CHAPTER 8

INCREASING CURRICULUM COHERENCE

In many school districts, the subjects making up a curriculum in any one year rarely have much to do with one another in practice, even if they do in some abstract description of the curriculum. The treatment of a subject in a given year has little to do with its treatment the prior year or with what its treatment will be the following year. Some topics appear year after year at about the same cognitive level and in the same context, whereas some important topics may never show up in any year at all. Perhaps this lack of intellectual and developmental coherence is not surprising since few K-12 curricula have been designed on the basis of a comprehensive, interconnected set of learning goals—not even within subject areas and certainly not across the entire array of subjects.

This chapter begins by looking at the idea of curriculum coherence and then goes on to discuss ways in which developmental and intellectual coherence of existing K-12 curricula can be improved. Throughout, the context is science literacy and the examples are mostly taken from the work of Project 2061, but there is no reason to believe that the ideas and procedures would not apply more generally.

TYPES OF CURRICULUM COHERENCE

In the context of this chapter, a coherent curriculum is one that focuses on the relatedness of particular knowledge and skills needed for science literacy, takes developmental considerations into account in deciding on the grade placement of specific learning goals in science, mathematics, and technology, and provides occasions for exploring thematic connections between science-related subjects and other fields. These three aspects of curriculum coherence—literacy goals, developmental sequence, and thematic connections—are discussed below.

> "Despite the development of national and state standards, and of standards-driven curricula and tests, the problem of superficial textbooks is still with us and appears to be getting worse, at least temporarily. But it should be said at the outset that mere topic reduction would not lead to higher levels of student achievement. The goal is not merely textbooks with fewer topics, or even lengthier treatment of "key" topics, but books with a coherent vision of the disciplines presented as an unfolding story, allowing even children in the early grades to connect the bits and pieces to larger concepts."
>
> –Harriet Tyson, *Overcoming Structural Barriers to Good Textbooks,* 1997

Literacy Goals

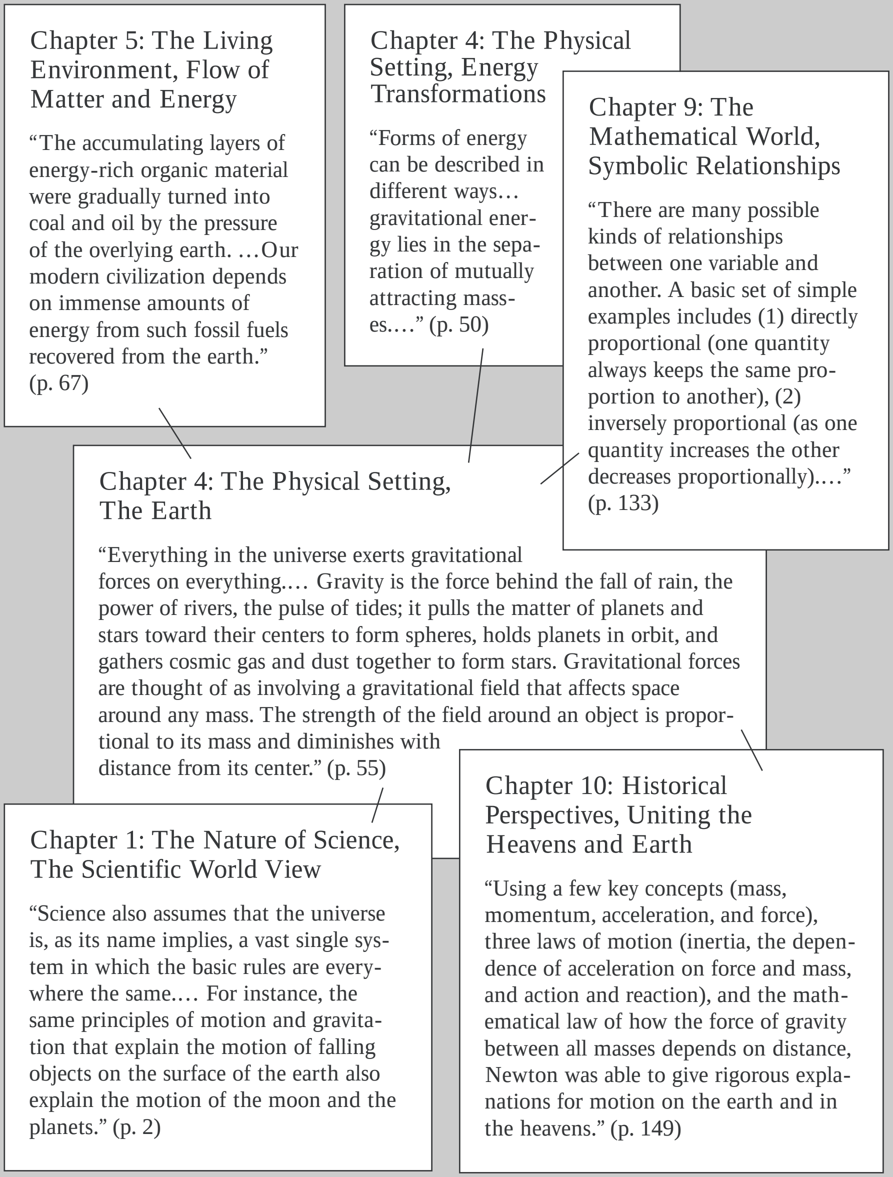
It is probably true that in every field there is more we would like students to learn than there is time for them to learn—even in the thirteen years from the start of kindergarten to the completion of high school. Surely this is the case with regard to science, mathematics, and technology. Hence great care must be taken to identify a limited set of essential, mutually supportive science-literacy goals to serve as the basis for making curriculum-content decisions. Reaching agreement on a *coherent set* of fundamental science literacy learning goals that can withstand critical scrutiny turns out, however, to be demanding, expensive, and time consuming. Fortunately, school districts do not have to do this for themselves, since the basic work has been carried out in a decade-long effort led by three distinguished organizations—the American Association for the Advancement of Science, the National Research Council of the National Academy of Sciences, and the National Council of Teachers of Mathematics—and involving dozens of other scientific societies and education associations.

Project 2061 of the American Association for the Advancement of Science began its work in 1985. It believed that K-12 reform in science, mathematics, and technology education leading to science literacy for all graduates would remain aimless and hence stalled unless a compelling vision of what constitutes science literacy could be formulated. The project mobilized natural and social scientists, mathematicians, engineers, and educators in pursuit of such a formulation, and the result was *Science for All Americans.* From the outset, the broad scope of natural and social sciences, mathematics, technology was chosen in the belief that these areas are so closely connected that the goals for any one of them ought to be conceived in the context of the others.

To be candidates for inclusion in *Science for All Americans*, ideas had to be justified in terms of one or more of the five fundamental criteria of significance and utility described in Chapter 1: employment, citizenship, cultural salience, philosophical reflection, and enriched experience. Moreover, to be included, an idea also had to fit into a set of ideas that would be mutually supporting and together maximize understanding and serve as a foundation for further learning. It is important to recognize that the understanding of science, mathematics, and technology expressed in *Science for All Americans* is not merely a *collection* of ideas, but a *network* of related ideas intended to optimize understanding and further learning of how the world works. Recognition of that relatedness is also part of science literacy. The box on the facing page shows an example of mutually supporting ideas in *Science for All Americans*.

The International Technology Education Association is working on a set of learning goals for technological literacy.

A NETWORK OF RELATED IDEAS IN *SCIENCE FOR ALL AMERICANS*



Chapter 5: The Living Environment, Flow of Matter and Energy

"The accumulating layers of energy-rich organic material were gradually turned into coal and oil by the pressure of the overlying earth. …Our modern civilization depends on immense amounts of energy from such fossil fuels recovered from the earth." (p. 67)

Chapter 4: The Physical Setting, Energy Transformations

"Forms of energy can be described in different ways… gravitational energy lies in the separation of mutually attracting masses.…" (p. 50)

Chapter 9: The Mathematical World, Symbolic Relationships

"There are many possible kinds of relationships between one variable and another. A basic set of simple examples includes (1) directly proportional (one quantity always keeps the same proportion to another), (2) inversely proportional (as one quantity increases the other decreases proportionally).…" (p. 133)

Chapter 4: The Physical Setting, The Earth

"Everything in the universe exerts gravitational forces on everything.… Gravity is the force behind the fall of rain, the power of rivers, the pulse of tides; it pulls the matter of planets and stars toward their centers to form spheres, holds planets in orbit, and gathers cosmic gas and dust together to form stars. Gravitational forces are thought of as involving a gravitational field that affects space around any mass. The strength of the field around an object is proportional to its mass and diminishes with distance from its center." (p. 55)

Chapter 1: The Nature of Science, The Scientific World View

"Science also assumes that the universe is, as its name implies, a vast single system in which the basic rules are everywhere the same.… 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." (p. 2)

Chapter 10: Historical Perspectives, Uniting the Heavens and Earth

"Using a few key concepts (mass, momentum, acceleration, and force), three laws of motion (inertia, the dependence of acceleration on force and mass, and action and reaction), and the mathematical law of how the force of gravity between all masses depends on distance, Newton was able to give rigorous explanations for motion on the earth and in the heavens." (p. 149)

Goals set by national organizations for mathematics and science can be found on the Project 2061 CD-ROM, *Resources for Science Literacy: Professional Development.*

Science for All Americans was published in 1989, as was *Curriculum and Evaluation Standards for School Mathematics*, a formulation of learning outcomes in K-12 mathematics prepared by the National Council of Teachers of Mathematics. In 1993, Project 2061's *Benchmarks for Science Literacy* appeared, and in 1996 the National Research Council of the National Academy of Sciences published *National Science Education Standards*, a document that includes recommendations for learning goals in science. Given the high level of consistency among the recommendations of these three groups—including tightened scope and increased emphasis on understanding, reasoning, and connectedness—a set of coherent goals for creating coherent curricula is readily available.

Developmental Sequence

For the ultimate science literacy envisioned in national goals to have any chance of being reached, K-12 benchmarks for learning along the way have to make developmental sense. One essential aspect of developmental coherence has to do with the logical dependence of complex ideas on precursor ideas. For example, the proposition that "force produces a change in motion" requires *some* prior understanding of what "force" and "change of motion" mean—but only some prior understanding, since part of understanding what "force" and "change of motion" mean involves knowing the relationship between them. Another aspect of coherence can be thought of as psychological, taking account of what preexisting notions students typically have with regard to given concepts and what difficulties they have in learning them. For instance, students tend not to distinguish among force, momentum, energy, pressure, power, and strength, and they tend to think of force as a property of objects rather than as a relation between objects.

Benchmarks for Science Literacy CHAPTER 15: THE RESEARCH BASE summarizes the cognitive research taken into account in assigning benchmarks to a particular grade range. In *Resources for Science Literacy: Professional Development,* this research summary is expanded further and electronically linked to the relevant sections of *Science for All Americans*.

Because a developmentally coherent set of learning goals must take such logical and psychological matters into account, cognitive scientists as well as teachers, scientists, mathematicians, and engineers were directly involved in the creation of *Benchmarks*. Three years of work beyond *Science for All Americans* on how student understanding and skills would grow with time went into *Benchmarks*. The main premise of the work was that what is learned now should be based on what was learned earlier, on what is capable of being learned now, and on what needs to be learned later. That rationale is readily seen in listings of benchmarks, as in the box on the facing page.

Thematic Connections

In principle, a coherent curriculum is one that makes conceptual sense at every level of instruction—from daily lesson plans to units, to courses, to the curriculum as a whole

A K-12 SET OF BENCHMARKS ON GRAVITY

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

- Things near the earth fall to the ground unless something holds them up.

By the end of 5th grade students should know that

- Things on or near the earth are pulled toward it by the earth's gravity.
- The earth's gravity pulls any object toward it without touching it.

By the end of 8th grade students should know that

- Everything on or anywhere near the earth is pulled toward the earth's center by gravitational force.
- Every object exerts gravitational force on every other object. The force depends on how much mass the objects have and on how far apart they are. The force is hard to detect unless at least one of the objects has a lot of mass.
- The sun's gravitational pull holds the earth and other planets in their orbits, just as the planets' gravitational pull keeps their moons in orbit around them.

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

- 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 billions 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.
- 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 the 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.
- Isaac Newton created a unified view of force and motion in which motion everywhere in the universe can be explained by the same few rules. His mathematical analysis of gravitational force and motion showed that planetary orbits had to be the very ellipse that Kepler had proposed two generations earlier.
- Newton's system was based on the concepts of mass, force, and acceleration, his three laws of motion relating them, and a physical law stating that the force of gravity between any two objects in the universe depends only upon their masses and the distance between them.
- General relativity theory pictures Newton's gravitational force as a distortion of space and time.

from *Benchmarks for Science Literacy* Chapter 4: The Physical Setting and Chapter 10: Historical Perspectives each year, to the curriculum over the years. Ideas and skills do not stand alone but are linked conceptually to other ideas and skills and appear in a variety of contexts.

This aspect of coherence, of course, is easier to achieve at the lesson-plan and unit levels than at higher ones. Indeed, the individual units making up a course of study are often very carefully organized, whereas the collection of units making up a course are largely independent of one another except for being in the same subject. Nevertheless, it is well within the reach of publishers to develop courses and even course sequences—blocks, in the language of earlier chapters of this book—in which the content is thoughtfully organized around a few pervasive themes, key ideas and skills are visited periodically (and with specific purpose) in different contexts, and their relationship is discussed explicitly. Crosscutting instructional themes can be used for creating such curriculum bridges. They can be concepts, applications, or historical episodes.

Conceptual themes—as the term is used in the Common Themes chapters of *Science for All Americans* and *Benchmarks*—help us think about and understand ideas, processes, and events in many different subject-matter contexts. For example, the idea of "scale" has powerful applications in mathematics, physics, biology, engineering, agriculture, politics, etc., and so can be used to find bridge-building opportunities in the curriculum. An application theme is based on the notion that achieving understanding of an idea or acquiring a skill requires that students exercise the idea or skill in multiple contexts. Different subjects provide mutually advantageous opportunities for accomplishing this. For instance, science, social studies, and physical-education courses offer many occasions for students to apply newly learned mathematical ideas and skills, and, reciprocally, those subjects can easily provide mathematics classes with meaningful data to analyze and interesting patterns to model.

For more information on the use of themes, see the two subsections below entitled Within the Sciences and Among Science, Mathematics, and Technology.

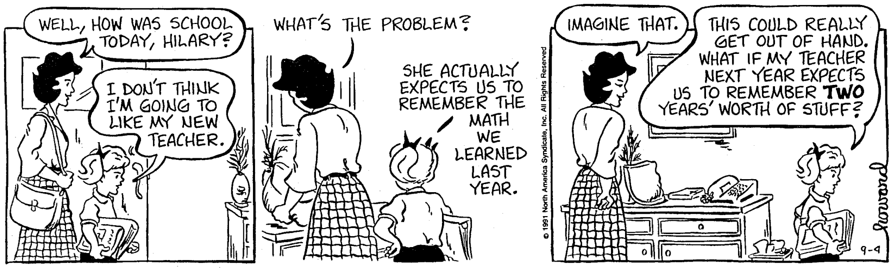
History is especially important in making cross-subject thematic connections. Science ought to have a major presence in history courses because of the enormous impact of science and technology on all of history. And history should be taken seriously in science courses because history alone provides a context for seeing how science really works over time and how it relates to mathematics and technology and to what else is happening in human culture.

So far in this chapter, we have briefly considered three separate aspects of curriculum coherence. In the following two sections, we use all three—literacy goals, developmental sequences, and thematic connections—to suggest ways to improve curriculum across grade levels and across subjects.

IMPROVING COHERENCE ACROSS GRADE LEVELS

Surely one of the most common complaints about existing curricula is the repetition of topics that bore and discourage students. Yet one of the most effective means of strengthening a grasp of concepts and skills is to exercise them repeatedly in new contexts, at progressively higher levels of sophistication, and in relation to other concepts. At an extreme of informality, teachers can individually and spontaneously ask students to think again about something they have learned before in light of something that they have learned since. (Obviously even this informal approach requires teachers to be aware of the content of the curriculum in the prior years.) At a formal extreme, the curriculum can be carefully worked out, cooperatively by teachers at all the grade levels involved, to have built-in occasions for reflection on and consolidation of ideas.

Yet fostering coherence across grades is not without problems. Teachers often choose to use only some parts of instructional materials that were designed to cover a whole year or even several years. This practice puts pressure on materials developers to avoid instructional units that depend on students having experienced earlier parts of the program.



Sally Forth by Howard & Macintosh

Whatever the teacher's deliberate role in such selection may be, however, there is also an unavoidable discontinuity that results from students changing schools and school districts. One approach to reducing this disruption is to promote more uniform instructional programs—districtwide, statewide, or even nationwide—and more uniform grade placement of specific learning goals. The means of achieving these goals would be left substantially open. Another approach is to expand curricular and instructional alternatives, but keep track of students' achievements so that they can eventually fill all requirements.

Project 2061's experience has shown that cooperative planning across grade levels even as broad as primary to high school seems to have surprising benefits for teachers, in terms of their understanding their role in curriculum planning, and for students, in terms of how they experience the coherence of the curriculum. It is important to contrast cooperative K-12 planning to a more traditional approach in which (in effect) high-school teachers tell middle-school teachers who in turn tell elementary teachers what topics they have to cover. Much more productive is planning in which teachers work together to create a curriculum that includes revisiting certain topics at successively more sophisticated levels and in different contexts, but avoids needless repetition. (The revisiting, needless to say, should not be merely a reprise, but be focused on growth in understanding of specific aspects.) Suggestions for organizing such an effort and for placing and relating benchmarks follow in the next two subsections.

Using *Benchmarks for Science Literacy*

For a good start on increasing grade-level coherence in science, mathematics, and technology, teachers can use *Benchmarks for Science Literacy*. The first step is to identify all of the benchmarks to be addressed in the curriculum for some topic of modest size. When agreement has been reached on relevant benchmarks, decisions need to be made on which particular grades or subjects will or will not target them. Finally, the desired configuration of instruction is compared with the actual configuration in the current curriculum and plans are made to bring the two closer together.

Consider, for instance, the example on the following page of how this approach could play out using benchmarks for the topic of heredity. If it is difficult to assemble a committee of K-12 teachers, then teachers from different grades within the same grade ranges can form groups. Thus, a committee of middle-school teachers would see that there are three heredity benchmarks in grades 6-8, which means students are expected to learn the ideas somewhere between the beginning of the 6th grade and the end of the 8th grade. The group would decide which grade would be responsible for targeting each of those benchmarks, and agree that the other grades would desist—or deliberately reinforce them in a thoughtful way. In doing so, some attention would have to be paid to closely related benchmarks that appear under other headings. For example, the third benchmark for grades 6-8 in the *Benchmarks* section Heredity is closely related to one at the 6-8 level in the *Benchmarks* section Evolution of Life.

Committees of elementary and high-school teachers could undertake similar tasks by assigning the heredity benchmarks for grades K-2, 3-5, and 9-12. A better procedure would be for teams to be made up of teachers from adjacent grade ranges or, better still, from the entire K-12 span. In all cases, the task is to reach agreement on which grades are responsible for targeting the specified benchmarks.

ASSIGNING BENCHMARKS TO GRADES

A Middle-School Example for the Topic of Heredity

Benchmark	Assigned Grade
From *Benchmarks* section Heredity, p. 108:	
• In some kinds of organisms, all the genes come from a single parent, whereas in organisms that have sexes, typically half of the genes come from each parent.	Grade 6
• In sexual reproduction, a single specialized cell from a female merges with a specialized cell from a male. As the fertilized egg, carrying genetic information from each parent, multiplies to form the complete organism with about a trillion cells, the same genetic information is copied in each cell.	Grade 6
• New varieties of cultivated plants and domestic animals have resulted from selective breeding for particular traits.	Grade 7
From *Benchmarks* section Evolution of Life, p. 124:	
• Small differences between parents and offspring can accumulate (through selective breeding) in successive generations so that descendants are very different from their ancestors.	Grade 8

The committee might reason that teaching the first two benchmarks in grade 6 would allow placing human fertilization at the beginning of grade 7, where it could contribute to subsequent benchmarks in the Human Development section (and health education) on conception and embryo growth. The third benchmark would be needed as a precursor to the fourth, which might well be postponed to grade 8, when students might be more ready to consider its implications for evolution.

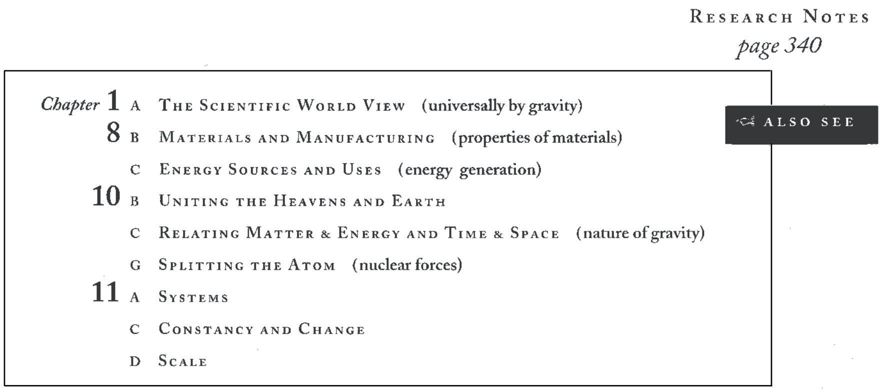
Teachers may be called upon to focus on benchmarks that heretofore they had not. In those instances, the team needs to agree on what is to be eliminated to make room (as described in Chapter 7). Before the beginning of the next cycle, the participating teachers should describe the experience and propose adjustments. Then another set of benchmarks should be selected and the process repeated.

Benchmarks provides further illumination of the coherence of ideas in brief essays that accompany the learning goals for each grade range. Consider the following excerpt from the Forces of Nature section:

> **Kindergarten through grade 2**
>
> The focus should be on motion and on encouraging children to be observant

> about when and how things seem to move or not move. They should notice that things fall to the ground if not held up. They should observe motion everywhere, making lists of different kinds of motion and what things move that way. Even in the primary years, children should use magnets to get things to move without touching them, and thereby learn that forces can act at a distance with no perceivable substance in between.
>
> **Grades 3 through 5**
>
> The main notion to convey here is that forces can act at a distance. Students should carry out investigations to become familiar with the pushes and pulls of magnets and static electricity. The term *gravity* may interfere with students' understanding because it often is used as an empty label for the common (and ancient) notion of "natural motion" toward the earth. The important point is that the earth *pulls* on objects.
>
> **Grades 6 through 8**
>
> 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.
>
> **Grades 9 through 12**
>
> Students should now learn how well the principle of universal gravitation explains the architecture of the universe and much that happens on the earth. The principle will become familiar from many different examples (star formation, tides, comet orbits, etc.) and from the study of the history leading to this unification of earth and sky. The "inversely proportional to the square" aspect is not a high priority for literacy. Much more important is escaping the common adult misconceptions that the earth's gravity does not extend beyond its atmosphere or that it is caused by the atmosphere....

Those comments can be extended conceptually by referring to other sections in *Benchmarks* that relate in interesting ways to the concept of gravity and its applica-



Research Notes
page 340

ALSO SEE

Chapter 1	A	The Scientific World View (universally by gravity)
8	B	Materials and Manufacturing (properties of materials)
	C	Energy Sources and Uses (energy generation)
10	B	Uniting the Heavens and Earth
	C	Relating Matter & Energy and Time & Space (nature of gravity)
	G	Splitting the Atom (nuclear forces)
11	A	Systems
	C	Constancy and Change
	D	Scale

tions. The ones found in the “Also See” box at the beginning of the Forces of Nature section are shown above.

Inspecting the cognitive research findings found in *Benchmarks* Chapter 15: The Research Base will also help when considering curriculum coherence. Those for Forces of Nature are reproduced here:

> The earth’s gravity and gravitational forces in general form the bulk of research related to Forces of Nature. Elementary-school students typically do not understand gravity as a force. They see the phenomenon of a falling body as “natural” with no need for further explanation or they ascribe it to an internal effort of the object that is falling (Ogborn, 1985). If students do view weight as a force, they usually think it is the air that exerts this force (Ruggiero et al., 1985). Misconceptions about the causes of gravity persist after traditional high-school physics instruction (Brown & Clement, 1992) but can be overcome by specially designed instruction (Brown & Clement, 1992; Minstrell et al., 1992).
>
> Students of all ages may hold misconceptions about the magnitude of the earth’s gravitational force. Even after a physics course, many high-school students believe that gravity increases with height above the earth’s surface (Gunstone & White, 1981) or are not sure whether the force of gravity would be greater on a lead ball than on a wooden ball of the same size (Brown & Clement, 1992). High-school students have also difficulty in conceptualizing gravitational forces as interactions. In particular, they have difficulty in understanding that the magnitudes of the gravitational forces that two objects of different mass exert on

> each other are equal. These difficulties persist even after specially designed instruction (Brown & Clement, 1992).

See the draft strand map on page 184 of Chapter 6. Labels identify the kinds of information the maps provide. Many additional maps have been brought together in the Project 2061 *Atlas of Science Literacy.*

Using Strand Maps

In *Benchmarks*, pointers to related ideas in other chapters are indicated by the "Also See" references. Strand maps display connections both over time and across topic areas. The maps depict the convergence of prior ideas into a new idea, the development of a conceptual strand through different stages of sophistication, and the linkage of several maps through ideas they share. Coherence is emphasized further by identifying "story lines" in strand maps that develop somewhat separately and eventually converge conceptually. Moreover, the maps are backed up with source materials from *Science for All Americans*, *Benchmarks* essays, and the research summaries in *Benchmarks* and *Resources for Science Literacy*. Maps also indicate connections to other maps. For example, the gravity map on page 184 shows connections to maps for climate and motion.

The prose in *Science for All Americans* helps to provide context for a map. For example, the coherent fabric of understanding that the gravity map depicts is articulated in *Science for All Americans* in the section Forces of Nature:

> Everything in the universe exerts gravitational forces on everything else, although the effects are readily noticeable only when at least one very large mass is involved (such as a star or planet). Gravity is the force behind the fall of rain, the power of rivers, the pulse of tides; it pulls the matter of planets and stars toward their centers to form spheres, holds planets in orbit, and gathers cosmic gas and dust together to form stars. Gravitational forces are thought of as involving a gravitational field that affects space around any mass. The strength of the field around an object is proportional to its mass and diminishes with distance from its center. For example, the earth's pull on an individual will depend on whether the person is, say, on the beach or far out in space.

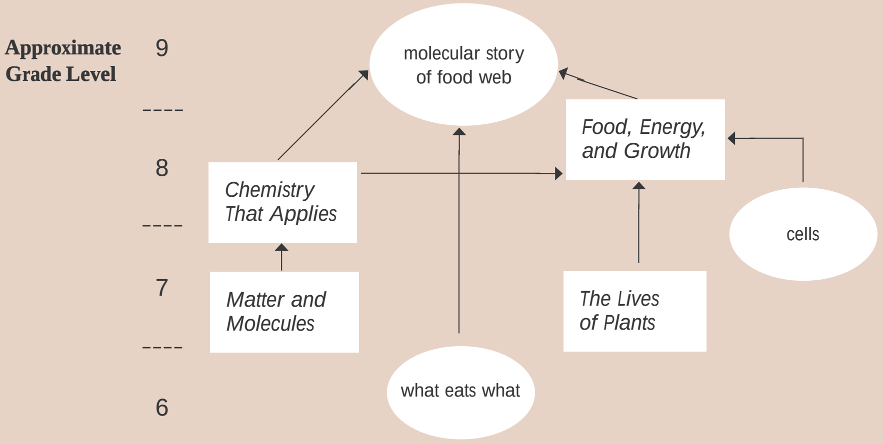
It is important to understand that strand maps are not intended as literal prescriptions for organizing instruction, as if benchmarks could be neatly taught or achieved one at a time. Maps can help developers and designers attend to constraints on sequence and to keep track of what could be going on in students' minds as they experience successive lessons or units. The box that follows provides an example of how the configuration of instructional units can be related to key learning goals at different grade levels. The diagram on page 250 shows how those same instructional units also can be related to strand maps.

BUILDING CURRICULUM COHERENCE WITH RELATED INSTRUCTIONAL UNITS

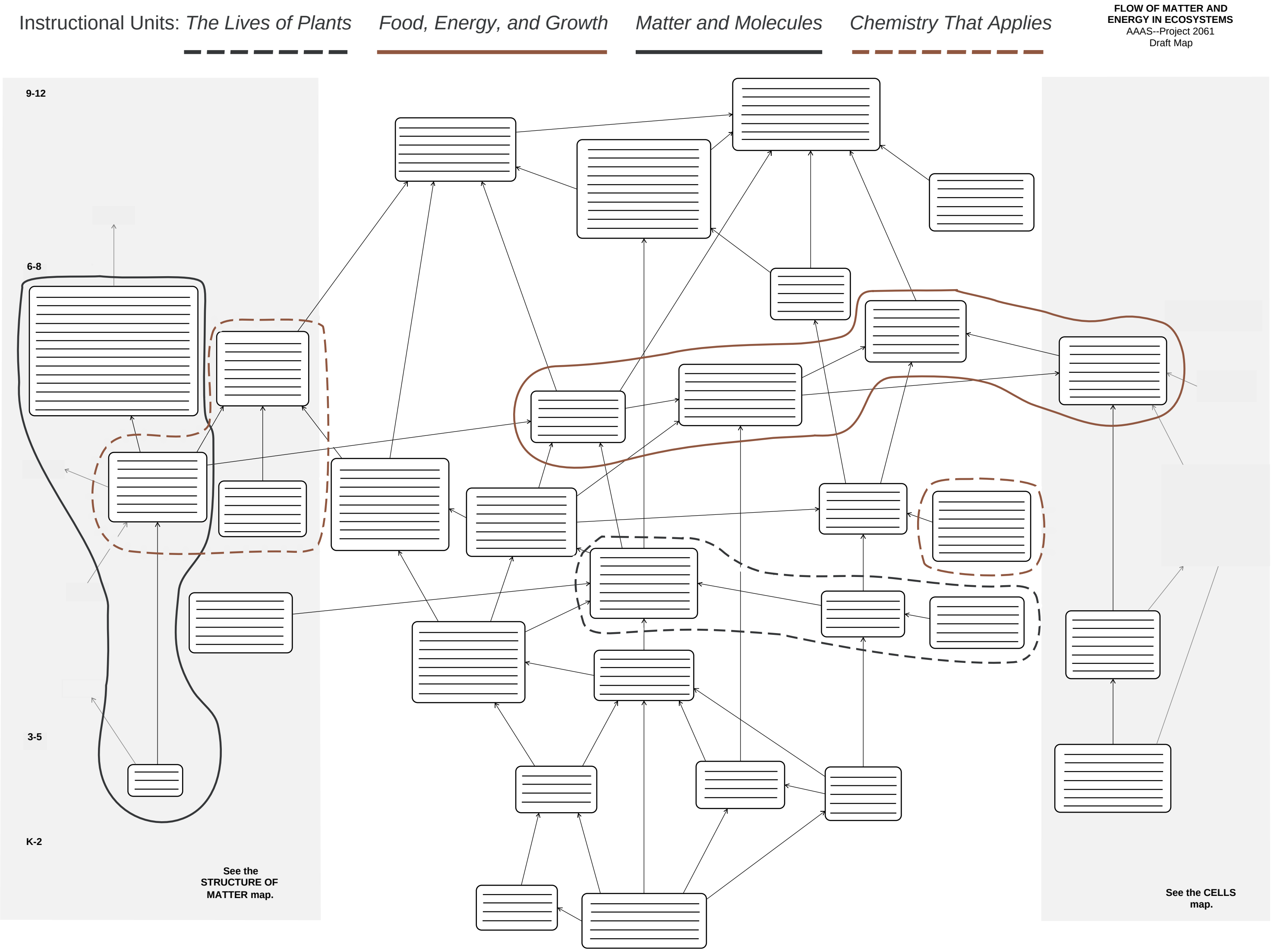
An example of reflecting on coherence across grade levels is provided by a set of four actual instructional materials identified by Project 2061's curriculum-materials evaluation as having some potential to help students achieve some important but difficult benchmarks. All four units were developed in a research and development effort involving Michigan State University and the Michigan State Department of Education. Each unit requires about six to eight weeks of instruction (and so is on the small side for curriculum blocks).

The Lives of Plants, which could be taught as early as grade 5, focuses chiefly on the manufacture of sugar by plants (considering carbon dioxide, oxygen, water, and sugars as substances, not as molecules). *Matter and Molecules*, designed for as early as grade 6 but more likely to work better in grade 7, focuses on the particulate nature of matter and its differing arrangement and motion in solids, liquids, and gases. With that understanding, students are later able to study *Food, Energy, and Growth* in grade 8 or above, which follows the molecular fate of food in digestion and metabolism. Students' understanding of *Matter and Molecules* also enables them to take on *Chemistry That Applies* in grade 8 or above, in which conservation of mass is explicated as an unchanging number of atoms during chemical reactions, as they recombine into different molecules.

The diagram below shows how the units are conceptually related to one another and to other ideas (which would need to be treated in other units). For example, these units would depend somewhat on familiarity with living cells as a precursor to the extensive role that cells play in *Food, Energy, and Growth*. The grand payoff in terms of a molecular account of food webs would come still later, drawing on both *Food, Energy, and Growth* and *Chemistry That Applies*, on other aspects of *The Lives of Plants*, and on earlier familiarity with facts about what eats what.



RELATING INSTRUCTIONAL UNITS TO STRAND MAPS



This diagram—derived from a composite of several maps from *Atlas of Science Literacy*—illustrates how instructional units can be related to strand maps. Loops on the maps enclose the benchmarks served by each unit. The *Matter and Molecules* unit serves a generally "vertical" set of learning goals, addressing a sequence of ideas over time. On the other hand, the *Lives of Plants* unit and the *Food, Energy, and Growth* unit serve a mostly "horizontal" set of goals, addressing a variety of ideas at approximately the same grade level. More than one unit can address the same idea—often a benefit if it is a particularly difficult idea.

In setting up this kind of intense study of strand maps, it may be difficult to put together a group to consider a map in its full K-12 range. A good first step is to create some pairs: K-2 teachers in a school can pair up with grade 3-5 teachers in the same school in addressing part of a growth-of-understanding sequence; or grade 3-5 teachers in an elementary school can pair with grade 6-8 teachers in a middle school; and similarly between a middle school and a high school. (The different groups need not all take on the same map.) The following year, each of these partial strands can expand up or down a grade range, and so on in each subsequent year. But if not right away, then as soon as possible, strand maps should be used by K-12 teams to ensure developmental coherence across the entire curriculum.

As teachers reach agreement on distributing the map’s benchmarks among the grades and subjects, the assignments should be described and entered in a computer file that can readily be found and accessed by others. After the first implementation of the plan, a debriefing can help to identify problems of articulation that arose and to make improvements in the grade sequencing. That information, too, should be recorded and filed accessibly. Each year, additional strands can be implemented as teachers become comfortable with the process.

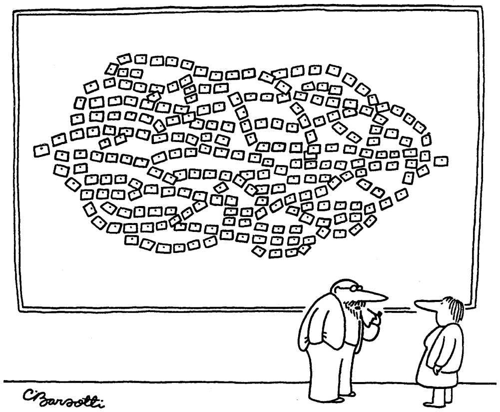
A reason to be circumspect about organizing lessons one-to-one on benchmarks is that often a benchmark contains several ideas that have similar content, but are not necessarily learned well at the same time. In strand maps, a single benchmark may be partitioned into separate boxes or even restated with a slightly different focus, to show more clearly its relationship to other ideas.

Designs on Disk provides suitable computer file forms in a database for assigning benchmarks to grade levels.

IMPROVING COHERENCE ACROSS SUBJECTS

There is no doubt that people learn, make sense of, and retain new concepts better when they are able to make clear connections to other ideas they are learning or already have, even if none of the ideas is completely clear. Sometimes that means instruction should relate ideas to students’ own experience, or that instruction should draw students’ attention to similar ideas in different subjects, or that students should exercise the ideas in a variety of contexts outside a particular course. Moreover, students’ eventual ability to apply ideas usefully in new situations will benefit from their having previously practiced applying the ideas in a variety of new situations. Many educators seem to count on students eventually being able to make valuable cross-connections by themselves; but there is little evidence that students put ideas from different courses together. Actual integrated courses may not necessarily be an efficient way for students to learn helpful cross-connections; the research on student learning in integrated settings is still sparse. At the least, however, one-subject courses should provide opportunities for students to relate new ideas to other subjects.

Some divisions between subjects are based on their historical independence, some on beliefs about how students best learn, and some may seem to have been shaped,



It’s plotted out. I just have to write it.”

"If students are expected to apply ideas in novel situations, then they must practice applying them in novel situations. If they practice only predictable exercises, or unrealistic 'word problems,' then that is all they are likely to learn."
—Science for All Americans, p.199

almost accidentally, by school tradition. It is entirely possible to have a curriculum in which there is essentially no commerce between subjects—and in fact that is often the case. For over a century there have been calls to break down those curricular walls, often on the philosophical basis that the world itself has no such divisions, less often on the psychological basis of how students learn. In the future, it may be possible to control the extent of curriculum interconnectedness by selecting appropriate instructional blocks from a pool of well-described candidates that range from strictly discipline-based to fully integrated courses. Until then, headway toward increasing subject-matter coherence—within each science, among the sciences, and between them and other subjects—can be made in ways outlined below.

Within the Sciences

At any grade level, an examination of the science offerings will reveal opportunities to make some useful connections. Of the possibilities suggested here, the first two are interdisciplinary in nature, the next one has to do with shared attributes, and the last one is thematic.

The natural sciences. The separation of physics, chemistry, biology, and earth and space science at the secondary level is a powerful tradition. Many high-school science teachers take their professional identity from the specific discipline they teach (in contrast to high-school mathematics teachers, who are less inclined to make such distinctions). Science teachers in the middle grades are less attached to a particular science discipline, but even so, most middle-school general-science courses cycle through separate blocks of physical, biological, and earth sciences. Even courses described as general or integrated science may be episodically disciplinary—physics topics one day or week, biology topics another day or week, and so forth.

This is the order of study in the "Chicago" plan referred to in Chapter 2, p. 89.

For generations, there has been argument about how the natural-science disciplines should be ordered in the high-school curriculum. The most popular order is based on the mathematical sophistication required (as the courses are usually designed): Earth and space science, biology, chemistry, physics. It is argued from time to time (as each generation of teachers and scientists rediscovers the insight) that a more logical order would be on the basis of conceptual dependency: biology after chemistry (because biology draws on chemistry), and chemistry after physics (because chemistry draws on physics), giving the order physics-chemistry-biology, with earth science and astronomy introduced anywhere along the line, depending how explicitly they deal with physics principles.

But it may well be that neither of these sequences is altogether satisfactory. Surely it is not the case that all of physics should come before all of chemistry or all of chemistry before all of physics; there are *parts* of chemistry that could well come before parts of physics, and vice versa. Similarly, some parts of biology may well come before and some parts after chemistry and physics. Perhaps the ideal schedule would stretch all science subjects out over time, with ideas sequenced in a way that would allow them to be taught when they are needed and learnable, without regard to discipline, but with the disciplines supporting each other. But until such coordination can be engineered, coherence can be enhanced by pointing to some of the connections among the sciences, first in the elementary programs to lead students to *expect* connections, then within each high-school or middle-school science course. Strand maps are a good source of clues about when ideas outside a topic are relevant or necessary.

An achievable goal would be for each science course to include at least one unit that explicitly deals with connections to one of the other science disciplines. Yet developing such units would be challenging for teachers who have not experienced this sort of instruction themselves, either as students or as teachers. The simplest approach in high school, perhaps, is to import a teacher from another subject to teach one or a few lessons. A chemistry teacher, for example, could be invited into a biology course to introduce the nature of proteins and the action of enzymes. A biology teacher could reciprocate and expand on the role of enzymes for the chemistry students. An improvement on that would be for the biology and chemistry teachers to plan together what the specific learning goals for the lesson should be and how students' understanding can be assessed. In either case, the teachers will want to confer afterward about how it went and how it could be done better next time.

A more elaborate operation would be to have a committee of science teachers agree on some exchanges of content and help one another develop the units, assemble the materials, and the like. The teachers would keep a record of what happened and report back to the committee on their experiences working with the students. Over time, an interweaving of science subject matter could develop, even though the courses remain as separate disciplines.

The social sciences. The domain of curriculum labeled “social studies” often contains scientific elements such as psychology, anthropology, sociology, economics, and political science, as well as citizenship, civics, American and world history, and reflections on problems of society and political systems. Of the scores of learning goals stipulated in the National Council for Social Studies' (NCSS) *Curriculum Standards for the Social*

The National Science Teachers Association’s *Scope, Sequence and Coordination* curricula have been a prominent attempt to coordinate high school science.

For efficiency, some strand maps are organized around topics that naturally draw on several disciplines—for example, “Flow of Matter and Energy in Ecosystems.”

Designs on Disk contains a listing of *Science for All Americans* sections relevant to all ten NCSS strands. (A similar comparison also appears in *Resources for Science Literacy: Professional Development.)*

Studies, about 40 percent are addressed by both *Science for All Americans* and *Benchmarks for Science Literacy*, mostly in Chapter 7: Human Society. For example, the first of the ten NCSS strands, "Culture," deals with the tendency for people from different cultures to arrive at different interpretations of information and experiences; benchmarks relevant to this idea occur in *Benchmarks* and *Science for All Americans* sections 1b: Scientific Inquiry, 6d: Learning, 7a: Cultural Effects on Behavior, and 12e: Critical Response Skills. Similar relationships can be found in the *National Science Education Standards (NSES)* sections Science and Technology, History and Philosophy of Science, and Science in Personal and Social Perspectives. From this area of common interest, science and social-studies teachers can work together to fashion units for each of their courses. The other social-studies strands provide similar opportunities.

Shared attributes. The individual science disciplines differ from one another in important ways, including their histories, interests, techniques, and languages. Yet they have much in common philosophically and operationally and borrow ideas, findings, and techniques from one another liberally. Some of the important shared attributes of the sciences are described in Chapter 1: The Nature of Science and Chapter 12: Habits of Mind in both *Science for All Americans* and *Benchmarks*. Readings germane to those two chapters can be found on the *Resources for Science Literacy: Professional Development* CD-ROM.

Because science curricula rarely include study of the nature of science or general habits of mind, these areas are equally unfamiliar to all faculty and therefore invite collaboration. One way to proceed is for groups of teachers of science to begin with a single attribute—a subsection from the Scientific Inquiry section of Chapter 1: The Nature of Science or from the Communication section in Chapter 12: Habits of Mind. For instance, the group might select this idea—"Science is a blend of logic and imagination"—for emphasis in all science courses. Teachers would agree to highlight it in the high-school physics unit on energy transformations, the high-school chemistry unit on periodic properties of elements, the high-school biology unit on heredity, the high-school earth-science unit on tectonic plates, the middle-school physical-science unit on force and motion, and an elementary-school science unit on diversity of life. In each of these contexts, there is a notable historical episode of a scientist—including such key individuals as Watt, Mendeleev, Mendel, Wegener, Newton, Darwin—coming up with a theory imaginatively, refining it logically, and substantiating it with empirical evidence.

As in other curriculum-related activities, discussion and study lead to recorded decisions, followed by development of instructional plans, implementation of the plans, debriefing, moving on to other topics and participation in another cycle.

Most, but not all, of these historical episodes appear in *Science for All Americans* Chapter 10: Historical Perspectives.

Themes. Another way for the science curriculum to reduce the seeming isolation of the science subjects is for each course to draw on some common themes from time to time. "Theme" is often used in education as a synonym for "topic," as in "The fifth graders studied the theme of 'food' for three months, including farming; cooking; digestion; and stories, paintings, and songs about food." Organizing the curriculum this way may or may not be helpful, but for Project 2061, the terms "common themes" or "cross-cutting themes" are used to mean something very different. Themes are not artful headlines for collections of loosely related topics, rather they are underlying ways of thinking that cross disciplinary boundaries and prove fruitful in making sense of phenomena that appear to be quite diverse. In the *Science for All Americans* and *Benchmarks* Chapter 11: Common Themes, thematic ideas are presented under four headings: Systems, Models, Constancy and Change, and Scale, each with several subheadings. (This organization is neither unique nor necessarily complete, and the subheadings could be arranged differently or even treated as distinct themes in their own right.)

Working in the collaborative manner outlined earlier, high-school teachers of earth and space science, biology, chemistry, and physics, middle-school general-science teachers, and science-interested elementary teachers as well, can select one theme to build into their respective courses. It is important not merely to provide examples of the theme in each course, but also to make explicit the connections among them. Another crucial step not to be overlooked is to select what content will be removed from each course to make room for emphasis on the theme. As the usual cycle of debriefing, modification, and expansion continues and confidence builds, the results should be shared with colleagues in the school district and even written up for publication in appropriate journals such as *The Science Teacher, American Biology Teacher, Journal of Chemical Education, Physics Teacher,* and *Journal of Geological Education*.

In *NSES,* themes similar to these appear under "Unifying Concepts and Processes" at the front of each grade-range content recommendation.

For easy reference, Chapter 11: Common Themes from *Science for All Americans* is reproduced on *Designs on Disk*, along with examples of where each of the *Science for All Americans* themes can be introduced into science courses.

Among Science, Mathematics, and Technology

Science literacy calls for an understanding of the scientific enterprise as a whole, not just of the natural-science disciplines. In the Project 2061 view, this understanding includes science, mathematics, technology, and their interconnections. Hence a curriculum that claims to address science literacy needs to find a way to illuminate some of the vital connections between science and mathematics, science and technology, and technology and mathematics. This goal can be accomplished by exchanges of content, the use of common themes, and drawing on history.

Content exchange. Exchanges can be carried out by separate pairs of teachers—science/mathematics, mathematics/technology, technology/science—or by a group of teachers representing all three domains. The basic idea is to use *Science for All Americans* and *Benchmarks* to identify contexts in the curriculum in which subject matter can be shared naturally and with relative ease.

Additional materials can be found in the *NSES* content standards section Science and Technology and in its Program Standard C on coordinating science and mathematics.

Ideally, the exchanges will go in both directions. For example, when middle-school mathematics teachers focus on different forms of graphing, they could use data provided by the science and technology teachers. Alternatively, the mathematics students could undertake science or technology activities that would generate real data for graphing. In turn, the science and technology teachers would agree to have those same students apply their developing graphing skills in laboratory and shop activities. (Even better, the teachers would plan together a study that would serve both subjects well.) Record keeping and debriefing would proceed as before as the number of exchanges grows gradually and without major disruptions of the curriculum.

The School Science and Mathematics Association has published several collections of materials in its monograph series Classroom Activities and Topics for Teachers (see Bibliography).

The situation is often different in the elementary grades because of the absence of departments and the prevalence of self-contained classrooms. Many teachers in the early grades do not feel comfortable enough in science and mathematics to stray far from the textbooks, and may not delve into technology at all. Still, they have greater flexibility in the use of time and they are less hemmed in by discipline traditions. Since mathematics is regarded as a high-priority subject in elementary education, a productive approach is for a committee of interested teachers to look for science and technology activities that provide interesting occasions for students to apply and extend the mathematics they are learning. There is no shortage of such activities. The School Science and Mathematics Association has amassed a large collection of such activities over many decades. Several publishers have developed a variety of interdisciplinary resources, including the Lawrence Hall of Science's *GEMS* units and the AIMS Education Foundation's activities. The task in considering any of these materials is, of course, to select ones that lead toward specific learning goals for all the subjects.

Themes. The themes from *Science for All Americans* and *Benchmarks* that are useful for making connections within the natural sciences—models, systems, constancy and change, and scale—are equally useful for linking science, mathematics, and technology. Although they are sophisticated concepts that may find their greatest value in the upper grades, modest beginnings toward them (as suggested in *Benchmarks*) can be made quite early.

After agreeing on a theme, a small group of teachers from different subject areas can identify contexts for developing, illustrating, or making explicit the theme. For the theme "models," biology students could examine the practice in medical research of using mice and other laboratory animals as stand-ins for humans, technology students could explore the ways in which scale models are used in architecture and manufacturing, and mathematics students could be introduced to the idea of mathematical models using computers. Students should reflect on all of these activities together, looking for specifics of how they are alike and different in the ways models are used.

History of science, mathematics, and technology. History is potentially a powerful unifier of science (natural as well as social), mathematics, and technology education. History provides many examples of how technological innovations have fostered whole new lines of scientific research, how scientific knowledge has led to the development of entirely new technologies, and of how mathematics has played an essential role in the advancement of scientific disciplines and technological fields.

Generalizations about these interdependencies will mean little to most students, however, unless they are generously supported by concrete, understandable examples. The episodes in *Science for All Americans* Chapter 10: Historical Perspectives provide some examples—such as linking germ theory to geometric growth of populations and to public sanitation—and should therefore be seriously considered when looking for ways to bring greater conceptual coherence to the high-school science curriculum.

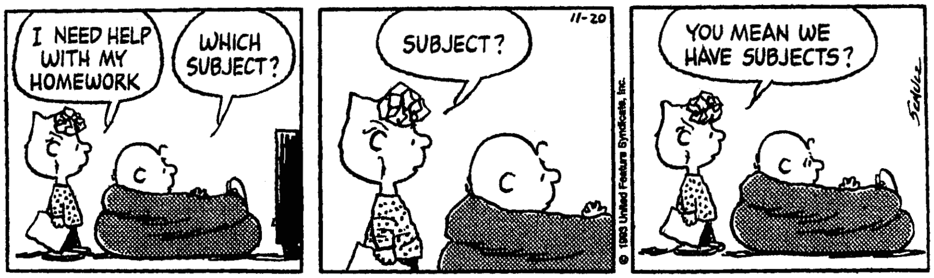
With Other Subjects

In his famous 1959 lecture "The Two Cultures and the Scientific Revolution," C. P. Snow argued that there is a large and widening chasm between the sciences and humanities. Not all observers are as convinced as Snow was of the danger of the cultural separation, but few would claim that a reconciliation is near at hand. Still, a well-balanced curriculum committed to general education for all students can find ways to show that the various domains of learning are not remote islands of human thought and action, and indeed they can inform and complement each other. Eventually, it may happen that the pool of curriculum building blocks available to teachers will make it possible for curriculum designers to select some blocks in which imaginative developers have found ways to do that.

Science and general history. *Science for All Americans* recommends that student learning goals include knowledge of some specific episodes in the history of science. Two reasons are given: (1) without concrete examples, generalizations about how the scientific enterprise operates are empty slogans, however well they may be remembered; (2) some episodes in the history of the scientific endeavor are of surpassing significance to our cultural heritage, being milestones in the development of thought in western civilization.

The *Science for All Americans* recommendations, however, do not specify how those episodes in the history of science are to be taught, or by whom. A strong case can be made that high-school science and history teachers ought to share the responsibility. The problem with this prescription is that usually neither science teachers nor history teachers are well prepared in the history of science, few of them ever having taken even one course in it. Moreover, with few exceptions, science textbooks treat history superficially if at all, and history textbooks largely ignore the impact of science on the world.

Nevertheless, a collaboration between history and science teachers could well lead in time to some fruitful curriculum connections—on the one hand, to presenting science in a context of social history and, on the other hand, to getting the science correct and complete enough, and at an appropriate developmental level. A good way to begin would be for a group of science and history teachers in a high school—or elementary teachers who have comparably different specializations—to examine one of the ten *Science for All Americans* history-of-science episodes in detail. The purpose should be to first understand the material and then decide on how to teach it. References to and descriptions of background reading can be found in the Science



Peanuts by Charles M. Schulz

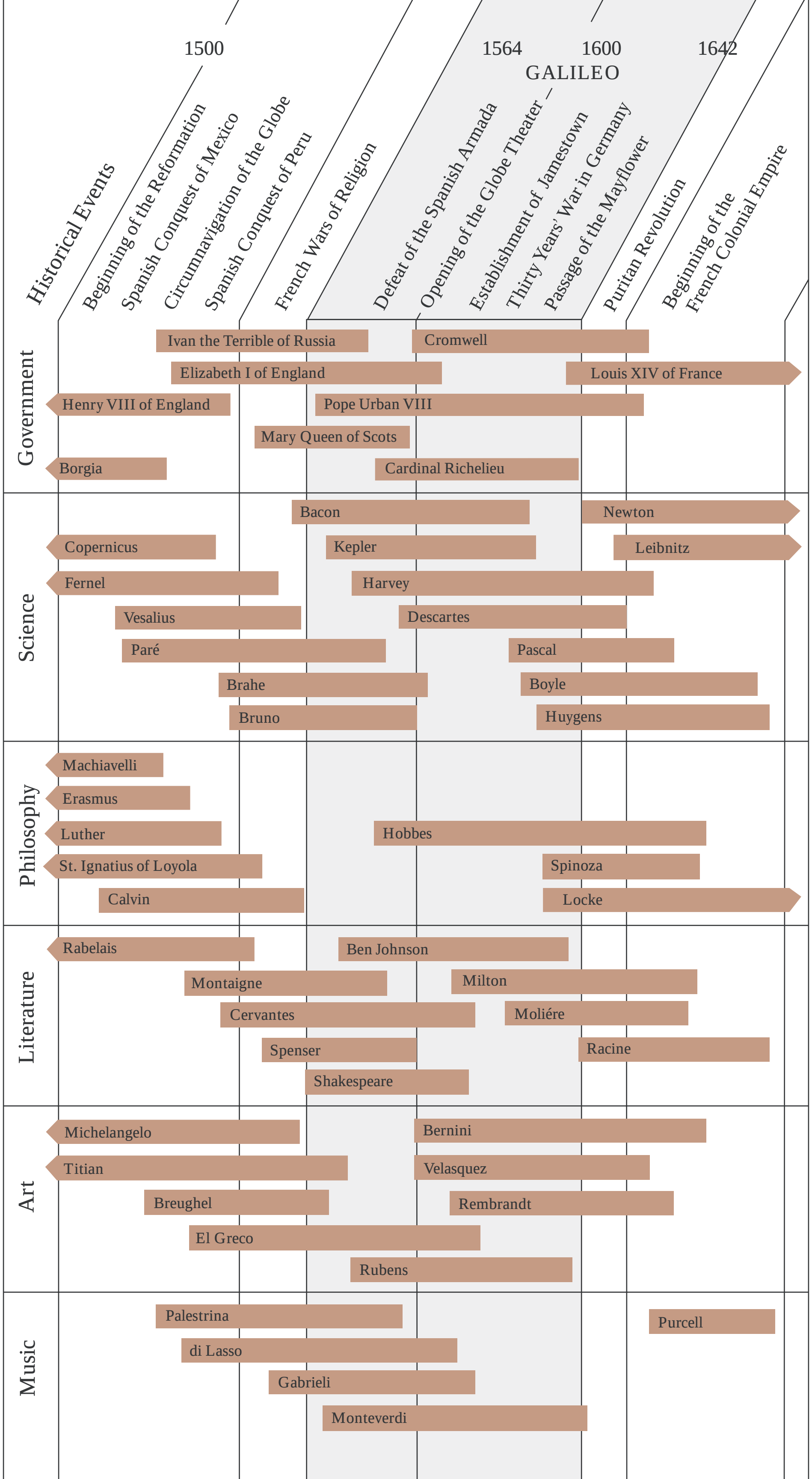


Chart of major cultural figures, in multiple fields, around the time of Galileo. This chart in the *Project Physics* high-school textbook was one of six, which centered on 300 B.C., and on 1500, 1600, 1700, 1800, and 1900 A.D.

Section headings for *Science for All Americans* CHAPTER 10: HISTORICAL PERSPECTIVES suggest the significant discoveries and changes that have shaped scientific knowledge:

- Displacing the Earth from the Center of the Universe
- Uniting the Heavens and Earth
- Relating Matter & Energy and Time & Space
- Extending Time
- Moving the Continents
- Understanding Fire
- Splitting the Atom
- Explaining the Diversity of Life
- Discovering Germs
- Harnessing Power

Trade Books component of the *Resources for Science Literacy: Professional Development* CD-ROM and also on *Designs on Disk*.

Once there is comfort with the episode on both sides, the study group should take up the instructional and curricular issues. Obviously the discussion should take account of the standards that have been written for history that would be relevant to that episode. After deciding which aspects of the episode will be introduced in which courses, the responsible teachers can then develop instructional plans to share with the group. Conceptually, different aspects of an episode can be treated in different courses, if scheduling allows the same group of students to be reached. The usual sequence of debriefing, modifications, and expansion should follow. The box on the previous page is an example of a time chart taken from a physics textbook that shows some possibilities for using historical events or figures to make cross-subject connections.

Science and social studies. Social-*studies* courses are usually not social-*science* courses, but there is every reason to call for greater interaction between the two. Social studies is becoming ever more quantitative, borrowing social-science methods and data (from sample surveys and demographic studies, for example) and using mathematics (especially statistics and probability, tables and graphs) to analyze data and display findings.

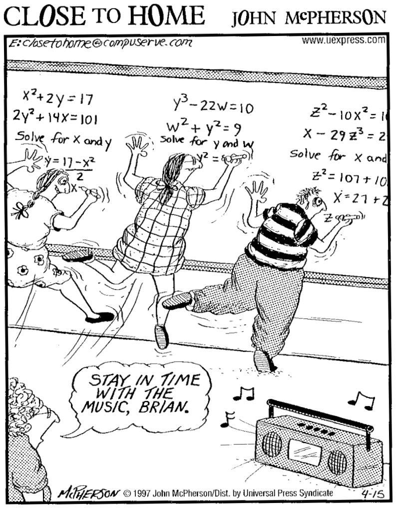
Drawing on the national mathematics education standards and on *Benchmarks* (Chapter 9: The Mathematical World and Chapter 12: Habits of Mind) and following the earlier described pattern of study, development, implementation, debriefing, and modification, a team of mathematics and social-studies teachers can begin introducing useful connections in both courses. For example, a mathematics teacher could use census and survey data from a social-studies course in teaching some aspect of data analysis—say, alternative ways to describe groups statistically. And a social-studies teacher could agree to have students use mathematical techniques, perhaps graphing, to look for relationships between variables from a mathematics course. Descriptions of outcomes, of course, would be made available to everyone in the school district.

In parallel, groups of social-studies teachers from as many different grades as possible can start with *Benchmarks*, one group using Chapter 7: Human Society, another group Chapter 8: The Designed World, and a third, the Critical Response Skills section from Chapter 12: Habits of Mind. In each case, the purpose would be to see if there are ways in which the ideas in *Benchmarks* can be used to flesh out some of the social-studies goals and strengthen the ties between the natural and social sciences. In return, science teachers could collaborate with social-studies teachers to devote some attention to social issues involving natural science, such as genetic engineering, costs of research, and environmental quality. This collaboration need not lead to team teaching but should involve cooperation in identifying topics and working out an instructional plan.

Science and literature. Science and English teachers can begin by exploring possibilities for collaboration without making a commitment in advance to introduce changes in their courses. They could read and discuss a book such as Swift's *Gulliver's Travels*, Wells's *The Time Machine*, Ibsen's *An Enemy of the People*, Camus' *The Plague*, Brecht's *Galileo*, or Vonnegut's *Galapagos* to see if they could reach agreement on how a science background could improve student responses to literature and vice versa. Science fiction (other than purely space melodrama) often raises interwoven issues of technology and society or uses a technological excuse to speculate about societal possibilities. Alternatively, the groups could go over benchmarks from the *Benchmarks* sections The Scientific Enterprise, Health Technology, or Values and Attitudes to see what literary works they bring to mind. After trying out some of their ideas, the group could prepare reading lists for students of various age levels recommending works of fiction that are relevant to both science and English, along with suggestions for teachers on how to use such readings.

Science and physical education. Physical education has long had a place in the curriculum for its presumed ability to foster lifelong habits of good health. In the lower grades, the connection between exercise and good health is easy to make because only one or two teachers are involved, but in the upper grades it is not uncommon for physical-education teachers and life-science teachers to collaborate informally. Unfortunately, physical education is rarely exploited in behalf of mathematics education—a lost opportunity.

Because it is a natural source of quantitative data, physical education provides an excellent and interesting context for helping students practice mathematics and become aware of its applications in everyday life. In a cooperative venture for which data collection is carefully planned, students could keep data on themselves (height, weight, temperature, heart rate, etc.) and their performance in different sports events (running different distances, jumping, throwing, lifting, etc.). As data accumulate, they can be analyzed and graphed to show distributions, correlations, trends, and cycles. And if students also keep records of how much they practice, or other factors that they believe affect their performance, the analysis becomes all the more interesting. Individual information can be transferred anonymously to a collection so that



In an effort to emphasize both physical fitness and academics, officials at Westbury High devised aerobic algebra.

population data can be used in mathematics classes to develop skills in data analysis, without possible embarrassment to individual students. Ideally, computers would be available in the gym so that students could easily record data in their own secure files for later (private or collective) use; but computers are not absolutely essential.

Science and the arts. Using *Benchmarks for Science Literacy* and *National Standards for Arts Education*, teams of science teachers and of teachers in each of the arts (dance, music, theater, and the visual arts) can collaborate to identify connections. Concrete connections occur in the science of sound (for example, how wave patterns differ for different instruments, acoustics of theaters), the science of light (pigments, shadows, aerial perspective), and the science of motion (forces involved in balance, starting, and stopping). In Chapter 11: Common Themes and Chapter 12: Habits of Mind of *Benchmarks*, the teams can seek higher-level connections with the arts standards related to creating, evaluating, and responding, and to making interdisciplinary connections. For example, they can introduce students to how modern technology has made possible new media and subjects for artistic expression or to how the ways in which scientists make scientific choices are similar to or different from the ways in which performing and visual artists make artistic choices. A similar process can be used for identifying connections between the arts goals and the mathematics goals in *Benchmarks* (or the national mathematics standards). The teachers should collaborate, as needed, in planning and in teaching, as well as in evaluating the effectiveness of their instruction.

Science and work. One reason that science, mathematics, and technology education is important to the future of students is that the scientific enterprise is the source of so many kinds of jobs in modern societies today and will in all likelihood be more so in the future. Too many students believe that science in this broad sense is the exclusive province of people with advanced university degrees. As students become interested in what they want to be when they grow up, teachers have the responsibility to inform them of the vast array of different kinds of interesting work (most of which are not at the Ph.D. level) that is possible for them if they keep up in their study of science and mathematics. Teachers should not try to push all students into science-related careers but should do what they can to help students keep their options open as long as possible.

One factor in relating science literacy to work is that many leaders in business have come to believe that career education is much too narrowly focused on particular jobs in the present. More and more, such leaders assert, vocational education fails to meet the entry demands for jobs that have a future—and a rapidly changing future at that. “Training,” it has been said, is for when you know exactly what people will be doing; “education” is for when you don't. In the ever more rapidly changing workplace, specific school training for highly specific jobs makes less sense. If more and more jobs require flexible and generalizable skills—such as the ability to reason, communicate, cooperate, learn new systems, and ask and find answers to questions—then the best vocational training starts to sound very much the same as the best general education.

Another factor in relating science literacy to work is that science and mathematics courses in the upper grades of high school focus so strenuously on what is seen as preparation for college; undecided students or those headed into the workforce after graduation avoid them. The curriculum has been such in most school districts that fewer than half of all high-school graduates have taken courses in chemistry, physics, and mathematics beyond algebra. Science and mathematics courses that are typically strongly academic in tone may not even prepare students well for college, and rarely point to the full range of jobs that science and mathematics make possible even without a college degree.

Teachers of vocational subjects can join with teachers of science and mathematics to improve the curriculum for all students. The former can introduce more science and mathematics in their courses, and they can encourage vocational education students to continue taking academic courses. Science and mathematics teachers can introduce career applications and information into their courses, and they can find ways to make those courses more interesting and accessible to students who may be headed to work after graduation rather than to college.

Some of the best experiments in bridging academic and career domains have been attempted by technology educators. The explicitly technological sections of both *Science for All Americans* and *Benchmarks*—Chapter 3: The Nature of Technology and Chapter 8: The Designed World—should provide opportunities for joint planning by science and technology teachers, following suggestions made earlier in this chapter. Also, Chapter 11: Common Themes and Chapter 12: Habits of Mind include directly relevant material.

This chapter, which could well have been expanded into a book of examples, completes the current account of Project 2061 ideas about curriculum reform. In the Epilogue that follows, we revisit some of the potentially controversial highlights.