Benchmarks for Science Literacy Grades Six through Eight Science Descriptions

Sixth Grade

Students should add more detail to their picture of the universe, pay increasing attention to matters of scale, and back up their understanding with activities using a variety of astronomical tools. Student access to star finders, telescopes, computer simulations of planetary orbits, or a planetarium can be useful at this level. Figuring out and constructing models of size and distance—for example, of the planets within the solar system—is probably the most effective activity. Models with three dimensions are preferable to pictures and diagrams. Everyone should experience trying to fashion a physical model of the solar system in which the same scale is used for the sizes of the objects and the distances between them (as distinct from most illustrations, in which distances are underrepresented by a factor of 10 or more).

Students can now consolidate their prior knowledge of the earth (as a planet) by adding more details (especially about climate), getting a firmer grasp of the geometry involved in explaining the seasons and phases of the moon, improving their ability to handle scale, and shifting their frame of reference away from the earth when needed. An inevitable paradox of the large scales involved is that an ocean that is difficult to imagine being 7 miles deep also can be considered a "relatively thin" layer on the earth's surface. Students should exercise their understanding of the paradox, perhaps by debating provocative questions such as "Is the ocean amazingly deep or amazingly shallow?"

Gravity, earlier thought of as acting toward the ground, can by now be thought of as acting toward the center of the spherical earth and reaching indefinitely into space. It is also time for students to begin to look at the planet's role in sustaining life—a complex subject that involves many different issues and benchmarks. In this section, the emphasis is on water and air as essential resources.

The cause of the seasons is a subtle combination of global and orbital geometry and of the effects of radiation at different angles. Students can learn part of the story at this grade level, but a complete picture cannot be expected until later.

At this level, students are able to complete most of their understanding of the main features of the physical and biological factors that shape the face of the earth. This understanding will still be descriptive because the theory of plate tectonics will not be encountered formally until high school. Of course, students should see as great a variety of landforms and soils as possible.

It is especially important that students come to understand how sedimentary rock is formed periodically, embedding plant and animal remains and leaving a record of the sequence in which the plants and animals appeared and disappeared. Besides the relative age of the rock layers, the absolute age of those remains is central to the argument that there has been enough time for evolution of species. The process of sedimentation is understandable and observable. But imagining the span of geologic time will be difficult for students.

Some experiences with how apparent positions of objects differ from different points of observation will make plausible the estimation of distances to the moon and sun. Finding distances by triangulation and scale drawings will help students to understand how the distances to the moon and sun were estimated and why the stars must be very much farther away. (The dependence of apparent size on distance can be used to pose the historically important puzzle that star patterns do not appear any larger from one season to the next, even though the earth swings a hundred million miles closer to them.)

Using light years to express astronomical distances is not as straightforward as it seems. (Many adults think of light years as a measure of time.) Beginning with analogs such as "automobile hours" may help.

Seventh Grade

Science in the middle grades should provide students with opportunities to enrich their growing knowledge of the diversity of life on the planet and to begin to connect that knowledge to what they are learning in geography. That is, whenever students study a particular region in the world, they should learn about the plants and animals found there and how they are like or unlike those found elsewhere. Tracing simple food webs in varied environments can contribute to a better understanding of the dependence of organisms (including humans) on their environment.

Students should begin to extend their attention from external anatomy to internal structures and functions. Patterns of development may be brought in to further illustrate similarities and differences among organisms. Also, they should move from their invented classification systems to those used in modern biology. That is not done to teach them the standard system but to show them what features biologists typically use in classifying organisms and why. Classification systems are not part of nature. Rather, they are frameworks created by biologists for describing the vast diversity of organisms, suggesting relationships among living things, and framing research questions. A provocative exercise is to have students try to differentiate between familiar organisms that are alike in many ways—for example, between cats and small dogs.

Now is the time to begin the study of genetic traits—what offspring get from parents. Students should examine examples of lineages for which breeding has been used to emphasize or suppress certain features of organisms.

Once they have some "magnification sense," students can use photomicrographs to extend their observations of cells, gradually concentrating on cells that make up internal body structures. Examining cells in other animals and plants can show students that cells are the fundamental building blocks of their own bodies and of other living things as well. Also, once students see that tissue in other animals looks pretty much the same as tissue in humans, two important claims of science will be reinforced: the ubiquity of cells and the unity of nature.

As students build up a collection of cases based on their own studies of organisms, readings, and film presentations, they should be guided from specific examples of the interdependency of organisms to a more systematic view of the kinds of interactions that take place among organisms. But a necessary part of understanding complex relationships is to know what a fair proportion of the possibilities are. The full-blown concept of ecosystem (and that term) can best be left until students have many of the pieces ready to put in place. Prior knowledge of the relationships between organisms and the environment should be integrated with students' growing knowledge of the earth sciences.

In the middle grades, the emphasis is on following matter through ecosystems. Students should trace food webs both on land and in the sea. The food webs that students investigate should first be local ones they can study directly. The use of films of food webs in other ecosystems can supplement their direct investigations but should not substitute for them. Most students see food webs and cycles as involving the creation and destruction of matter, rather than the breakdown and reassembly of invisible units. They see various organisms and materials as consisting of different types of matter that are not convertible into one another. Before they have an understanding of atoms, the notion of reusable building blocks common to plants and animals is quite mysterious. So following matter through ecosystems needs to be linked to their study of atoms.

Students' attention should be drawn to the transfer of energy that occurs as one organism eats another. It is important that students learn the differences between how plants and animals obtain food and from it the energy they need. The first stumbling block is food, which represents one of those instances in which differences between the common use of a term and the technical one cause persistent confusion. In popular language, food is whatever nutrients plants and animals must take in if they are to grow and survive (solutions of minerals that plants need traces of frequently bear the label "plant food"); in scientific usage, food refers only to those substances, such as carbohydrates, proteins, and fats, from which organisms derive the energy they need to grow and operate and the material of which they are made. It's important to emphasize that the sugars that plants make out of water and carbon dioxide are their only source of food. Water and minerals dissolved in it are not sources of energy for plants or for animals.

During middle school, several lines of evidence are further developed. The fossil evidence can be expanded beyond extinctions and survivals to the notion of biological 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.

<u>**Eighth Grade**</u>

Historically, much of the evidence and reasoning used in developing atomic/molecular theory was complicated and abstract. In traditional curricula too, very difficult ideas have been offered to children before most of them had any chance of understanding. The law of definite proportions in chemical combinations, so obvious when atoms (and proportions) are well understood, is not likely to be helpful at this level. The behavior of gases—such as their compressibility and their expansion with temperature—may be investigated for qualitative explanation; but the mathematics of quantitative gas laws is likely to be more confusing than helpful to most students. When students first begin to understand atoms, they cannot confidently make the distinction between atoms and molecules or make distinctions that depend upon it—

among elements, mixtures, and compounds, or between "chemical" and "physical" changes. An understanding of how things happen on the atomic level—making and breaking bonds—is more important than memorizing the official definitions (which are not so clear in modern chemistry anyway). Definitions can, of course, be memorized with no understanding at all.

Going into details of the structure of the atom is unnecessary at this level, and holding back makes sense. By the end of the 8th grade, students should have sufficient grasp of the general idea that a wide variety of phenomena can be explained by alternative arrangements of vast numbers of invisibly tiny, moving parts. Possible differences in atoms of the same element should be avoided at this stage. Historically, the identical nature of atoms of the same element was an assumption of atomic theory for a very long time.

When isotopes are introduced later, to explain subsequent observations, they can be a surprise and a lesson in the nature of progress in science. The alternative—teaching atoms' variety at the same time as the notion of their identity—seems likely to be prohibitively confusing to most students.

To that end, students should become familiar with characteristics of different states of matter—now including gases—and transitions between them. Most important, students should see a great many examples of reactions between substances that produce new substances very different from the reactants. Then they can begin to absorb the rudiments of atomic/molecular theory, being helped to see that the value of the notion of atoms lies in the explanations it provides for a wide variety of behavior of matter. Each new aspect of the theory should be developed as an explanation for some observed phenomenon and grasped fairly well before going on to the next.

At this level, students should be introduced to energy primarily through energy transformations. Students should trace where energy comes from (and goes next) in examples that involve several different forms of energy along the way: heat, light, motion of objects, chemical, and elastically distorted materials. To change something's speed, to bend or stretch things, to heat or cool them, to push things together or tear them apart all require transfers (and some transformations) of energy.

At this early stage, there may be some confusion in students' minds between energy and energy sources. Focusing on energy transformations may get around this somewhat. Food, gasoline, and batteries obviously get used up. But the energy they contain does not disappear; it is changed into other forms of energy.

The most primitive idea is that the energy needed for an event must come from somewhere. That should trigger children's interest in asking, for any situation, where the energy comes from and (later) asking where it goes. Where it comes from is usually much more evident than where it goes, because some usually diffuses away as radiation and random molecular motion.

A slightly more sophisticated proposition is the semi-quantitative one that whenever some energy seems to show up in one place, some will be found to disappear from another. Eventually, the energy idea can become quantitative: If we can keep track of how much energy of each kind increases and decreases, we find that whenever the energy in one place decreases, the energy in other places increases by just the same amount. This energy-cannot-be-created-or-destroyed way of stating conservation fully may be more intuitive than the abstraction of a constant energy total within an isolated system. The quantitative (equal amounts) idea should probably wait until high school.

Convection is not so much an independent means of heat transfer as it is an aid to transfer of heat by conduction and radiation. Convection currents appear spontaneously when density differences caused by heating (conduction and radiation) are acted on by a gravitational field. (Though not in space stations, unless they are rotating.) But these subtleties are not appropriate for most 8th graders.

The force/motion relationship can be developed more fully now and the difficult idea of inertia be given attention. Students have no trouble believing that an object at rest stays that way unless acted on by a force; they see it every day. The difficult notion is that an object in motion will continue to move unabated unless acted on by a force. Telling students to disregard their eyes will not do the trick—the things around them do appear to slow down of their own accord unless constantly pushed or pulled. The more experiences the students can have in seeing the effect of reducing friction, the easier it may be to get them to imagine the friction-equals-zero case.

Students can now learn some of the properties of waves by using water tables, ropes, and springs, and quite separately they can learn about the electromagnetic spectrum, including the assertion that it consists of wavelike radiations. Wave length should be the property receiving the most attention but only minimal calculation.

The idea of gravity—up until now seen as something happening near the earth's surface—can be generalized to all matter everywhere in the universe. Some demonstration, in the laboratory or on film or videotape, of the gravitational force between objects may be essential to break through the intuitive notion that things just naturally fall. Students should make devices to observe the magnetic effects of current and the electric effects of moving magnets. At first, the devices can be simple electromagnets; later, more complex devices, such as motor kits, can be introduced.