of the procedures and findings can provide the beginnings of scientific argument and debate.

Students' investigations at this level can be expected to bear on detecting the similarities and differences among the things they collect and examine. They should come to see that in trying to identify and explain likenesses and differences, they are doing what goes on in science all the time. What students may find most puzzling is when there are differences in the results they obtain in repeated investigations at different times or in different places, or when different groups of students get different results doing supposedly the same experiment. That, too, happens to scientists, sometimes because of the methods or materials used, but sometimes because the thing being studied actually varies.

Research studies suggest that there are some limits on what to expect at this level of student intellectual development. One limit is that the design of carefully controlled experiments is still beyond most students in the middle grades. Others are that such students confuse theory (explanation) with evidence for it and that they have difficulty making logical inferences. However, the studies say more about what students at this level do not learn in today's schools than about what they might possibly learn if instruction were more effective.

In any case, some children will be ready to offer explanations for why things happen the way they do. They should be encouraged to "check what you think against what you see." As explanations take on more and more importance, teachers must insist that students pay attention to the explanations of others and remain open to new ideas. This is an appropriate time to introduce the notion that in science it is legitimate to offer different explanations for the same set of observations, although this notion is apparently difficult for many youngsters to comprehend.

By the end of the 5th grade, students should know that:

- 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. Investigations can focus on physical, biological, and social questions.
- Results of scientific investigations are seldom exactly the same, but if the differences are large, it is important to try to figure out why. One reason for following directions carefully and for keeping records of one's work is to provide information on what might have caused the differences.
- Scientists' explanations about what happens in the world come partly from what they observe, partly from what they think. Sometimes scientists have different explanations for the same set of observations. That usually leads to their making more observations to resolve the differences.
- Scientists do not pay much attention to claims about how something they know about works unless the claims are backed up with evidence that can be confirmed and with a logical argument.

Grades 6 through 8

At this level, students need to become more systematic and sophisticated in conducting their investigations, some of which may last for weeks or more. That means closing in on an understanding of what constitutes a good experiment. The concept of controlling variables is straightforward but achieving it in practice is difficult. Students can make some headway, however, by participating in enough experimental investigations (not to the exclusion, of course, of other kinds of investigations) and explicitly discussing how explanation relates to experimental design.

Student investigations ought to constitute a significant part—but only a part—of the total science experience. Systematic learning of science concepts must also have a place in the curriculum, for it is not possible for students to discover all the concepts they need to learn, or to observe all of the phenomena they need to encounter, solely through their own laboratory investigations. And even though the main purpose of student investigations is to help students learn how science works, it is important to back up such experience with selected readings. This level is a good time to introduce stories (true and fictional) of scientists making discoveries-not just world-famous scientists, but scientists of very different backgrounds, ages, cultures, places, and times.

By the end of the 8th grade, students should know that:

- Scientists differ greatly in what phenomena they study and how they go about their work. Although there is no fixed set of steps that all scientists follow, 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.
- 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), but collaboration among investigators can often lead to research designs that are able to deal with such situations.
- What people expect to observe often affects what they actually do observe. Strong beliefs about what should happen in particular circumstances can prevent them from detecting other results. Scientists know about this danger to objectivity and take steps to try and avoid it when designing investigations and examining data. One safeguard is to have different investigators conduct independent studies of the same questions.

Grades 9 through 12

Students' ability to deal with abstractions and hypothetical cases improves in high school. Now the unfinished and tentative nature of science may make some sense to them. Students should not be allowed to conclude, however, that the mutability of science permits any belief about the world to be considered as good as any other belief. Theories compete for acceptance, but the only serious competitors are those theories that are backed by valid evidence and logical arguments.

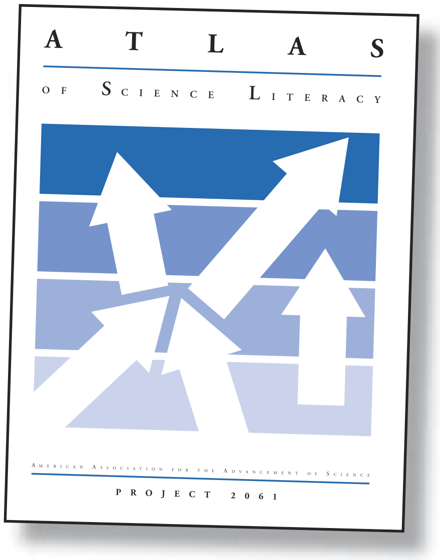
The nature and importance of prediction in science can also be taken up at this level. Coverage of this topic should emphasize the use of statistics, probability, and modeling in making scientific predictions about complex phenomena often found in biological, meteorological, and social systems. Care also should be taken to dissociate the study of scientific prediction from the general public's notions about astrology and guessing the outcomes of sports events.

By the end of the 12th grade, students should know that:

- 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 different theories.
- 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 the data (both new and previously available).
- Sometimes, scientists can control conditions in order to obtain evidence. 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.
- 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. And there is agreement that progress in all fields of science depends on intelligence, hard work, imagination, and even chance.
- Scientists in any one research group tend to see things alike, so even groups of scientists may have trouble being entirely objective about their methods and findings. For that reason, scientific teams are expected to seek out the possible sources of bias in the design of their investigations and in their data analysis. Checking each other's results and explanations helps, but that is no guarantee against bias.
- In the short run, new ideas that do not mesh well with mainstream ideas in science often encounter vigorous criticism. In the long run, theories are judged by how they fit with other theories, the range of observations they explain, how well they explain observations, and how effective they are in predicting new findings.
- New ideas in science are limited by the context in which they are conceived; are often rejected by the scientific establishment; sometimes spring from unexpected findings; and usually grow slowly, through contributions from many investigators.

Benchmarks for Science Literacy is available in print from Oxford University Press at 1-800-451-7556 or online at **www.project2061.org/publications/bsl/online**

The following excerpts are from *Atlas of Science Literacy*



Displays in a map-like format how key ideas related to important topics in science, mathematics, and technology connect with each other and progress from one grade to the next.

About *Atlas of Science Literacy* Strand Maps

A strand map focuses on a topic important for literacy in science, mathematics, and technology and displays the benchmarks—from primary school to high school—that are most relevant to understanding it, suggesting for each benchmark along the way earlier benchmarks it builds on and later benchmarks it supports.

The ideas and skills presented in the maps are specific goals for student learning. We call these learning goals benchmarks because they are derived from *Benchmarks for Science Literacy,* where each one is prefaced by the stem "Students should know that..." or the stem "Students should be able to..." In the maps, the text of each benchmark is followed by a code that references the chapter and section of the corresponding goal statement in *Benchmarks.*

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.

Labeled Strands

In each map, a few principal strands are pointed out to help the reader find things in the map and get a sense of its content. These strands are labeled along the bottom of the map, and, where possible, relevant benchmarks are positioned in a column above each label.

Grade Ranges

The horizontal lines in each map delineate the grade ranges in which most students should be able to achieve particular benchmarks. Benchmarks may be achieved in higher or lower grades depending on students interests, abilities, and experience. But they cannot be sorted into grades arbitrarily. When ideas and skills are pushed inappropriately lower in the grades—often to fit more into the curriculum— students' understanding suffers. When they are left until too late, students' interest and readiness may wane.

Connections to Other Maps

We have not simply sorted the benchmarks into separate maps. Rather, each map includes benchmarks relevant to understanding a literacy topic, regardless of where else in *Atlas* those benchmarks appear.

Maps will not be understood as well, or used as effectively, if they are seen as independent entities.

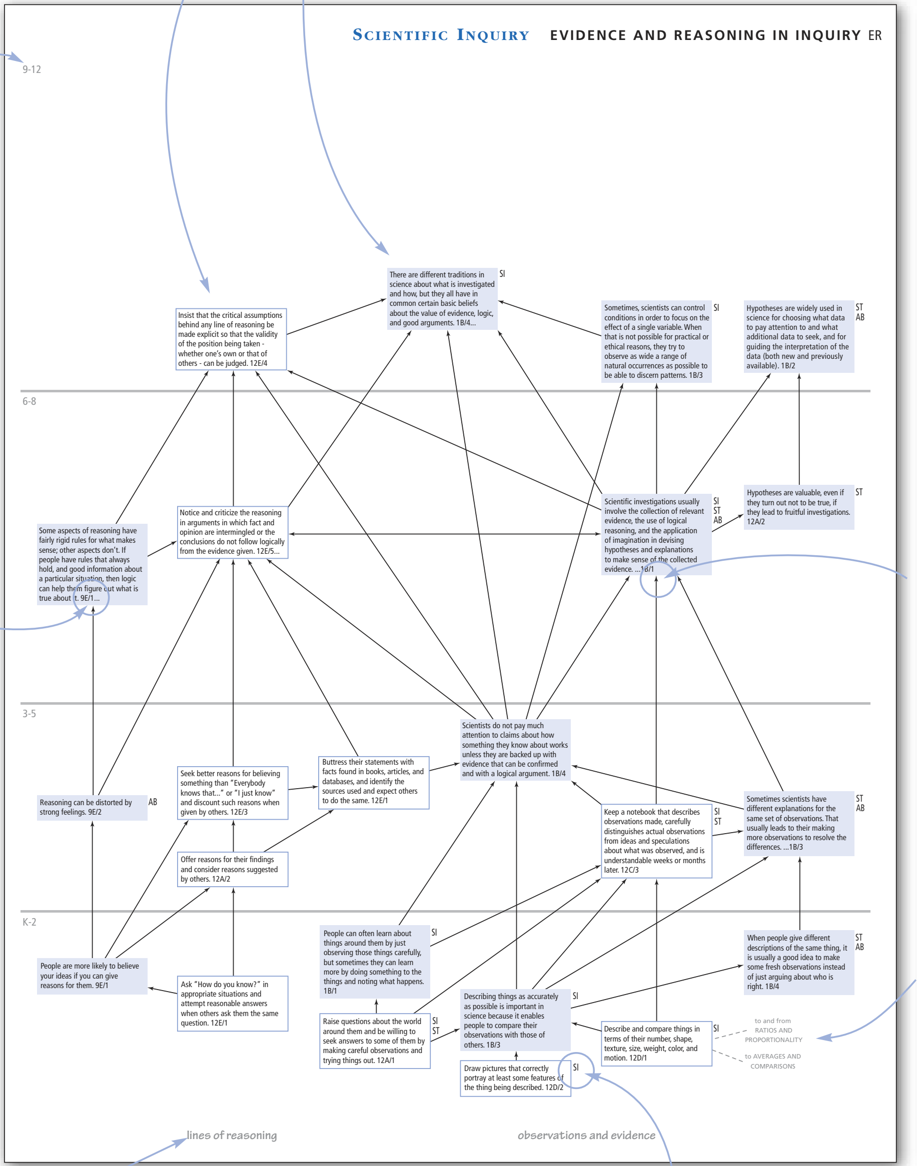
To help the reader keep in mind the notion of a larger fabric from which we have teased out this set of threads, the maps indicate connections both between maps in different clusters and between maps in the same cluster.

Atlas of Science Literacy is available in print from Project 2061 at 1-888-737-2061.

MAP KEY

BENCHMARKS
are specific learning goals derived from *Benchmarks for Science Literacy.* Benchmarks that specify knowledge appear in solid color boxes and those that specify skills appear in bordered boxes. The benchmarks are sometimes condensed or truncated in the maps to clarify their connections to other benchmarks.

GRADE RANGE
suggests when most students could reach these benchmarks. The relative vertical position of two benchmarks within a grade range does not necessarily mean one is more difficult than the other unless there is a connection between them.



BENCHMARK CODES
indicate chapter, section, and number of the corresponding goal statement in *Benchmarks.* Dots before or after the code show if it is the first, last, or middle part of the statement in *Benchmarks.* Ideas from *Science for All Americans* or *Benchmarks* essays reference page numbers. Newly written benchmarks say "new benchmark."

CONNECTING ARROWS
indicate that achieving one benchmark contributes to achieving the other. The exact meaning of a connection is not indicated explicitly, but connections can be based on the logic of the subject matter or on cognitive research about how students learn.

CONNECTIONS TO OTHER MAPS
indicate that the benchmark connects to benchmarks in another map (outside the cluster), where it may also appear.

LABELED STRANDS
help the reader find things in the map and get a sense of the map's content. Strands loosely suggest ideas or skills that develop over time. Strands often interweave and share benchmarks.

CONNECTIONS WITHIN CLUSTERS
can be inferred from shared benchmarks. Benchmarks that are shared with another map in the cluster have the initials for the other map title just to the right of the benchmark.

EVOLUTION OF LIFE:

BIOLOGICAL EVOLUTION

CLUSTER: **EVOLUTION OF LIFE**

MAPS: **BIOLOGICAL EVOLUTION** BE
NATURAL SELECTION NS

One of the most striking things about the living world around us is the great diversity among the different kinds of organisms now on this planet. And yet the deeper scientists have probed, the greater the similarities that have emerged. The scientific concept of evolution draws on observable facts about life on earth to explain similarities within the diversity of life according to descent from common ancestors.

This map shows the evidence for biological evolution from two kinds of observations: patterns of similarity and variety among living organisms and corresponding patterns of similarity and variety in fossils of organisms that lived long ago. In high school, these lines of evidence are brought together with benchmarks about natural selection (which also appear on the **NATURAL SELECTION** map) to provide a summation of modern scientific ideas about biological evolution.

The **EXPLAINING THE DIVERSITY OF LIFE** section of *Science for All Americans* and *Benchmarks* Chapter 10: HISTORICAL PERSPECTIVES is important for understanding biological evolution and illustrates the role of evidence and reasoning—in particular the reliance on the recognition of patterns in historical evidence. Evolutionary change as a more general concept and the notion of scale to convey the immense amount of time involved are covered in *Benchmarks* Chapter 11: COMMON THEMES and could also enhance students' understanding of biological evolution.

NOTES

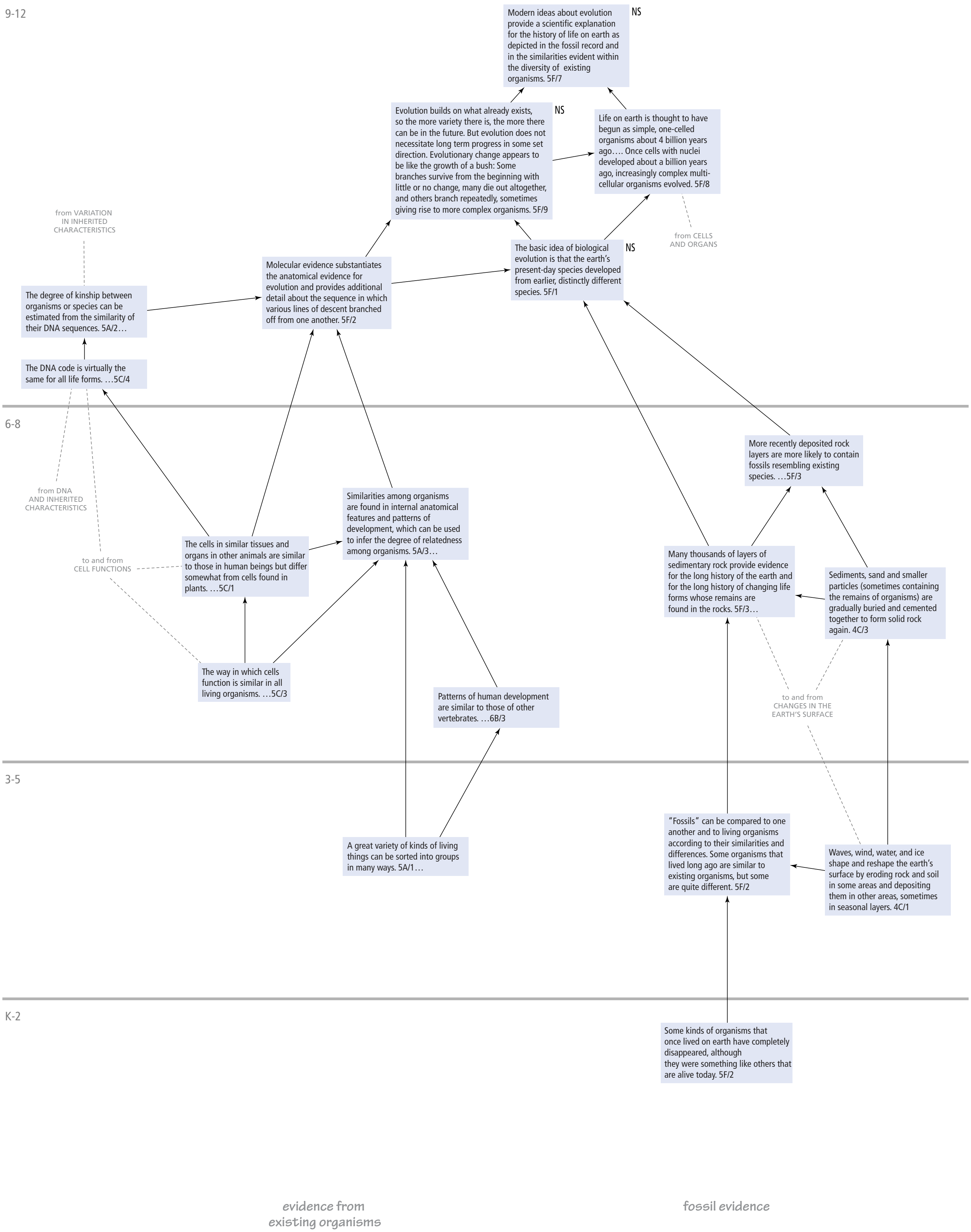
In the *fossil evidence* strand, two benchmarks address erosion and sedimentation of soil. For students to comprehend the implications of fossil evidence, they need to have a sense for how fossils came to be, which requires that they understand the deposition of seasonal layers of what eventually becomes rock. Further support for and development of benchmarks about erosion and sedimentation can be found in the **CHANGES IN THE EARTH'S SURFACE** map (in Chapter 4).

In the *evidence from existing organisms* strand, several benchmarks about similarity at the cellular level contribute to the evidence for evolution. Connections to the **CELL FUNCTIONS** and **CELLS AND ORGANS** maps, which provide more extensive coverage of benchmarks about cells, can enhance students' understanding of the benchmarks presented here.

Through 6-8, the ideas in this map are generally considered to be true and desirable for children to learn. In 9-12, ideas appear that some people interpret to be inconsistent with their own beliefs about the diversity of life on earth. These 9-12 ideas are nonetheless an important part of modern science, and science literacy requires at least knowing what they are (whether students believe them to be true or not).

RESEARCH IN *BENCHMARKS*

Some research suggests that students' understanding of evolution is related to their understanding of the nature of science and their general reasoning abilities (Lawson & Thomson, 1988; Lawson & Worsnop, 1992; Scharmann & Harris, 1992). Findings indicate that poor reasoners tend to retain nonscientific beliefs such as "evolutionary change occurs as a result of need" because they fail to examine alternative hypotheses and their predicted consequences, and they fail to comprehend conflicting evidence. Thus, they are left with no alternative but to believe their initial intuitions or the misstatements they hear.



Modern ideas about evolution provide a scientific explanation for the history of life on earth as depicted in the fossil record and in the similarities evident within the diversity of existing organisms. 5F/7

Evolution builds on what already exists, so the more variety there is, the more there can be in the future. But evolution does not necessitate long term progress in some set direction. Evolutionary change appears to be like the growth of a bush: Some branches survive from the beginning with little or no change, many die out altogether, and others branch repeatedly, sometimes giving rise to more complex organisms. 5F/9

Life on earth is thought to have begun as simple, one-celled organisms about 4 billion years ago…. Once cells with nuclei developed about a billion years ago, increasingly complex multi-cellular organisms evolved. 5F/8

The basic idea of biological evolution is that the earth's present-day species developed from earlier, distinctly different species. 5F/1

Molecular evidence substantiates the anatomical evidence for evolution and provides additional detail about the sequence in which various lines of descent branched off from one another. 5F/2

The degree of kinship between organisms or species can be estimated from the similarity of their DNA sequences. 5A/2…

The DNA code is virtually the same for all life forms. …5C/4

More recently deposited rock layers are more likely to contain fossils resembling existing species. …5F/3

Similarities among organisms are found in internal anatomical features and patterns of development, which can be used to infer the degree of relatedness among organisms. 5A/3…

The cells in similar tissues and organs in other animals are similar to those in human beings but differ somewhat from cells found in plants. …5C/1

Many thousands of layers of sedimentary rock provide evidence for the long history of the earth and for the long history of changing life forms whose remains are found in the rocks. 5F/3…

Sediments, sand and smaller particles (sometimes containing the remains of organisms) are gradually buried and cemented together to form solid rock again. 4C/3

The way in which cells function is similar in all living organisms. …5C/3

Patterns of human development are similar to those of other vertebrates. …6B/3

A great variety of kinds of living things can be sorted into groups in many ways. 5A/1…

"Fossils" can be compared to one another and to living organisms according to their similarities and differences. Some organisms that lived long ago are similar to existing organisms, but some are quite different. 5F/2

Waves, wind, water, and ice shape and reshape the earth's surface by eroding rock and soil in some areas and depositing them in other areas, sometimes in seasonal layers. 4C/1

Some kinds of organisms that once lived on earth have completely disappeared, although they were something like others that are alive today. 5F/2

EVOLUTION OF LIFE:

NATURAL SELECTION

CLUSTER: **EVOLUTION OF LIFE**

MAPS: **BIOLOGICAL EVOLUTION** BE
NATURAL SELECTION NS

Natural selection explains how the diversity of species we see today and in the fossil records could all descend from common ancestors. The idea of natural selection requires a fairly complex sense of both similarities and differences evident in diverse organisms and the advantages or disadvantages of those differences (relative to particular environments).

Students' growth of understanding about the mechanism of natural selection relies on benchmarks about artificial selection (breeding), inherited characteristics, variation and advantage, and changes in the environment. A subtlety in this story is that other organisms, too, are part of the environment. So organisms adapt in part to one another—all of life evolves together. Consequently, the interdependence of life, a topic that will be mapped in the next edition of *Atlas*, relates closely to this map.

Ideas about natural selection are also intimately related to the explanatory and predictive role of scientific theories. Further, the **EXPLAINING THE DIVERSITY OF LIFE** section in *Science for All Americans* and *Benchmarks* Chapter 10: HISTORICAL PERSPECTIVES could be used to elaborate on the benchmarks in this map.

NOTES

Three essential benchmarks in K-2 deal with differences and similarities within families and within kinds of organisms. They are difficult to grasp because they appear paradoxical: siblings are like one another, but they are also different. To pull this apparent paradox together, students have to realize that every organism is different from every other—but they are less different from their close relatives.

The inherited characteristics strand omits several 6-8 benchmarks about heredity that appear in the **DNA AND INHERITED CHARACTERISTICS** and **VARIATION IN INHERITED CHARACTERISTICS** maps because they are not specifically relevant to natural selection.

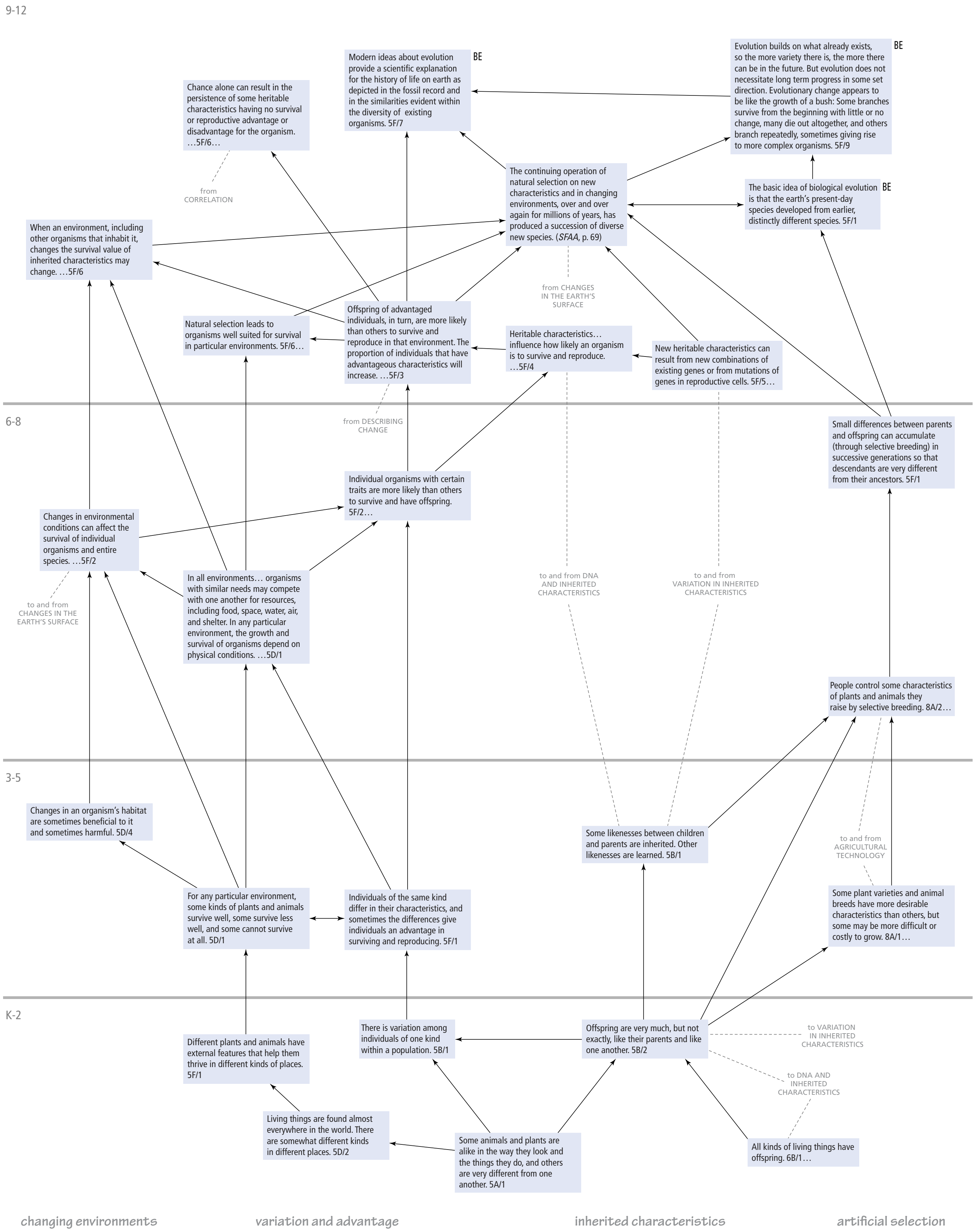
The artificial selection strand makes the point that some characteristics of plants and animals can be changed significantly over a few generations through selective breeding. Nearly all of this strand is repeated in the **AGRICULTURAL TECHNOLOGY** map (in Chapter 8), where it is related to agriculture in general and to 9-12 benchmarks about genetic manipulation.

The 9-12 benchmark "The continuing operation…" shows a connection from the **CHANGES IN THE EARTH'S SURFACE** map (in Chapter 4), providing evidence through the extreme age of the earth for the enormous time available for natural selection to act. The theme of scale from *Benchmarks* Chapter 11: COMMON THEMES is particularly relevant here.

RESEARCH IN *BENCHMARKS*

High-school and college students, even after some years of biology instruction, have difficulties understanding the notion of natural selection (Brumby, 1979; Bishop & Anderson, 1990). A major hindrance to understanding natural selection appears to be students' inability to integrate two distinct processes in evolution, the occurrence of new traits in a population and their effect on long-term survival (Bishop & Anderson, 1990). Many students believe that environmental conditions are responsible for changes in traits, or that organisms develop new traits because they need them to survive, or that they over-use or under-use certain bodily organs or abilities (Bishop & Anderson, 1990). By contrast, students have little understanding that chance alone produces new heritable characteristics by forming new combinations of existing genes or by mutations of genes (Brumby, 1979; Clough & Wood-Robinson, 1985b; Hallden, 1988). Some students believe that a mutation modifies an individual's own form during its life rather than only its germ cells and offspring (see almost any science-fiction movie). Students also have difficulties understanding that changing a population results from the survival of a few individuals that preferentially reproduce, not from the gradual change of all individuals in the population. Explanations about "insects or germs becoming more resistant" rather than "more insects or germs becoming resistant" may reinforce these misunderstandings (Brumby, 1979). Specially designed instruction can improve students' understanding of natural selection (Bishop & Anderson, 1990).

Middle-school and high-school students may have difficulties with the various uses of the word "adaptation" (Clough & Robinson, 1985; Lucas, 1971; Brumby, 1979). In everyday usage, individuals adapt deliberately. But in the theory of natural selection, populations change or "adapt" over generations, inadvertently. Students of all ages often believe that adaptations result from some overall purpose or design, or they describe adaptation as a conscious process to fulfill some need or want. Elementary- and middle-school students also tend to confuse non-inherited adaptations acquired during an individual's lifetime with adaptive features that are inherited in a population (Kargbo et al., 1980).



Chance alone can result in the persistence of some heritable characteristics having no survival or reproductive advantage or disadvantage for the organism. …5F/6…

Modern ideas about evolution provide a scientific explanation for the history of life on earth as depicted in the fossil record and in the similarities evident within the diversity of existing organisms. 5F/7

Evolution builds on what already exists, so the more variety there is, the more there can be in the future. But evolution does not necessitate long term progress in some set direction. Evolutionary change appears to be like the growth of a bush: Some branches survive from the beginning with little or no change, many die out altogether, and others branch repeatedly, sometimes giving rise to more complex organisms. 5F/9

The continuing operation of natural selection on new characteristics and in changing environments, over and over again for millions of years, has produced a succession of diverse new species. (*SFAA*, p. 69)

The basic idea of biological evolution is that the earth's present-day species developed from earlier, distinctly different species. 5F/1

When an environment, including other organisms that inhabit it, changes the survival value of inherited characteristics may change. …5F/6

Natural selection leads to organisms well suited for survival in particular environments. 5F/6…

Offspring of advantaged individuals, in turn, are more likely than others to survive and reproduce in that environment. The proportion of individuals that have advantageous characteristics will increase. …5F/3

Heritable characteristics… influence how likely an organism is to survive and reproduce. …5F/4

New heritable characteristics can result from new combinations of existing genes or from mutations of genes in reproductive cells. 5F/5…

Small differences between parents and offspring can accumulate (through selective breeding) in successive generations so that descendants are very different from their ancestors. 5F/1

Individual organisms with certain traits are more likely than others to survive and have offspring. 5F/2…

Changes in environmental conditions can affect the survival of individual organisms and entire species. …5F/2

In all environments… organisms with similar needs may compete with one another for resources, including food, space, water, air, and shelter. In any particular environment, the growth and survival of organisms depend on physical conditions. …5D/1

People control some characteristics of plants and animals they raise by selective breeding. 8A/2…

Changes in an organism's habitat are sometimes beneficial to it and sometimes harmful. 5D/4

Some likenesses between children and parents are inherited. Other likenesses are learned. 5B/1

For any particular environment, some kinds of plants and animals survive well, some survive less well, and some cannot survive at all. 5D/1

Individuals of the same kind differ in their characteristics, and sometimes the differences give individuals an advantage in surviving and reproducing. 5F/1

Some plant varieties and animal breeds have more desirable characteristics than others, but some may be more difficult or costly to grow. 8A/1…

Different plants and animals have external features that help them thrive in different kinds of places. 5F/1

There is variation among individuals of one kind within a population. 5B/1

Offspring are very much, but not exactly, like their parents and like one another. 5B/2

Living things are found almost everywhere in the world. There are somewhat different kinds in different places. 5D/2

Some animals and plants are alike in the way they look and the things they do, and others are very different from one another. 5A/1

All kinds of living things have offspring. 6B/1…

SCIENTIFIC INQUIRY:

EVIDENCE AND REASONING IN INQUIRY

CLUSTER: **SCIENTIFIC INQUIRY**

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

Scientific inquiry is built on the interaction of evidence and logical reasoning—the importance of careful observation, the role of observations in supporting a line of reasoning, and the value of reasoning in suggesting new observations. For basic literacy, students should be able to observe and describe things accurately and understand why those things are important in scientific inquiry. At the same time, they should understand what constitutes good reasoning, and practice judging reasons in others' arguments and in their own.

Instructionally, it may be helpful to think about the benchmarks in this map in conjunction with the scientific content in the other chapters of *Benchmarks*, particularly when student-inquiry activities involve observation, gathering evidence, and making arguments. Related topics in *Benchmarks* that will be mapped in the next edition of *Atlas* will provide further context for the benchmarks in this map. They include measurement, estimation, and the use of technology to improve observation and measurement.

NOTES

Many early ideas and skills come together in the 3-5 benchmark "Scientists do not pay much attention to claims...," which has a wide fan of connections to later benchmarks. It provides a reasonably good summation of the central ideas, framed in language appropriate to the 3-5 level.

The lines of reasoning strand progresses from giving and looking for reasons in K-2, to evaluating reasons in 3-5, to evaluating lines of reasoning in 6-8 and 9-12 (when students have some understanding of logic and inference). This strand also includes a benchmark about how reasoning can be distorted, which is also in the **AVOIDING BIAS IN SCIENCE** map. Further benchmarks on detailed principles of reasoning can be found in *Benchmarks* Chapter 9: THE MATHEMATICAL WORLD and will appear in the next edition of *Atlas*.

In the observations and evidence strand, the relationship between evidence and theory is hinted at in four early-grades benchmarks, that also appear in the **SCIENTIFIC THEORIES** map. In addition, the 9-12 benchmark in that strand, "Sometimes, scientists can control conditions . . . ," appears in and is supported by benchmarks in the **SCIENTIFIC INVESTIGATIONS** map.

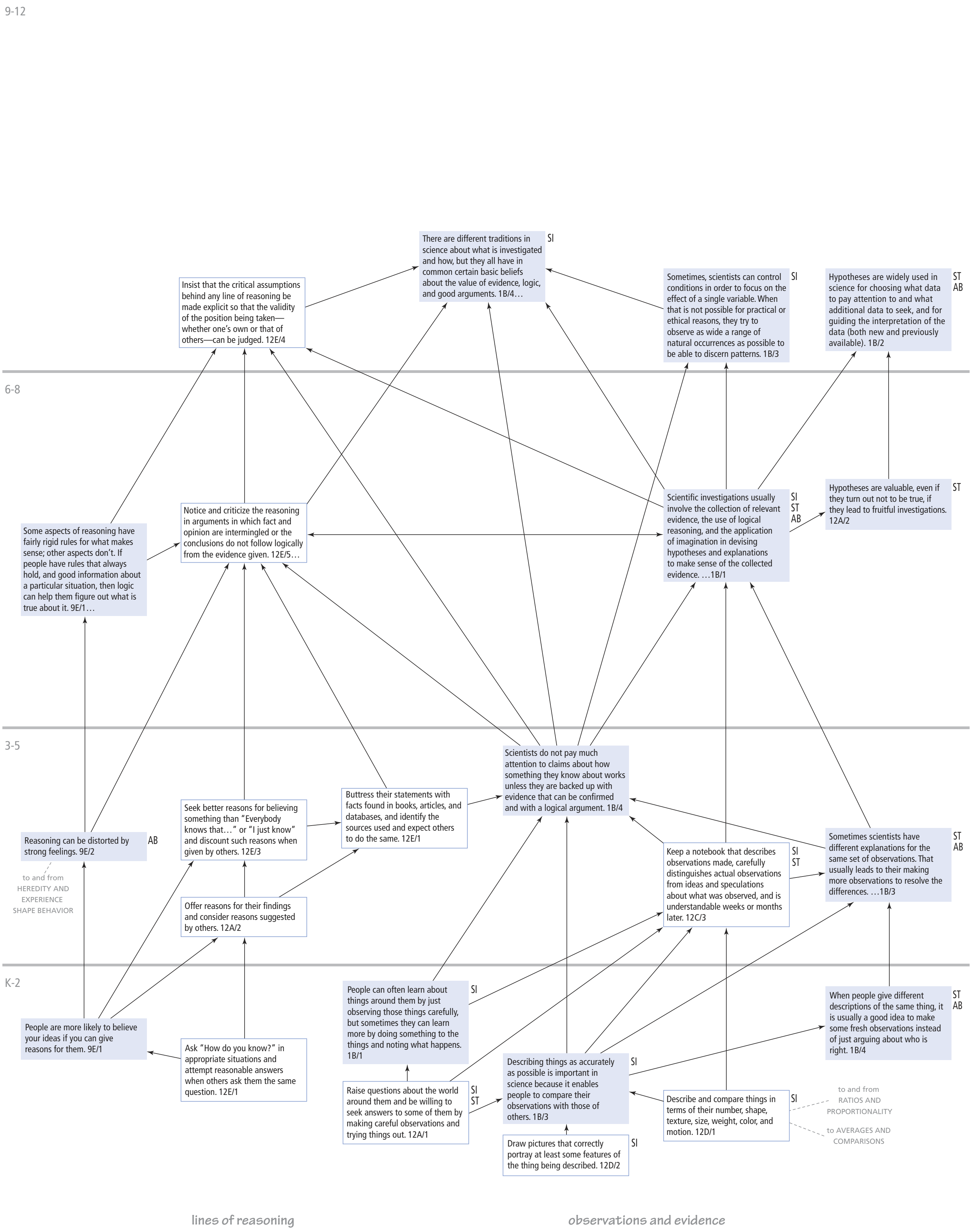
RESEARCH IN *BENCHMARKS*

Middle-school students tend to invoke personal experiences as evidence to justify a particular hypothesis. They seem to think of evidence as selected from what is already known or from personal experience or second-hand sources, not as information produced by experiment (Roseberry et al., 1992). Most 6th-graders can judge whether evidence is related to a theory, although they do not always evaluate this evidence correctly (Kuhn et al., 1988). When asked to use evidence to judge a theory, students of all ages may make only theory-based responses with no reference made to the presented evidence. Sometimes this appears to be because the available evidence conflicts with the students' beliefs (Kuhn et al., 1988).

Most high-school students will accept arguments based on inadequate sample size, accept causality from contiguous events, and accept conclusions based on statistically insignificant differences (Jungwirth & Dreyfus, 1990, 1992; Jungwirth, 1987). More students can recognize these inadequacies in arguments after prompting (for example, after being told that the conclusions drawn from the data were invalid and asked to state why) (Jungwirth & Dreyfus, 1992; Jungwirth, 1987).

See the **AVOIDING BIAS IN SCIENCE** map

SCIENTIFIC INQUIRY: EVIDENCE AND REASONING IN INQUIRY 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…

Insist that the critical assumptions behind any line of reasoning be made explicit so that the validity of the position being taken—whether one's own or that of others—can be judged. 12E/4

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

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 the data (both new and previously available). 1B/2

Some aspects of reasoning have fairly rigid rules for what makes sense; other aspects don't. If people have rules that always hold, and good information about a particular situation, then logic can help them figure out what is true about it. 9E/1…

Notice and criticize the reasoning in arguments in which fact and opinion are intermingled or the conclusions do not follow logically from the evidence given. 12E/5…

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

Hypotheses are valuable, even if they turn out not to be true, if they lead to fruitful investigations. 12A/2

Scientists do not pay much attention to claims about how something they know about works unless they are backed up with evidence that can be confirmed and with a logical argument. 1B/4

Buttress their statements with facts found in books, articles, and databases, and identify the sources used and expect others to do the same. 12E/1

Seek better reasons for believing something than "Everybody knows that…" or "I just know" and discount such reasons when given by others. 12E/3

Reasoning can be distorted by strong feelings. 9E/2

Offer reasons for their findings and consider reasons suggested by others. 12A/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

Sometimes scientists have different explanations for the same set of observations. That usually leads to their making more observations to resolve the differences. …1B/3

People are more likely to believe your ideas if you can give reasons for them. 9E/1

Ask "How do you know?" in appropriate situations and attempt reasonable answers when others ask them the same question. 12E/1

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

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

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

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

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

When people give different descriptions of the same thing, it is usually a good idea to make some fresh observations instead of just arguing about who is right. 1B/4

Questions and Answers on Evolution

From the American Association for the Advancement of Science (AAAS)

Q: What is evolution?

A: Evolution is a broad, well-tested description of how Earth's present-day life forms arose from common ancestors reaching back to the simplest one-celled organisms almost 4 billion years ago. It helps explain both the similarities and the differences in the enormous number of living organisms we see around us.

Evolution occurs in populations when heritable changes are passed from one generation to the next. Genetic variation, whether through random mutations or the gene shuffling that occurs during sexual reproduction, sets the stage for evolutionary change. That change is driven by forces such as natural selection, in which organisms with advantageous traits, such as color variations in insects that cloak some of them from predators, are better enabled to survive and pass their genes on to future generations.

Ultimately, evolution explains both small-scale changes within populations and large-scale changes in which new species diverge from a common ancestor over many generations.

Q: What is intelligent design (ID)?

A: Intelligent design consists of two hypothetical claims about the history of the universe and of life: first, that some structures or processes in nature are "irreducibly complex" and could not have originated through small changes over long periods of time; and second, that some structures or processes in nature are expressions of "complex specified information" that can only be the product of an intelligent agent.

Q: Does intelligent design have a scientific basis?

A: No. In December 2005, Judge John E. Jones III ruled, in Kitzmiller versus the Dover School District, that intelligent design (ID) is based on religion and not science. "The evidence at trial demonstrates that ID is nothing less than the progeny of creationism," he concluded. Moreover, many scientists have noted that the concept necessarily presupposes that there is an "intelligent designer" outside of nature who, from the beginning or from time to time, inserts design into the world around us. But whether there is an intelligent designer is a matter of religious faith. It is not a scientifically testable question.

Q: Why not "teach both sides" in science class?

A: First, presenting non-scientific views in the science classroom is bound to confuse students about what is and isn't science. At a time when U.S. students are expressing reduced enthusiasm for science; Baby Boomer scientists are retiring in growing numbers; and international students are returning home to work, America can ill afford to risk compromising the integrity of its science education. Second, it would be unfair to present students with only one religious viewpoint and not all others. And, it would be unreasonable to ask teachers of science to try to teach religion in science classes.

Q: Are science and religion in opposition?

A: No. Science does not take a position on an intelligent designer, which is a matter of religious faith and is not testable from the scientific standpoint. Science and religion ask different questions about the world. Many individual scientists — from Rev. George Coyne, Director of The Vatican Observatory, to Dr. Francis Collins, director of the National Human Genome Research Institute of the U.S. National Institutes of Health — are deeply religious and see no conflict between believing in God and accepting the contemporary theory of evolution. In fact, many religious leaders and scientists alike view scientific investigation and religious faith as complementary components of a well-rounded life.

Q: Are there "gaps" in our understanding of evolution?

A: No, not in the sense that ID advocates have suggested. Certainly, there are still many puzzles in biology about the particular pathways of the evolutionary process and how various species are related to one another. But, these puzzles neither invalidate nor challenge Charles Darwin's basic theory of "descent with modification," nor the theory's present form that incorporates and is supported by the genetic sciences. Contemporary evolutionary theory provides the conceptual framework in which these puzzles can be addressed and points toward ways to solve them. As scientists are constantly solving nature's mysteries, today's "irreducible complexity" can quickly becomes tomorrow's clear scientific explanation.

Q: Don't students have a right to learn about intelligent design?

A: Absolutely. AAAS and others have proposed that discussions of such concepts as intelligent design might be perfectly appropriate in courses examining world views, philosophy, religion, or current affairs — but not in science classrooms. Presenting non-scientific views together with science could confuse students about the nature of science.

The following material is from *High School Biology Textbooks: A Benchmarks-Based Evaluation*

Analyzes the science content and quality of instructional support in a wide range of biology textbooks.

Project 2061's textbook evaluation study examined whether or not textbooks presented a coherent set of ideas about evolution—ideas about natural selection and common descent, the supporting evidence from the fossil record, and the similarity observed within the diversity of existing organisms. The study also examined whether textbooks both presented important ideas about the nature of science and related them to ideas about evolution. It is important for students to appreciate that, like all scientific ideas, modern ideas about evolution and natural selection result from evidence, logic, and sound arguments. Hence, textbook reviewers looked to see if textbooks presented these ideas as well. In the following map labeled "Ideas the textbook reviewers looked for," ideas about the nature of science are shown in the upper left. The second map, "What the textbooks typically do," displays a composite of how the topic of natural selection was actually treated across the nine textbooks evaluated.

A Guide to Reading the Maps

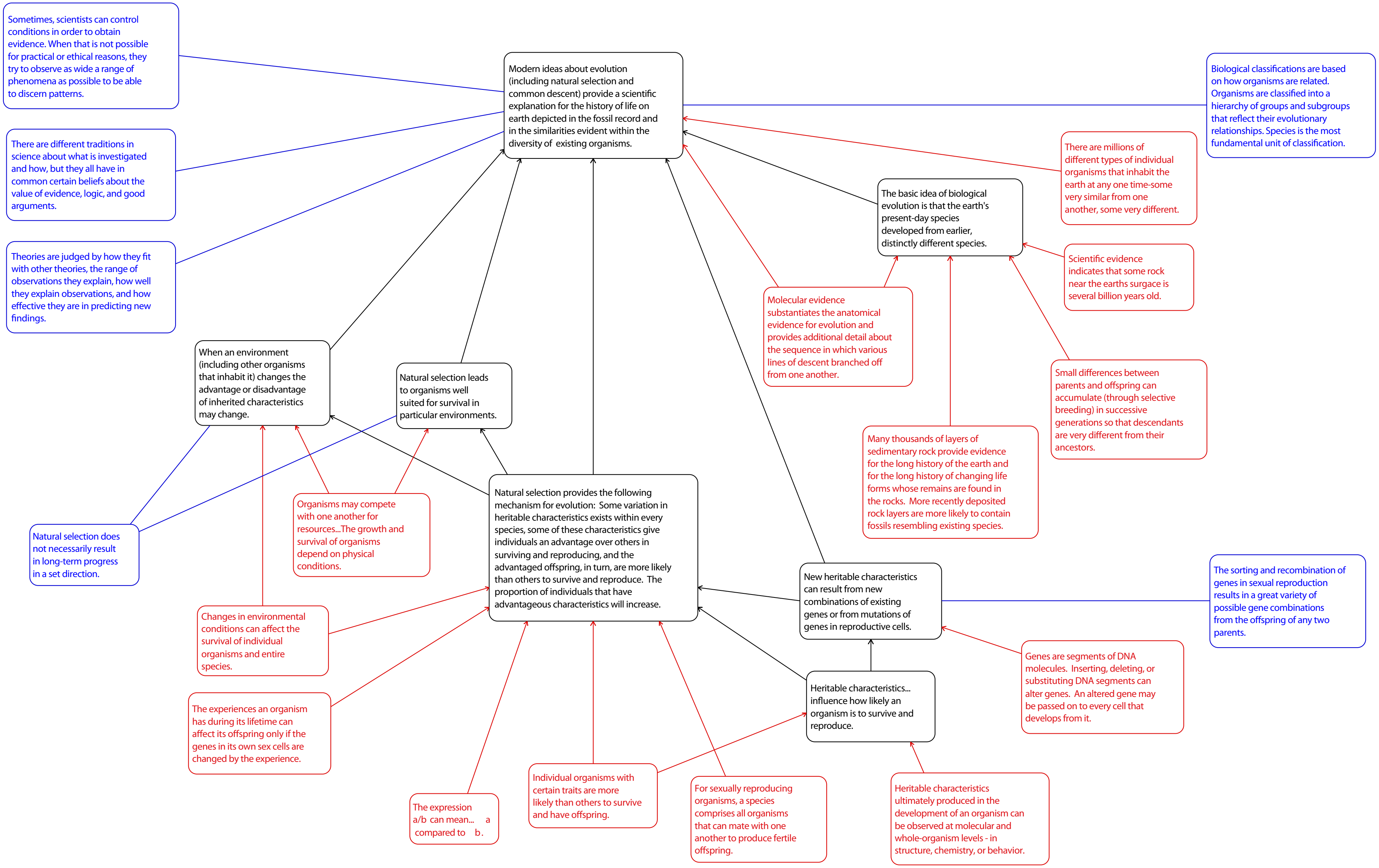
- **Black boxes** contain the target key ideas that served directly as the basis for the analysis.
- **Red boxes** contain prerequisites needed for the key ideas (from the same or even an earlier grade range).
- **Blue boxes** contain ideas that are closely related to the key ideas and that could strengthen students' understanding of them.
- **Lines with arrowheads:** an arrow between two ideas implies that understanding one contributes in some way to understanding the other.
- **Lines without arrowheads:** a line between two ideas implies that they are related, though no conceptual sequence seems necessary.

What to do if your students' textbook does not treat evolution well

- Use some of the excellent trade books that have been published on science topics to enhance your own understanding and help to compensate for the textbooks' lack of content coherence.
- Study the research on student learning cited in the evaluation reports to revise classroom activities and develop new ones.
- Take advantage of professional development experiences that focus not only on increasing your knowledge of key biology ideas, but also on strategies for teaching those ideas more effectively.
- Encourage funders, policy makers, and the scientific and education communities to support a new round of curriculum development focused on creating a coherent picture of key ideas for specific biology topics, using a research-based development and testing process to ensure that the instructional strategies promote learning the key ideas.

High School Biology Textbooks: A Benchmarks-Based Evaluation is available online at **http://www.project2061.org/publications/textbook/default.htm?nav**

Natural Selection and Evolution—
Ideas the textbook reviewers looked for:



Sometimes, scientists can control conditions in order to obtain evidence. When that is not possible for practical or ethical reasons, they try to observe as wide a range of phenomena as possible to be able to discern patterns.

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

Theories are judged by how they fit with other theories, the range of observations they explain, how well they explain observations, and how effective they are in predicting new findings.

Modern ideas about evolution (including natural selection and common descent) provide a scientific explanation for the history of life on earth depicted in the fossil record and in the similarities evident within the diversity of existing organisms.

Biological classifications are based on how organisms are related. Organisms are classified into a hierarchy of groups and subgroups that reflect their evolutionary relationships. Species is the most fundamental unit of classification.

There are millions of different types of individual organisms that inhabit the earth at any one time-some very similar from one another, some very different.

The basic idea of biological evolution is that the earth's present-day species developed from earlier, distinctly different species.

Scientific evidence indicates that some rock near the earths surgace is several billion years old.

Molecular evidence substantiates the anatomical evidence for evolution and provides additional detail about the sequence in which various lines of descent branched off from one another.

Small differences between parents and offspring can accumulate (through selective breeding) in successive generations so that descendants are very different from their ancestors.

Many thousands of layers of sedimentary rock provide evidence for the long history of the earth and for the long history of changing life forms whose remains are found in the rocks. More recently deposited rock layers are more likely to contain fossils resembling existing species.

When an environment (including other organisms that inhabit it) changes the advantage or disadvantage of inherited characteristics may change.

Natural selection leads to organisms well suited for survival in particular environments.

Natural selection does not necessarily result in long-term progress in a set direction.

Organisms may compete with one another for resources...The growth and survival of organisms depend on physical conditions.

Natural selection provides the following mechanism for evolution: Some variation in heritable characteristics exists within every species, some of these characteristics give individuals an advantage over others in surviving and reproducing, and the advantaged offspring, in turn, are more likely than others to survive and reproduce. The proportion of individuals that have advantageous characteristics will increase.

New heritable characteristics can result from new combinations of existing genes or from mutations of genes in reproductive cells.

The sorting and recombination of genes in sexual reproduction results in a great variety of possible gene combinations from the offspring of any two parents.

Changes in environmental conditions can affect the survival of individual organisms and entire species.

Genes are segments of DNA molecules. Inserting, deleting, or substituting DNA segments can alter genes. An altered gene may be passed on to every cell that develops from it.

Heritable characteristics... influence how likely an organism is to survive and reproduce.

The experiences an organism has during its lifetime can affect its offspring only if the genes in its own sex cells are changed by the experience.

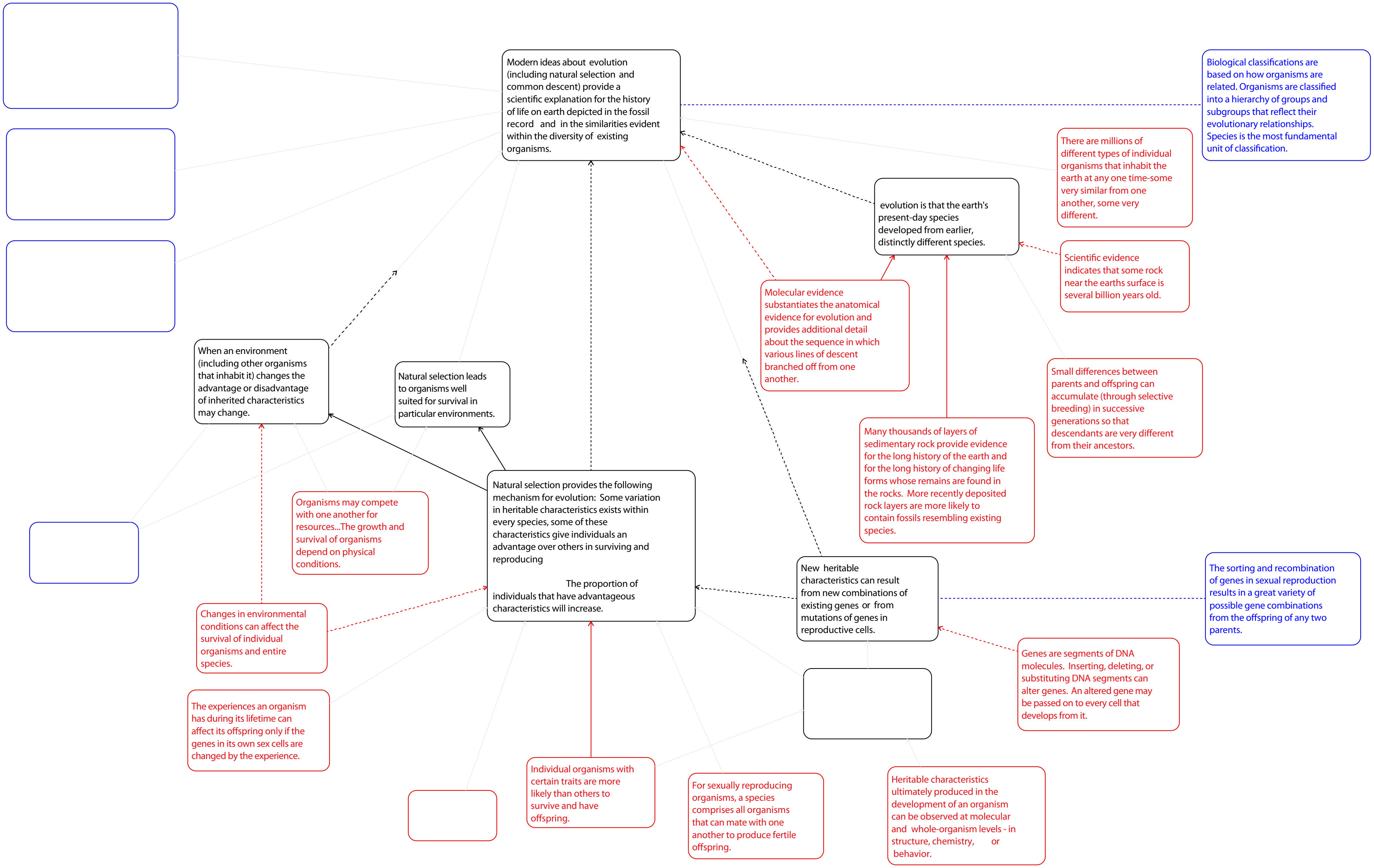
The expression a/b can mean... a compared to b.

Individual organisms with certain traits are more likely than others to survive and have offspring.

For sexually reproducing organisms, a species comprises all organisms that can mate with one another to produce fertile offspring.

Heritable characteristics ultimately produced in the development of an organism can be observed at molecular and whole-organism levels - in structure, chemistry, or behavior.

Natural Selection and Evolution—
What the textbooks typically do:



Modern ideas about evolution (including natural selection and common descent) provide a scientific explanation for the history of life on earth depicted in the fossil record and in the similarities evident within the diversity of existing organisms.

Biological classifications are based on how organisms are related. Organisms are classified into a hierarchy of groups and subgroups that reflect their evolutionary relationships. Species is the most fundamental unit of classification.

There are millions of different types of individual organisms that inhabit the earth at any one time-some very similar from one another, some very different.

evolution is that the earth's present-day species developed from earlier, distinctly different species.

Scientific evidence indicates that some rock near the earths surface is several billion years old.

Molecular evidence substantiates the anatomical evidence for evolution and provides additional detail about the sequence in which various lines of descent branched off from one another.

When an environment (including other organisms that inhabit it) changes the advantage or disadvantage of inherited characteristics may change.

Natural selection leads to organisms well suited for survival in particular environments.

Small differences between parents and offspring can accumulate (through selective breeding) in successive generations so that descendants are very different from their ancestors.

Many thousands of layers of sedimentary rock provide evidence for the long history of the earth and for the long history of changing life forms whose remains are found in the rocks. More recently deposited rock layers are more likely to contain fossils resembling existing species.

Organisms may compete with one another for resources...The growth and survival of organisms depend on physical conditions.

Natural selection provides the following mechanism for evolution: Some variation in heritable characteristics exists within every species, some of these characteristics give individuals an advantage over others in surviving and reproducing

The proportion of individuals that have advantageous characteristics will increase.

New heritable characteristics can result from new combinations of existing genes or from mutations of genes in reproductive cells.

The sorting and recombination of genes in sexual reproduction results in a great variety of possible gene combinations from the offspring of any two parents.

Changes in environmental conditions can affect the survival of individual organisms and entire species.

Genes are segments of DNA molecules. Inserting, deleting, or substituting DNA segments can alter genes. An altered gene may be passed on to every cell that develops from it.

The experiences an organism has during its lifetime can affect its offspring only if the genes in its own sex cells are changed by the experience.

Individual organisms with certain traits are more likely than others to survive and have offspring.

For sexually reproducing organisms, a species comprises all organisms that can mate with one another to produce fertile offspring.

Heritable characteristics ultimately produced in the development of an organism can be observed at molecular and whole-organism levels - in structure, chemistry, or behavior.

More AAAS Evolution Resources Online

AAAS has played a prominent role in responding to efforts to weaken or compromise the teaching of evolution in public school science classrooms. The AAAS Web site provides a wealth of helpful background materials on the controversy and links to AAAS resources on evolution at:

http://www.aaas.org/news/press_room/evolution/

The 2006 AAAS Annual Meeting in St. Louis brought together several hundred teachers, scientists, students and others for a special "Evolution on the Front Line" event. They discussed the challenges confronting science teachers and resources that teachers can tap as they seek to preserve scientific integrity in the classroom. To see more on the event, including videos and speaker presentations, visit:

http://www.aaas.org/programs/centers/pe/evoline/index.shtml.

AAAS Project 2061
1200 New York Avenue, NW
Washington, DC 20005

Phone: 202 326 6666
Toll-free: 888 737 2061
Fax: 202 842 5196
E-mail: project2061@aaas.org
Web: www.Project2061.org

Project 2061
AAAS