

Benchmarks Excerpts: related to Earth and Space Science

For May PSEWG Advance— not from the point of view of how we conduct activities or give workshops, but what should classroom teachers need to know before they go into the classroom.

Complete chapter on the *The Physical Setting* is at <http://www.project2061.org/publications/bsl/online/ch4/ch4.htm>

4. THE PHYSICAL SETTING

Any one arrangement of topics inevitably neglects many cross-connections among topics. Benchmarks for any section are connected to others and should be read in the context of the others. The curriculum can focus on experiences and ideas that are accessible to children—for example, how different other planets are from the earth, or the different kinds of materials found in nature. And it can build in precursors to eventual understanding, such as observable motions in the sky and observable changes in materials.

A. The Universe

In thinking about what students should learn about the heavens, at least three aspects of the current scientific view ought to be taken into account: (1) the composition of the cosmos and its scale of space and time; (2) the principles on which the universe seems to operate; and (3) how the modern view of the universe emerged. The benchmarks in this section deal primarily with composition and scale; principles are dealt with in subsequent sections of the chapter, and some rudiments of the history of the scientific picture appear in Chapter 10: Historical Perspectives.

Kindergarten through Grade 2

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

- There are more stars in the sky than anyone can easily count, but they are not scattered evenly, and they are not all the same in brightness or color.
- The sun can be seen only in the daytime, but the moon can be seen sometimes at night and sometimes during the day. The sun, moon, and stars all appear to move slowly across the sky.
- The moon looks a little different every day, but looks the same again about every four weeks.

Grades 3 through 5

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

- The patterns of stars in the sky stay the same, although they appear to move across the sky nightly, and different stars can be seen in different seasons.
- Telescopes magnify the appearance of some distant objects in the sky, including the moon and the planets. The number of stars that can be seen through telescopes is dramatically greater than can be seen by the unaided eye.
- Planets change their positions against the background of stars.
- The earth is one of several planets that orbit the sun, and the moon orbits around the earth.
- Stars are like the sun, some being smaller and some larger, but so far away that they look like points of light.

Grades 6 through 8

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

- The sun is a medium-sized star located near the edge of a disk-shaped galaxy of stars, part of which can be seen as a glowing band of light that spans the sky on a very clear night. The universe contains many billions of galaxies, and each galaxy contains many billions of stars. To the naked eye, even the closest of these galaxies is no more than a dim, fuzzy spot.
- The sun is many thousands of times closer to the earth than any other star. Light from the sun takes a few minutes to reach the earth, but light from the next nearest star takes a few years to arrive. The trip to that star would take the fastest rocket thousands of years. Some distant galaxies are so far away that their light takes several billion years to reach the earth. People on earth, therefore, see them as they were that long ago in the past.
- Nine planets of very different size, composition, and surface features move around the sun in nearly circular orbits. Some planets have a great variety of moons and even flat rings of rock and ice particles orbiting around them. Some of these planets and moons show evidence of geologic activity. The earth is orbited by one moon, many artificial satellites, and debris.
- Large numbers of chunks of rock orbit the sun. Some of those that the earth meets in its yearly orbit around the sun glow and disintegrate from friction as they plunge through the atmosphere-and sometimes impact the ground. Other chunks of rocks mixed with ice have long, off-center orbits that carry them close to the sun, where the sun's radiation (of light and particles) boils off frozen material from their surfaces and pushes it into a long, illuminated tail.

Grades 9 through 12

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

- The stars differ from each other in size, temperature, and age, but they appear to be made up of the same elements that are found on the earth and to behave according to the same physical principles. Unlike the sun, most stars are in systems of two or more stars orbiting around one another.
- On the basis of scientific evidence, the universe is estimated to be over ten billion years old. The current theory is that its entire contents expanded explosively from a hot, dense, chaotic mass. Stars condensed by gravity out of clouds of molecules of the lightest elements until nuclear fusion of the light elements into heavier ones began to occur. Fusion released great amounts of energy over millions of years. Eventually, some stars exploded, producing clouds of heavy elements from which other stars and planets could later condense. The process of star formation and destruction continues.
- Increasingly sophisticated technology is used to learn about the universe. Visual, radio, and x-ray telescopes collect information from across the entire spectrum of electromagnetic waves; computers handle an avalanche of data and increasingly complicated computations to interpret them; space probes send back data and materials from the remote parts of the solar system; and accelerators give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed.
- Mathematical models and computer simulations are used in studying evidence from many sources in order to form a scientific account of the universe.

B. The Earth

Perhaps the most important reason for students to study the earth repeatedly is that they take years to acquire the knowledge that they need to complete the picture. The full picture requires the introduction of such concepts as temperature, the water cycle, gravitation, states of matter, chemical concentration, and energy transfer. Understanding of these concepts grows slowly as children mature and encounter them in different contexts.

The benchmarks here call for students to be able to explain two phenomena-the seasons and the phases of the moon-that are usually not learned well.

Kindergarten through Grade 2

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

- Some events in nature have a repeating pattern. The weather changes some from day to day, but things such as temperature and rain (or snow) tend to be high, low, or medium in the same months every year.

- Water can be a liquid or a solid and can go back and forth from one form to the other. If water is turned into ice and then the ice is allowed to melt, the amount of water is the same as it was before freezing.
- Water left in an open container disappears, but water in a closed container does not disappear.

Grades 3 through 5

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

- Things on or near the earth are pulled toward it by the earth's gravity.
- Like all planets and stars, the earth is approximately spherical in shape. The rotation of the earth on its axis every 24 hours produces the night-and-day cycle. To people on earth, this turning of the planet makes it seem as though the sun, moon, planets, and stars are orbiting the earth once a day.
- When liquid water disappears, it turns into a gas (vapor) in the air and can reappear as a liquid when cooled, or as a solid if cooled below the freezing point of water. Clouds and fog are made of tiny droplets of water.
- Air is a substance that surrounds us, takes up space, and whose movement we feel as wind.

Grades 6 through 8

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

- We live on a relatively small planet, the third from the sun in the only system of planets definitely known to exist (although other, similar systems may be discovered in the universe).
- The earth is mostly rock. Three-fourths of its surface is covered by a relatively thin layer of water (some of it frozen), and the entire planet is surrounded by a relatively thin blanket of air. It is the only body in the solar system that appears able to support life. The other planets have compositions and conditions very different from the earth's.
- Everything on or anywhere near the earth is pulled toward the earth's center by gravitational force.
- Because the earth turns daily on an axis that is tilted relative to the plane of the earth's yearly orbit around the sun, sunlight falls more intensely on different parts of the earth during the year. The difference in heating of the earth's surface produces the planet's seasons and weather patterns.
- The moon's orbit around the earth once in about 28 days changes what part of the moon is lighted by the sun and how much of that part can be seen from the earth-the phases of the moon.
- Climates have sometimes changed abruptly in the past as a result of changes in the earth's crust, such as volcanic eruptions or impacts of huge rocks from space. Even relatively small changes in atmospheric or ocean content can have widespread effects on climate if the change lasts long enough.
- The cycling of water in and out of the atmosphere plays an important role in determining climatic patterns. Water evaporates from the surface of the earth, rises and cools, condenses into rain or snow, and falls again to the surface. The water falling on land collects in rivers and lakes, soil, and porous layers of rock, and much of it flows back into the ocean.
- Fresh water, limited in supply, is essential for life and also for most industrial processes. Rivers, lakes, and groundwater can be depleted or polluted, becoming unavailable or unsuitable for life.
- Heat energy carried by ocean currents has a strong influence on climate around the world.
- Some minerals are very rare and some exist in great quantities, but-for practical purposes-the ability to recover them is just as important as their abundance. As minerals are depleted, obtaining them becomes more difficult. Recycling and the development of substitutes can reduce the rate of depletion but may also be costly.
- The benefits of the earth's resources-such as fresh water, air, soil, and trees-can be reduced by using them wastefully or by deliberately or inadvertently destroying them. The atmosphere and the oceans have a limited capacity to absorb wastes and recycle materials naturally. Cleaning up polluted air, water, or soil or restoring depleted soil, forests, or fishing grounds can be very difficult and costly.

Grades 9 through 12

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

- Life is adapted to conditions on the earth, including the force of gravity that enables the planet to retain an adequate atmosphere, and an intensity of radiation from the sun that allows water to cycle between liquid and vapor.

- Weather (in the short run) and climate (in the long run) involve the transfer of energy in and out of the atmosphere. Solar radiation heats the land masses, oceans, and air. Transfer of heat energy at the boundaries between the atmosphere, the land masses, and the oceans results in layers of different temperatures and densities in both the ocean and atmosphere. The action of gravitational force on regions of different densities causes them to rise or fall-and such circulation, influenced by the rotation of the earth, produces winds and ocean currents.
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C. Processes that Shape the Earth

Students should learn what causes earthquakes, volcanos, and floods and how those events shape the surface of the earth. Students, however, may show more interest in the phenomena than in the role the phenomena play in sculpting the earth. So teachers should start with students' immediate interests and work toward the science.

Kindergarten through Grade 2

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

- Chunks of rocks come in many sizes and shapes, from boulders to grains of sand and even smaller.
- Change is something that happens to many things.
- Animals and plants sometimes cause changes in their surroundings.

Grades 3 through 5

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

- Waves, wind, water, and ice shape and reshape the earth's land surface by eroding rock and soil in some areas and depositing them in other areas, sometimes in seasonal layers.
- Rock is composed of different combinations of minerals. Smaller rocks come from the breakage and weathering of bedrock and larger rocks. Soil is made partly from weathered rock, partly from plant remains- and also contains many living organisms.

Grades 6 through 8

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

- The interior of the earth is hot. Heat flow and movement of material within the earth cause earthquakes and volcanic eruptions and create mountains and ocean basins. Gas and dust from large volcanoes can change the atmosphere.
- Some changes in the earth's surface are abrupt (such as earthquakes and volcanic eruptions) while other changes happen very slowly (such as uplift and wearing down of mountains). The earth's surface is shaped in part by the motion of water and wind over very long times, which act to level mountain ranges.
- Sediments of sand and smaller particles (sometimes containing the remains of organisms) are gradually buried and are cemented together by dissolved minerals to form solid rock again.
- Sedimentary rock buried deep enough may be reformed by pressure and heat, perhaps melting and recrystallizing into different kinds of rock. These re-formed rock layers may be forced up again to become land surface and even mountains. Subsequently, this new rock too will erode. Rock bears evidence of the minerals, temperatures, and forces that created it.
- Thousands of layers of sedimentary rock confirm the long history of the changing surface of the earth and the changing life forms whose remains are found in successive layers. The youngest layers are not always found on top, because of folding, breaking, and uplift of layers.
- Although weathered rock is the basic component of soil, the composition and texture of soil and its fertility and resistance to erosion are greatly influenced by plant roots and debris, bacteria, fungi, worms, insects, rodents, and other organisms.
- Human activities, such as reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming, have changed the earth's land, oceans, and atmosphere. Some of these changes have decreased the capacity of the environment to support some life forms.

Grades 9 through 12

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

- Plants alter the earth's atmosphere by removing carbon dioxide from it, using the carbon to make sugars and releasing oxygen. This process is responsible for the oxygen content of the air.
- The formation, weathering, sedimentation, and reformation of rock constitute a continuing "rock cycle" in which the total amount of material stays the same as its forms change.
- The slow movement of material within the earth results from heat flowing out from the deep interior and the action of gravitational forces on regions of different density.
- The solid crust of the earth-including both the continents and the ocean basins-consists of separate plates that ride on a denser, hot, gradually deformable layer of the earth. The crust sections move very slowly, pressing against one another in some places, pulling apart in other places. Ocean-floor plates may slide under continental plates, sinking deep into the earth. The surface layers of these plates may fold, forming mountain ranges.
- Earthquakes often occur along the boundaries between colliding plates, and molten rock from below creates pressure that is released by volcanic eruptions, helping to build up mountains. Under the ocean basins, molten rock may well up between separating plates to create new ocean floor. Volcanic activity along the ocean floor may form undersea mountains, which can thrust above the ocean's surface to become islands.

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Complete chapter on the Nature of Science is at
<http://www.project2061.org/publications/bsl/online/ch1/ch1.htm>

1. THE NATURE OF SCIENCE

Acquiring scientific knowledge about how the world works does not necessarily lead to an understanding of how science itself works, and neither does knowledge of the philosophy and sociology of science alone lead to a scientific understanding of the world. The challenge for educators is to weave these different aspects of science together so that they reinforce one another.

For students in the early grades, the emphasis should overwhelmingly be on gaining experience with natural and social phenomena and on enjoying science. Abstractions of all kinds can gradually make their appearance as students mature and develop an ability to handle explanations that are complex and abstract. This phasing-in certainly applies to generalizations about the scientific world view, scientific inquiry, and the scientific enterprise.

That does not mean, however, that abstraction should be ignored altogether in the early grades. By gaining lots of experience doing science, becoming more sophisticated in conducting investigations, and explaining their findings, students will accumulate a set of concrete experiences on which they can draw to reflect on the process. At the same time, conclusions presented to students (in books and in class) about how scientists explain phenomena should gradually be augmented by information on how the science community arrived at those conclusions. Indeed, as students move through school, they should be encouraged to ask over and over, "How do we know that's true?"

A. The Scientific World View

Kindergarten through Grade 2

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

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

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

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.

B. Scientific Inquiry

Kindergarten through Grade 2

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

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

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

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.

C. The Scientific Enterprise

Scientific activity is one of the main features of the contemporary world and distinguishes present times from earlier periods. Students also need to be exposed to four other aspects of the scientific enterprise: its social structure, its discipline and institutional identification, its ethics, and the role of scientists in public affairs.

Kindergarten through Grade 2

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

- Everybody can do science and invent things and ideas.
- In doing science, it is often helpful to work with a team and to share findings with others. All team members should reach their own individual conclusions, however, about what the findings mean.
- A lot can be learned about plants and animals by observing them closely, but care must be taken to know the needs of living things and how to provide for them in the classroom.

Grades 3 through 5

As student research teams become more adept at doing science, more emphasis should be placed on how to communicate findings. As students learn to describe their procedures with enough detail to enable others to replicate them, make greater use of tables and graphs to summarize and interpret data, and submit their work to the criticism of others, they should understand that they are engaged in the scientific way of doing research.

Career information can be introduced to acquaint students with science as an occupation in which there is a wide variety of different kinds and levels of work. Films, books (science adventure, biographies), visits by scientists, and visits (if possible) to science centers and to university, industrial, and government laboratories provide multiple opportunities for students to become informed.

Teachers should emphasize the diversity to be found in the scientific community: different kinds of people (in terms of race, sex, age, nationality) pursuing different sciences and working in different places (from isolated field sites to labs to offices). Students can learn that some scientists and engineers use huge instruments (e.g., particle accelerators or telescopes), and others use only notebooks and pencils. And most of all, students can begin to realize that doing science involves more than "scientists," and that many different occupations are part of the scientific enterprise.

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

- Science is an adventure that people everywhere can take part in, as they have for many centuries.
- Clear communication is an essential part of doing science. It enables scientists to inform others about their work, expose their ideas to criticism by other scientists, and stay informed about scientific discoveries around the world.
- Doing science involves many different kinds of work and engages men and women of all ages and backgrounds.

Grades 6 through 8

Teachers should continue to seize opportunities for introducing information on science as a diverse line of work. Above all, children in early adolescence need to see science and science-related careers as a real option for themselves personally.

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

- Important contributions to the advancement of science, mathematics, and technology have been made by different kinds of people, in different cultures, at different times.

- Until recently, women and racial minorities, because of restrictions on their education and employment opportunities, were essentially left out of much of the formal work of the science establishment; the remarkable few who overcame those obstacles were even then likely to have their work disregarded by the science establishment.
- No matter who does science and mathematics or invents things, or when or where they do it, the knowledge and technology that result can eventually become available to everyone in the world.
- Scientists are employed by colleges and universities, business and industry, hospitals, and many government agencies. Their places of work include offices, classrooms, laboratories, farms, factories, and natural field settings ranging from space to the ocean floor.
- In research involving human subjects, the ethics of science require that potential subjects be fully informed about the risks and benefits associated with the research and of their right to refuse to participate. Science ethics also demand that scientists must not knowingly subject coworkers, students, the neighborhood, or the community to health or property risks without their prior knowledge and consent. Because animals cannot make informed choices, special care must be taken in using them in scientific research.
- Computers have become invaluable in science because they speed up and extend people's ability to collect, store, compile, and analyze data, prepare research reports, and share data and ideas with investigators all over the world.
- Accurate record-keeping, openness, and replication are essential for maintaining an investigator's credibility with other scientists and society.

Grades 9 through 12

No matter how the curriculum is organized, it should provide students with opportunities to become aware of the great range of scientific disciplines that exist.

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

- The early Egyptian, Greek, Chinese, Hindu, and Arabic cultures are responsible for many scientific and mathematical ideas and technological inventions.
- Modern science is based on traditions of thought that came together in Europe about 500 years ago. People from all cultures now contribute to that tradition.
- Progress in science and invention depends heavily on what else is happening in society, and history often depends on scientific and technological developments.
- Science disciplines differ from one another in what is studied, techniques used, and outcomes sought, but they share a common purpose and philosophy, and all are part of the same scientific enterprise. Although each discipline provides a conceptual structure for organizing and pursuing knowledge, many problems are studied by scientists using information and skills from many disciplines. Disciplines do not have fixed boundaries, and it happens that new scientific disciplines are being formed where existing ones meet and that some subdisciplines spin off to become new disciplines in their own right.
- Current ethics in science hold that research involving human subjects may be conducted only with the informed consent of the subjects, even if this constraint limits some kinds of potentially important research or influences the results. When it comes to participation in research that could pose risks to society, most scientists believe that a decision to participate or not is a matter of personal ethics rather than professional ethics.
- Scientists can bring information, insights, and analytical skills to bear on matters of public concern. Acting in their areas of expertise, scientists can help people understand the likely causes of events and estimate their possible effects. Outside their areas of expertise, however, scientists should enjoy no special credibility. And where their own personal, institutional, or community interests are at stake, scientists as a group can be expected to be no less biased than other groups are about their perceived interests.
- The strongly held traditions of science, including its commitment to peer review and publication, serve to keep the vast majority of scientists well within the bounds of ethical professional behavior. Deliberate deceit is rare and likely to be exposed sooner or later by the scientific enterprise itself. When violations of these scientific ethical traditions are discovered, they are strongly condemned by the scientific community, and the violators then have difficulty regaining the respect of other scientists.
- Funding influences the direction of science by virtue of the decisions that are made on which research to support. Research funding comes from various federal government agencies, industry, and private foundations.