CHAPTER 7
UNBURDENING THE CURRICULUM

CUTTING MAJOR TOPICS

PRUNING SUBTOPICS FROM MAJOR TOPICS

TRIMMING TECHNICAL VOCABULARY

REDUCING WASTEFUL REPETITION

THE CHALLENGE

Time in school for teaching and learning is not limitless. Yet many textbooks and course syllabi seem to assume otherwise. They include a great abundance of topics, many of which are treated in superficial detail and employ technical language that far exceeds most students' understanding. And even as new content is added to the curriculum—little is ever subtracted—students are being asked to learn with greater depth. Rarely is more time made available for accomplishing this. Coverage almost always wins out over student understanding, quantity takes precedence over quality.

Many decades of overload have shaped curriculum, textbooks, tests, and teacher expectations into an industry of superficiality. Many teachers know, or at least suspect, how little their students understand, but do not know how to transform the system. Lengthening the school day and year and reducing the number of different subjects students study are obvious though apparently unpopular remedies for the mismatch between curricular time and content, but in any event would not by themselves solve the problem.

Another remedy sometimes proposed is to move concepts lower in the grade sequence, thereby leaving time free in high school for students to learn better what they study. That would be a tenable ambition if high-school students were learning those ideas well now. Because they are not, however, it is no more than wishful thinking to believe that younger children will be able to learn what older children apparently do not.

Improvements in teaching methods and curriculum design may eventually make it possible for students to learn more than they do now, hour for hour, but the current and critical need is for them to acquire at least some important knowledge and skills better, even at the price of covering fewer topics overall. This chapter describes four strategies aimed at reallocating time—time to focus on understanding important facts,

Some researchers in science education estimate that even good students understand and retain only a small fraction of what they study. As disturbing as this claim is, there is a great deal of research—on school children, college students, and adult citizens—that substantiates it. See *Benchmarks* CHAPTER 15: THE RESARCH BASE.

The pernicious effects of an overstuffed curriculum is one of the major messages in the Third International Mathematics and Science Study (TIMSS) reports of 1997-1998.

principles, and applications in science, mathematics, and technology, not time to enable still more material to be superficially covered. The underlying purpose is to realize a better cost-to-benefit ratio, using time and resources in ways that will maximize students' eventual science literacy. The strategies are:

- Reduce the number of major topics taught.
- Prune some topics by removing unnecessary details.
- Limit technical vocabulary to essential terms.
- Eliminate wasteful repetition.

Cutting Major Topics

Although the ambiguous meaning of "topics" is addressed later in this chapter, what this section says holds for almost any of its meanings.

The case for reducing the number of different topics taught in science, mathematics, and technology is straightforward. A basic message from research on how children learn science is that (1) many science concepts are inconsistent with children's beliefs about how the natural world works, and (2) for children to understand science concepts often requires that they wrestle with how those concepts are more satisfactory than their own current beliefs. Learning science effectively, therefore, requires direct involvement with phenomena and much discussion of how to interpret observations. Moreover, it requires encountering the intended concepts in a variety of contexts and successively more adequate formulations—activities that obviously take time.

Thinking about Major Topics

Of course there is a trade-off to be made. The argument here is to give up some "coverage" to enable students to gain an understanding of key ideas. According to TIMSS researchers, the state curriculum guides they sampled in 1993 for their study "included so many topics that we cannot find a single, or even a few, major topics at any grade that are the focus of these curricular intentions. These official documents, individually or as a composite, are unfocused. They express policies, goals, and intended content coverage in mathematics and the sciences with little emphasis on particular, strategic topics." (Schmidt, McKnight, & Raizen, 1997). It is true that teachers already regularly eliminate topics from the overload in their textbooks—sometimes by not getting to the final chapters, sometimes by skipping chapters that are too difficult for many of their students (or are troublesome for some community or personal reason). Clearly there are some undeniable limits to how much students can be expected to study even superficially.

Deciding what topics to keep and what to give up was the task undertaken by Project 2061 in a three-year study involving hundreds of the nation's leading scientists and educators. Their work resulted in *Science for All Americans*, a statement of the knowledge and skills students should have by the time they graduate from high school. *Science for All Americans* was followed by a four-year study involving an even larger number of scientists and educators that led to *Benchmarks for Science Literacy*, a statement of what students most need to learn as they progress through school. The bar graphs in the box on the following page show the number of ideas included in *Benchmarks* that are also found in the traditional science curriculum that almost everyone is exposed to. Whatever minor uncertainties there may be in the count, it is evident that well over half of the traditional curriculum content was omitted from the recommended core.

In determining what topics to exclude, Project 2061 developed two basic criteria for evaluating candidate topics. A topic was not included in either *Science for All Americans* or *Benchmarks* if there were no compelling argument that it would be essential for science literacy, or if its importance were judged to be out of proportion to the amount of time and effort that would be needed for all students to learn a coherent set of concepts about it.

For example, Project 2061 took a close look at the topic of electrical circuits. This happens to have been the subject of considerable research on students' learning difficulties, in terms of both the necessary input of learning effort and the likely output of fruitful knowledge.

On the input side, how learnable are circuit ideas? Some researchers have spent their careers trying to understand why students—from elementary school to college—have so much difficulty in understanding not just the differences in behavior of series and parallel circuits, but even the very notion of what a circuit is. Even when researchers have thought they understood the nature of students' difficulties and misconceptions, they still have had trouble figuring out how to overcome them. So, at best, a great deal of extra classroom time would have to be spent on getting students to understand electrical circuits.

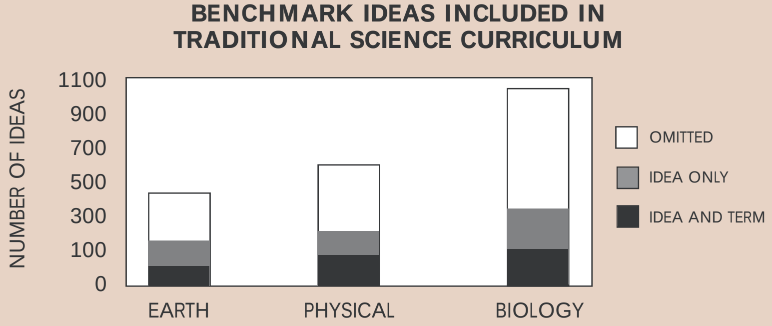
On the outcome side, how important is it to science literacy for students to understand electrical circuits? The judgment has to be made on the basis of the importance of that knowledge itself, the prior knowledge required to learn it, and what other knowledge it will lead to or support. By itself, electrical circuitry does not have much to offer science literacy. Practical knowledge of electrical circuits may be required for students who will specialize in physics or engineering, and it would also be of value to

Electric Currents

"Grades 6-8: Electric currents and magnets can exert a force on each other.

Grades 9-12: Magnetic forces are very closely related to electric forces and can be thought of as different aspects of a single electromagnetic force. Moving electric charges produce magnetic forces and moving magnets produce electric forces. The interplay of electric and magnetic forces is the basis for electric motors, generators, and many other modern technologies, including the production of electromagnetic waves."

—*Benchmarks for Science Literacy,* p. 95 and p. 97



In developing *Benchmarks for Science Literacy,* a count was made of ideas found in a traditional textbook series—physical science, earth science, and biological science—that approximate the science curriculum to which all students are exposed. “Ideas” were defined as boldface subsection headings in the text and/or glossary entries.

Through eliminating, pruning, and trimming (as described in this chapter), fewer than half of these ideas were retained as essential to basic science literacy. The black areas in the bar graphs above indicate the number of instances in which both the idea and the technical term for it were included in *Benchmarks*. The gray areas indicate the number of instances in which *Benchmarks* included the idea, but not associated technical terms judged to be unhelpful to understanding or required for science literacy. The white areas indicate the number of ideas that were not included explicitly in *Benchmarks.*

The reduction in biology is particularly striking. In some areas, *Benchmarks* has effected a wholesale reduction of myriad details in favor of understanding general principles. The most dramatic example deals with the characteristics of different phyla, represented in three grade 6-8 benchmarks:

- One of the most general distinctions among organisms is between plants, which use sunlight to make their own food, and animals, which consume energy-rich foods. Some kinds of organisms, many of them microscopic, cannot be neatly classified as either plants or animals.
- Animals and plants have a great variety of body plans and internal structures that contribute to their being able to make or find food and reproduce.
- Similarities among organisms are found in internal anatomical features, which can be used to infer the degree of relatedness among organisms. In classifying organisms, biologists consider details of internal and external structures to be more important than behavior or general appearance.

Some textbooks devote hundreds of pages to conveying these concepts, but in no way do the benchmarks themselves justify keeping all of this detail (other than as reference material for students studying chosen aspects of differences).

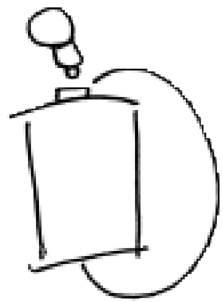
do-it-yourselfers to understand what is happening in, say, a three-way switch arrangement, but even they would be well advised to follow standard wiring diagrams rather than figure it out on their own.

On the other hand, the idea of an electric current plays an important role in science literacy because of its relationship to magnetic fields in electric motors, power generators, Earth's magnetic field, and more. For those links, however, less need be known about currents than is necessary for making sense of series and parallel circuits. The marginal note on page 213 presents the benchmarks for grades 6-8 and 9-12 that are relevant to an understanding of electric currents.

Project 2061 concluded, therefore, that series and parallel electrical circuits as a subject was best left out of the goals for the core science curriculum on the grounds that it would require a high instructional cost and provide a low payoff. Paradoxically, one of the most popular instructional units among elementary- and middle-school science educators is the hands-on science activity "batteries and bulbs," in which students investigate series and parallel circuits. It may be that this engaging activity can be adequately justified by its contribution to understanding scientific reasoning—hypotheses, evidence, modeling, observation, and so on—even if students are not likely to retain knowledge about series and parallel electrical circuits. And of course any student with an interest in electrical or electronics technology ought to have some opportunity outside of the common core to study circuits. In any case, the point here is not to single out conclusions about the topic of electrical circuits for special attention but to illustrate the kind of analysis that is needed in deciding which topics ought to be included and which left out.

Understanding electric circuits is problematic for most students, even in college. In the videotape *Minds of Our Own* (Harvard/Smithsonian), researchers feature recent MIT graduates who are unable to light a bulb with a battery and wire. One student's drawing below illustrates a typical misunderstanding.

There are similar findings for Harvard University and MIT graduates unable to explain photosynthesis, seasons, or molecules.



A Process for Cutting Topics

There are few substantive differences between what is included in the content recommendations of AAAS (Project 2061's *Benchmarks*) and those of the National Research Council (*National Science Education Standards*) for what all students should learn. Yet neither organization explicitly states which topics can prudently be eliminated from the basic science-literacy core. Rather, they recommend what knowledge and skills are to be learned, leaving it to teachers and curriculum developers to decide which topics to have students study to achieve those learning goals. The following box explores this important distinction further. The process of reaching a consensus on which topics to eliminate is itself an effective way for teachers to clarify those distinctions in their own minds.

Designs on Disk can help teachers select topics to be dropped from the core curriculum in science, mathematics, and technology by providing appropriate databases and record-keeping forms.

There is an important distinction between "topics" and "learning goals."

"TOPICS"

The word "topic" carries several meanings in teaching and distinguishing among them is important for following *Designs for Science Literacy* in general and this chapter in particular. Its ambiguity carries risk for misunderstanding curriculum design.

"Topic" as a category of learning goals. One meaning is a heading in an outline of goals or instructional materials—for example, "Cells." There are a great many different facts, ideas, and principles that could be taught or tested under the topic heading "Cells," and the heading by itself gives little or no clue as to what will be included or what is most important. Yet, in the context of a well-established curriculum, topic headings may imply a particular collection of ideas traditionally included under those headings. The heading "Cells," for example, would typically include the names of nucleotides A, C, G, and T, transfer RNA, and endoplasmic reticulum—none of which is in *Benchmarks for Science Literacy.* At one time, Project 2061 considered deliberately avoiding such familiar headings, in the worry that people would read into them the full list of traditional details, in addition to the specific important ideas that were intended. (That is still a worry.)

Obviously, topic headings are not in themselves pernicious. But unless learning goals get more specific than topic headings, they can seriously undermine less-is-better reform, by allowing everything in the current curriculum to be stuffed back in under one heading or another. For that reason, topic headings, though obviously necessary, are viewed with suspicion by Project 2061.

"Topic" as a context for learning. Another meaning of "topic" is something that students study. When students are asked what they are currently studying in school, their answer is likely to be the topic in this sense. Examples include "lakes," "earthquakes," "environmental pollution," "paper," or "bridges." They may be studying one of these topics, not necessarily because it is important to learn about in itself, but because it provides opportunities to learn and use some ideas and skills that are important. So, for example, in studying "paper making" (to which there are no direct references in *Benchmarks*), students may learn about measurement, experimental design, materials and manufacturing, the side effects of technology, communication, and other learning goals for which *Benchmarks does* indeed specify particular learning goals.

Topics as headings are more likely to be discipline divisions (chemical equations, heredity, or multiplication). Topics as learning contexts are more likely to be phenomena (lakes or earthquakes), events (the Olympics or exploring space), or societal issues (health care or environmental pollution). But some topics can be both – "Cells," "Nuclear Power," and "The Solar System," for example, come with their own benchmarks and also provide opportunities to learn.

A "topic" can mean a set of learning goals (such as understanding plant classification) or it can mean a teaching unit (such as "Rainforests"). And of course it often can be both, when a familiar teaching unit has some obviously associated goals—such as a unit named "Electromagnets," which implies both a familiar set of ideas to be learned and relevant activities with batteries, wires, and nails. So "dropping a topic" may mean giving up on a set of expectations for what students will learn, or forgoing a set of customary teaching activities, or both. But whatever the overlap between goals and activities for a particular "topic," the recommendation in this chapter is the same: to hold it up against benchmarks and consider dropping it if its true cost is too high compared to its learning benefits.

These comparison tables can be formatted for sharing electronically by using *Designs on Disk*. A computer utility for making such a comparison is available from Project 2061.

To begin eliminating whole topics from the core, faculty teams in science and mathematics for each grade or grade band could be challenged to drop one major science topic and one major mathematics topic from the curriculum in the next semester. The teams should then go through the following step-by-step process:

1. Discuss the distinction between (1) "topics" as categories of goals for what students will end up knowing or being able to do, and (2) "topics" as contexts for learning, rather than content to be learned. (They could consider just not using the word "topic" for one or the other of those meanings, but the word is so firmly embedded in education discourse that it is best to wrestle with it for a while.)
2. Begin with a list of topics in the current curriculum (often textbooks can serve as proxies for the curriculum) and indicate whether there are learning goals in *Benchmarks* that match. The various teams in the district can share and compare lists.
3. As the number of items on the lists grows, begin to make a master list of topics to be considered for elimination from the core. The criteria for making such judgments would, of course, have to take into account any pertinent district or state requirements.
4. From the list of candidate topics for elimination, each team member selects one topic to drop and identifies a core topic in which to invest the additional time made available.
5. Each team member evaluates the effect of dropping one topic and spending more time on another. It may be useful to consult with teachers in later grades about their expectations for what their students should already have learned. (Since those teachers too are struggling with the importance of topics, their advice is desirable but not definitive.) In each instance, after full discussion, the faculty team decides whether to recommend that other teachers in the district also drop the topic in question from the basic science and mathematics core.

The evident overcrowding of the curriculum may be sufficient motivation for many teachers to undertake the kind of topic-reduction process described here. More motivation can be generated by viewing and discussing videotapes in the Annenberg/CPB Multimedia Collection that demonstrate how easy it is to overestimate what students learn. Information on this collection can be found on *Designs on Disk.*

Ideally, an evaluation of trade-offs associated with cutting topics would also consider what students had learned in the time saved. Good use of freed-up time is far from a trivial task in itself and is brought up again at the end of this chapter.

The five-step process is then repeated, involving more teachers and topics as confidence in the process grows and as the benefit of spending more time on fewer topics becomes apparent—and also as it becomes clear that there are no terrible side effects associated with the process.

This gradual approach to topic elimination is manageable and not terribly risky, since action is based on careful group analysis and is limited in scope. It does not threaten to strip teachers summarily of their favorite topics or to mandate wholesale changes in curriculum content. But it is intended to begin a systematic process of thought and action that stresses basing topic decisions on intended learning outcomes, takes benchmarks and national standards seriously, and tries out ideas on a small scale before making recommendations for districtwide implementation.

It is undoubtedly painful to eliminate familiar, even beloved, parts of instruction. As one teacher said, "I have to teach gas laws. I have always taught gas laws. I like to teach gas laws." Curriculum conservationists often ask, "How can you leave out important topic X?" But, since resources are limited, two other questions also need to be asked: "How long does learning X take?" and "What topics would you like to leave out to make room for X?"

Some educators are against taking any topics at all out of the current curriculum, and indeed, would like to add more, which often requires pushing topics into ever lower grade levels. Project 2061 would hope that the educators make sure that students learn at least the ideas in *Benchmarks*. If they do, the project is happy to have them learn any additional number.

The box opposite lists topics that appear in traditional textbooks yet do not contribute toward students' achieving the learning goals specified in *Benchmarks* or *National Science Education Standards* (*NSES*). Although these topics conceivably could be treated in a way that would serve related benchmarks, they were not treated that way in the textbook they appeared in. There remains the possibility that any one of these topics, as in the instance of electrical circuits, could be studied in a way that would carry benefits for achieving "process" goals—say, those in the *Benchmarks* chapters The Nature of Science or Habits of Mind.

Many of the listed topics could also constitute advanced work for students who understand the basic ideas in the core. But claims of promoting higher-order thinking cannot be used as a justification for any topic whatever without considering the efficiency of the experience. One should ask, for example, how much of the time devoted to batteries and bulbs promotes learning scientific reasoning, how much goes into the

TRADITIONAL TOPICS TO CONSIDER EXCLUDING FROM LITERACY CORE

Here are some topic headings taken from typical textbooks under which few (if any) relevant benchmarks could be identified:

from a typical **Physical Science** textbook

Gas Laws
Periodic Table
Properties of Solutions
Acids & Bases
Nuclear Chemistry
Buoyancy
Flight
Work & Power
Simple Machines
Calorimetry
Heating Systems
Refrigeration Systems
Engines
Electric Circuits
Optics
Nuclear Reactors
Mining
Petroleum Processing
Electronics
Computer Hardware

from a typical **Earth Science** textbook

Solar Features
Stellar Evolution
Lunar Features
Atmospheric Layers
Rivers
Geological Eras

from a typical **Biology** textbook

Branches of Biology
Classification System

from typical **Algebra** and **Geometry** textbooks

Rational Expressions
Conic Sections
Matrix Operations
Polynomials
Factoring
Radical Expressions
Fractional Equations
Quadratic Inequalities
Systems of Inequalities
Axiomatic Systems
Locus
Synthetic Methods
Right Triangle Trigonometry
Sets and Truth Tables

Another possible response to this information is to claim that benchmarks and standards are themselves lacking—for example, that simple machines should be part of science literacy. Local educators should always have the option of setting different priorities (though they would be well advised to consider what other ideas should be neglected to make room for simple machines). The main point here is not that the current version of *Benchmarks* is inviolable, but that the argument for including questionable topics has to be linked to specific learning goals, not rest on the mere familiarity of topics.

fundamental notion of a circuit, and how much goes only into a fruitless struggle with series and parallel principles—and whether processes of science could be learned just as well by studying a more important topic.

It should not be inferred that the topics in the list on the previous page are absent altogether from *Benchmarks*. For example, there is nothing explicit in *Benchmarks* about the periodic table as such, but there is the notion of periodicity in elemental properties—that is, that there are families of elements with similar properties and that similar sequences of properties appear when elements are arranged in order of their atomic mass. Similarly, there is nothing about gas laws in their symbolic-quantitative form, but the benchmarks on temperature and molecular motion would likely require experience with compressibility of gases and their increase in pressure when heated.

It is evident from the list that, at least in terms of the traditional way of organizing textbooks, low-priority *major topics* are distinctly easier to identify in physical science than in the more interconnected life science. In the next section, it is evident that low-priority *subtopics* are easier to identify in life science.

Pruning Subtopics from Major Topics

Similar arguments can be made for a less radical adjustment of traditional curriculum content that will leave time for higher-priority learning goals. Part of the curriculum problem is that, in addition to treating too many major topics, the curriculum treats many subtopics within them with excessive detail (relative to the topic's importance for literacy). In addition to eliminating whole topics, therefore, progress can be made by cutting back on the extent and complexity of the treatment of at least some topics. Whereas dropping whole topics can lead to the elimination of whole chapters or units, pruning may correspond loosely to cutting out paragraphs at the subtopic level. The purpose of such pruning is to focus on what is really important to know about a topic rather than on how to make it easier to learn.

It is important to remember that Project 2061 does not claim these topics to be unimportant, only less important than those with higher priority for basic literacy in the limited time available in school.

The following four tables suggest subtopics (for physical, earth, and biological science and for algebra and geometry) that could be considered for pruning from the lists found in a typical set of textbooks intended for all students in grades 8–10. The textbooks themselves (subject to weight limits) could contain all these ideas for students going beyond basic literacy—and as a reference for all. But a full understanding of the most important ideas first will facilitate learning these extras.

SUBTOPICS TO CONSIDER FOR PRUNING

Subtopics in a typical **Physical Science** textbook under which few (if any) relevant benchmarks could be identified

Atomic Structure
Thomson's model
Rutherford model
Bohr model
mass number
shell filling
quarks

Chemical Reactions
network solids
metallic bonds
oxidation number
single replacement
double replacement

Organic Chemistry
structural formulas
isomers
saturated hydrocarbons
alkanes, alkenes, alkynes, cycloalkanes
aromatic hydrocarbons
substituted hydrocarbons
alcohols & hydroxyl group
organic acids & carboxyl group
esters & esterification
halogen derivatives
lipids

Force & Motion
conservation of momentum
sliding vs. rolling friction
free fall
inclined planes

Electrostatics
electrostatic induction
electric discharges
grounding

Electric Circuits
volts, amperes, ohms
Ohm's law
electrochemical cells
electrodes
electrolyte
thermocouple
alternating & direct current
series & parallel circuits
fuses & circuit breakers

Magnetism
magnetic lines of force
magnetic induction
temporary magnets
magnetic variation
magnetic domain
transformers

Sound
intensity, quality, timbre
decibels
fundamental & overtones
resonance
reverberations

Light
polarized light
photoelectric effect
index of refraction
primary & complementary colors
primary & complementary pigments
incandescent & fluorescent
phosphors
neon light

SUBTOPICS TO CONSIDER FOR PRUNING

Subtopics in a typical **Earth Science** textbook under which few (if any) relevant benchmarks could be identified

Ocean Features
variable salinity
surface zone & deep zone
continental margin & shelf
turbidity
fringing reefs
atolls & barrier reefs
intertidal zone
neritic, bathyl, abyssal
tsunamis

Hydrosphere Features
valley & continental glaciers
zone of saturation
zone of aeration

Lithosphere Features
coastal & interior plains
primary & secondary waves
composition of mantle
Mohorovic layer
asthenosphere
hanging & foot walls
normal & reverse faults
thrust & lateral faults
fault-clock mountains
anticlines & synclines
isostasy
surface waves
volcanic dust, ash, & bombs
shield & composite volcanoes
Pangaea
transform faults
divergent boundary
convergent boundary
strike-slip

Rock & Soil
streak
cleavage
extrusive & intrusive rocks
chemical rocks
stable rock
plant acids
carbonation
pore spaces
soil profile
subsoil
loess

Climate
sea & land breezes
doldrums
trade winds
prevailing westerlies
polar easterlies
anemometer
microclimates
glacial & interglacial periods

Fossils
molds, casts, & imprints
trace & index fossils
unconformity
intrusions & extrusions
varves

Fuels & Environment
peat
types of coal
petrochemicals
photovoltaic cells
geothermal
biomass & gasohol
contour plowing & terracing
strip cropping
desertification
desalination
temperature inversion
acid rain
catalytic converters
point and nonpoint sources

SUBTOPICS TO CONSIDER FOR PRUNING

Subtopics in a typical **Biology** textbook under which few (if any) relevant benchmarks could be identified

General
steps for scientific method
branches of biology
specific microscopes
limits of resolution
lab techniques of biologists
chemical vs. physical change

Organic Chemistry
dehydration synthesis
hydrolysis
lipids & saturation
phospholipids & cholesterol
peptides & peptide bonds
nucleic acids & nucleotides
RNA = ribonucleic acid

Cell Structure
nucleolus
vacuoles
plastids
osmosis
facilitated diffusion
active transport
endoplasmic reticulum
Golgi apparatus
lysosome

Cell Energy
photosystems
electron transport
ATP formation
dark reactions
Calvin cycle
glycolysis
Krebs cycle
anaerobic energy production
lactic acid fermentation
alcoholic fermentation

DNA & Protein Synthesis
structure of DNA
base pairing
replication of DNA
RNA and its structure
transcription & translation
A, C, G, T
double helix

Cell Growth & Division
rates of cell growth
controls of cell growth
phases of mitosis
cytokinesis
chromatin
chromosome structure
centriole & spindle

Genetics
self- & cross-pollination
dominant & recessive
segregation
F1 cross
Punnett square
homozygous & heterozygous
two-factor cross F1 & F2
phases of meiosis
crossing over

Genes & Chromosomes
chromosomes
linkage groups
sex linkage
X, Y chromosomes
sex determination
sex-linked genes
chromosome mutation types
point mutations
frameshift mutation
dominance & codominance
polygenic inheritance
operon & operator
promoter, inducer, repressor
eukaryote gene expression
exons & introns

Human Genetics
human blood groups
Huntington disease
sickle cell anemia
sex determination
sex-linked genetic disorders
sex-influenced traits
chromosomal abnormality
genome

Ecology
climax community
nitrogen fixation & cycle
denitrification

Populations
“exponential” growth curve
logistic growth curve
carrying capacity
density-dependent limiting
density-independent limiting

Evolution
eras, epochs, & periods
gaps in fossil record
quality of fossil preservation
relative & absolute dating
reproductive isolation
gradualism
mass extinction
adaptive radiation
divergent & convergent
early atmosphere
microfossils
anaerobes

SUBTOPICS TO CONSIDER FOR PRUNING

Subtopics in typical **Algebra** and **Geometry** textbooks under which few (if any) relevant benchmarks could be identified

Rational Expressions
- simplifying rational expressions
- rationalizing the denominator
- operations on rational expressions

Factoring
- factoring polynomials
- solving quadratics by factoring

Matrices
- operations on matrices

Polynomials
- multiplication of polynomials
- division of polynomials
- FOIL method

Radicals
- simplifying radical expressions
- operations with radicals
- solving radical equations

Logarithms
- solving logarithmic equations
- converting bases

Axiomatic Systems & Proof
- incidence & betweenness theorems
- two-column proofs
- synthetic methods

Circles
- theorems about ratios of segments, tangents, and chords
- theorems about angles formed by tangents and chords

Vectors
- operations

Sets
- Venn diagrams
- union & intersection operations and properties

Angles and Polygons
- alternate exterior angles
- oblique polyhedra
- polyhedral angles
- reflex angle
- trapezeum
- Heron's formula

Thinking about Subtopics

With regard to electric circuits, for example, one could give up on the time-consuming distinction between series and parallel, on the quantitative relation $I=V/R$, and even on the distinction between voltage and current, and focus instead on the centrally important principle that electric circuits require a complete conducting path. (The complete circuit idea is difficult enough in itself, as the ample research on students' electrical misconceptions shows.) Similarly, in teaching about DNA and protein synthesis, it should be enough to concentrate on helping students to understand that cells construct proteins according to instructions coded on DNA molecules without teaching them about introns, exons, A, G, C, T nucleotide codons, and messenger, transfer, and ribosomal RNA—details that are found in nearly all introductory high-school biology textbooks and many middle-school ones. Although a few students are fascinated by and eager to learn about the complexity of the actual mechanism, many more students are intimidated by it; they barely remember the details long enough for a test and, even worse, never get the general idea at all.

The optimistic notion that students may forget the details but remember the basic idea is rarely supported by research findings. Yet some details are surely necessary to make the basic ideas intelligible and plausible in the first place. How many and which details, and how they are best tied to the basic ideas, are issues that are waiting to be demonstrated by more focused research on learning. It seems likely that the optimum solution will include frequent reminders of how the details relate to the big ideas.

Science for All Americans and *Benchmarks for Science Literacy* are as concerned with the level of understanding of topics in science, mathematics, and technology as they are with which particular topics are essential. The Project 2061 recommendations have been painstakingly worded to signal the level of understanding that is sufficient for purposes of general science literacy, and they agree extensively with the *National Science Education Standards* on what those expectations are. Of course, many students will go further and deeper into at least some topics.

The general similarity in pruning topics implied in *Benchmarks* and in *NSES* sends a strong signal from the scientific community that teachers would do well to focus on student understanding of key ideas. The reports do not argue against the introduction of detail in teaching, nor argue in favor of having students memorize only vague generalizations. Just the opposite. Teaching should present key topics with enough concrete detail and hands-on involvement to make them interesting and memorable, but not with so much that the main ideas are obscured and that students believe that memorizing a collection of details or carrying out a collection of steps constitutes understanding those ideas.

Resources for Science Literacy: Professional Development compares *Benchmarks for Science Literacy* and *National Science Education Standards* thoroughly. The summary of the comparison lists differences in what they recommend—and therefore differences in what they imply can be pruned out.

An issue related to what traditional topics to prune is what traditional experiences to prune. Some experiences (say, planting beans, or measuring volume by displacement of water) have as fixed a role in the traditional curriculum as some topics. Again, the Project 2061 position is that time in the curriculum has to be justified by what students learn. Eventually, well-designed curriculum blocks will solve many of the problems of efficacy and efficiency. But in the meantime, all components of instruction can be questioned and experimented with.

Students often have to wrestle with new ideas that are inconsistent with the ideas they already have; experiences that evoke and resolve that struggle can often be arranged for students, without requiring that they discover the new ideas themselves.

And how much time should be allowed for students to invent or discover ideas for themselves? Although there is little research to suggest "discovery" learning is actually more effective, most educators wish that more time were available for hands-on experimentation and student inquiry. To the extent that a set of specific learning goals is believed to be important, however, the time cost of discovery is a serious limitation. The more time spent on discovering any one idea, the less time there is available for learning all other ideas. Almost all educators agree that there should be a balance between how much is learned and how well it is learned—and that there should be at least enough discovery, inefficient as it may be, for students to learn what it feels like.

A Process for Pruning Subtopics

A utility on *Designs on Disk* linked to *Atlas of Science Literacy* makes it possible to identify, for any subtopic being considered for pruning, which *Benchmarks* concepts may depend on it.

A modification of the process outlined above for cutting major topics can be used to reduce those that are retained. Grade-related faculty teams should be formed in science and mathematics to find subtopics that can be pruned away and to suggest what specific material to remove. The teams should start by exploring the relationship between specific goals and the study topics intended to target them. Eventually, teams should build a school-district database of topics that have been tightened up in terms of how well they target specific learning goals.

At some point in their deliberations, the teams should begin to formulate a list of topics to be considered as candidates for pruning. Then each team selects a topic from the candidate list for intense examination. Working in small groups and using either *Benchmarks* or *NSES* for guidance, the team members should decide which details can be removed or how the topic can otherwise be simplified without limiting its ability to serve the identified learning goals. Of course the team members have to make sure they do not cut material that is necessary for the understanding of some other idea in the same or later grade ranges. Inviting consultation (but not veto power) from teachers at higher grade levels can be a useful part of the process.

The teachers on the teams may then volunteer to test the slimmed-down topic in their classrooms using the time saved to ensure better learning of that topic. They should keep notes on what happens so they can answer such questions as: What effect did pruning have on student interest in the topic? Did the students learn the essential ideas or skills? How much time was actually saved? What changes should be made next time around to improve the quality of the learning? Once the treatment of a topic has been worked out to the satisfaction of the team, it should be written up and entered in a *Designs on Disk* file and made available to all teachers in the district.

The pruning of details from a topic may well be more difficult than the elimination of major topics that can more or less stand alone. The details may be so woven together that the instructional strategy unravels when some threads are pulled out. (In the Project 2061 curriculum-materials evaluation procedure, one of the criteria for describing a material is how easily the core ideas can be distinguished from extended detail—and then how easily the instruction for the two can be separated.) Close attention has to be paid to how well the closely surrounding instruction holds together when some aspect is deleted.

Trimming Technical Vocabulary

A special case of pruning topics involves cutting back on the teaching of technical terms for their own sake. It is not an easy task. Some teachers say that technical vocabulary has been an integral part of their instruction for so long that they can barely conceive of what topics would be without it. And de-emphasizing vocabulary may not produce immediate cheers from students either, particularly the older ones, since many of them have come to believe that memorizing words is the same thing as understanding the concepts—and they have become very good at it. Students' inclination, reinforced over years of schooling, to substitute memorization for understanding is all the more reason for teachers to

One of the 25 criteria that Project 2061 uses for judging the quality of instructional materials is labeled Introducing Terms. This is a very short statement of it.

Criterion: Introducing Terms
Does the material introduce technical terms only in conjunction with related experience and only as needed to facilitate thinking and promote effective communication?

Clarification. Terms are important to scientific communication. For students to be able to communicate efficiently about phenomena, some technical terms are helpful. However, concentrating on vocabulary rather than on understanding carries the risk of leading both students and teachers to mistake fluency with terms for understanding. It also mistakenly portrays science as learning "big words" rather than as asking and answering questions about the world. Understanding, rather than vocabulary, should be the main purpose of science teaching and hence, the number of terms used should be limited to those that are essential for communicating about experiences.

Responding to this criterion involves examining whether the material (1) introduces technical vocabulary mainly in conjunction with experiences and (2) limits the use of technical terms to those needed for communication about those experiences.

help students get better at learning content that has greater utility and durability.

Take, for example, the topic "Cells." For some teachers, its importance justifies having students learn the names of the parts of the compound microscope, copy drawings of generalized cells from the book, or learn to spell "endoplasmic reticulum," "mitochondrion," "organelles," and "cytogenesis." This is not to disparage the topic of cells itself, for indeed it is emphasized by both the *NSES* and Project 2061's *Benchmarks.* Nor is it to downplay the need for correct spelling. But as the figure on the facing page shows, there is a vast difference between the language Project 2061 uses to express what students need to know about cells and the language used in traditional textbooks and hence in curricula. Where one popular high-school biology textbook uses 120 cell-related technical terms, *Science for All Americans* uses but 11.

Thinking about Technical Vocabulary

In the lower grades, *Benchmarks* uses simpler language than *Science for All Americans,* in an attempt to characterize what all students at each level may be expected to understand.

In *Benchmarks*, as in *Science for All Americans*, there is a strong tendency to avoid using a specialized vocabulary. Once students can explain that cells get energy from food and use the energy to put together complex proteins, their knowing such terms as "oxidation," "respiration," "mitochondrion," and "ribosome" can be helpful, but learning the words without the basic notion is empty. (Could the words be learned first and then later be put together meaningfully? Probably so—but all too often the learn-

CELL TERMINOLOGY

cytoplasm electron transport chain **PROTEIN** lysosomes
GENE energy gradient organelles
RDP hydrolysis **NUCLEUS** **CATALYST** PGAL
CHROMOSOMES glycolysis substrate chromatin
pyruvic acid peptide bond nuclear envelope
pyruvic acid conversion monomer nuclear pores
aerobic respiration polymer **CELL MEMBRANE**
anaerobic polysaccharide nucleolus acetyl-CoA
CELL WALL Krebs cycle middle lamella
interphase endoplasmic reticulum prophase
ribosome cytokinesis Golgi bodies metaphase
mitochondria anaphase plastids telophase
vacuoles cell plate homologous chromosomes
microtubules diploid spindle fibers
haploid centrioles somatic cilia mitosis
flagella meiosis eukaryotic polar body
prokaryotic **REPLICATION**
binary fission chhloroplast vegetative propagation
leukoplast regeneration contractile vacuoles
gametes facilitated diffusion **SPERM** active transport
ovum carrier molecule zygote hypertonic solution
centromere hypotonic solution synapsis
solute tetrad solution **DNA**
RNA concentration gradient nucleotide
endocytosis adenine turgor guanine
exocytosis thymine phagocytosis cytosine
pincocytosis purines ADP pyramidines ATP
deoxyribose **ENZYME** ribonucleic acid
phosphate group ribose cellular uracil
PHOTOSYNTHESIS messenger RNA xanthophylls
transfer RNA carotenes ribosomal RNA grana
transcription stoma codon

Here is a list of technical terms found in two chapters on cells found in a typical high school biology textbook. Terms that appear in color are those that also appear in *Science for All Americans* and *Benchmarks for Science Literacy.*

The intention of the criterion for introducing terms is evident in these verbatim passages from middle-school textbooks. In the passage from textbook A, the term "photosynthesis" appears abruptly, without preparation. (There are accompanying activities on food webs but not photosynthesis.) In the passage from textbook B, the term appears only after relevant phenomena have been studied, and the basic process has been described in plain English.

TEXTBOOK A

ENERGY FLOW

Every community of living things, whether in a forest or in a city, needs energy to support life. You know that an automobile gets its energy from burning a fuel, usually gasoline. Well, a community of living things also gets its energy from "burning" a fuel, but it gets energy in a different way and from a different fuel—food.

Think about how energy "moves" through a forest community. Some animals get their energy (or food) by eating other animals. Some animals eat plants. But what do plants eat? What is their source of energy?

ENERGY→PLANTS→ANIMALS→ANIMALS

A few plants, such as the pitcher plant and the Venus' flytrap, eat animals (insects). But this is not the ususal niche that plants occupy. So how do plants usually get their energy? During **photosynthesis,** green plants change carbon dioxide (a gas they get from the air) and water (from the soil) into food. This food supplies energy not only for the plants, but also for the animals that eat the plants. The process of photosynthesis also *requires* energy. Green plants use energy from sunlight to manufacture their food, as you can see from the following energy diagram.

SUN'S ENERGY→PLANTS→ANIMALS→ANIMALS

TEXTBOOK B

PUT IT ALL TOGETHER!

So now what do you think about how plants get food? If you decided, as a result of doing these actvities, that plants use light, water, and carbon dioxide to make starch, you are right. Plants actually *make* their own food in their leaves. To do this, they need energy from the sun plus two raw materials: water and carbon dioxide. The process by which plants make food is called **photosynthesis**. Like many scientific terms, this one is a combination of two Greek words: *photo*, which means "light," and *synthesis*, which means "putting together." Given what you learned in doing the activities, why do you think the process is called *photosynthesis*?

Ultimately, photosynthesis is responsible for feeding practically all of the organisms on Earth! Plants use photosynthesis to make their own food. Animals feed directly on plants, and other animals feed on those animals. At your next meal, think about the fact that none of the food on your plate could exist without photosynthesis.

ing stops well short of understanding.) And in the end, the idea is understandable without those terms to a degree sufficient for general science literacy.

Technical language is helpful when the same idea needs to be referred to again and again. If there is a legitimate reason to refer to where food is oxidized in a cell, it obviously doesn't make sense to endlessly repeat "that special part of the cell where food is oxidized." Although Project 2061 recommends minimizing unnecessary technical terms, it is committed to expanding students' useful scientific vocabulary. The correct use of technical vocabulary by students is to be applauded once they understand the meanings. But as a rule of thumb, understanding should come first, definition after. (See the facing page for contrasting examples of how two textbooks introduce technical terms.)

But why not encourage the use of poorly understood terms, just to get students accustomed to the use of technical language and develop in them a sense of having learned something special? In fact, isn't that how we ordinarily build vocabulary—first only dimly understanding new words and then refining their meaning with time? Perhaps so, but it is clear that in school many negative consequences come from the premature use of technical vocabulary—not the least of which is the persistent impression that "science" means having mysterious names for everything. "Evaporation" is an excellent example of a term that children often are taught to say long before they have any idea of what a vapor is, or even know that air is a substance. Although a child's use of "evaporates" may signify no more than a fancy word for "disappears," some listeners are prone to interpret it as evidence of understanding kinetic-molecular theory.

The pressure to cover the curriculum and test students efficiently makes many teachers, administrators, test makers, and parents—not to mention materials developers and textbook publishers—too willing to interpret students' glib use of technical terms as evidence of understanding. As a result, learning is short-circuited and students are not able to increase their sophistication gradually. Teachers and test makers should require students to explain what they mean, not just come up with the right word. (For example, the question should not be "What do we call the part of a cell that does x?" but rather "What processes in a cell have special parts to perform them?" Only then, perhaps for *extra credit*, "What are those parts called?")

Another reason for de-emphasizing technical vocabulary is to concentrate attention on what ideas are required for literacy. If a goal stated that students "should become familiar with kinetic-molecular theory," many readers would be satisfied. But what has really been recommended? Knowledge of the ideal gas laws? The vectorial argument for equipartition of energy? If instead it is said that students should know

SOME EXAMPLES OF HOW *BENCHMARKS* USES TECHNICAL VOCABULARY

Both the term and the concept are included in *Benchmarks***:**

feedback

"The feedback of output from some parts of a system to input of other parts can be used to encourage what is going on in a system, discourage it, or reduce its discrepancy from some desired value." — *Benchmarks* section SYSTEMS

ecosystem

"Like many complex systems, ecosystems tend to have cyclic fluctuations around a state of rough equilibrium." — *Benchmarks* section INTERDEPENDENCE OF LIFE

electromagnetic

"The interplay of electric and magnetic forces is the basis for electric motors, generators and…the production of electromagnetic waves." — *Benchmarks* section FORCES OF NATURE

The concept, but not the term, is included in *Benchmarks*:

photosynthesis

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

— *Benchmarks* section FLOW OF MATTER AND ENERGY

entropy

"In any interactions of large numbers of atoms and molecules, the statistical odds are that they will end up with less order than they began with — that is, with the energy spread out more evenly.

"Transformations of energy usually produce some energy in the form of heat, which spreads around by radiation or conduction into cooler places. Although just as much total energy remains, its being spread out more evenly means less can be done with it."

— *Benchmarks* section ENERGY TRANSFORMATIONS

quantum

"When energy of an isolated atom or molecules changes, it does so in a definite jump from one value to another, with no possible values in between. The change in energy occurs when radiation is absorbed or emitted, so the radiation also has distinct energy values."

— *Benchmarks* section ENERGY TRANSFORMATIONS

Neither the concept nor the term is included in *Benchmarks*:

osmosis

(Yes, this is important in transpiration and cell maintenance. The term is commonly used, but as a synonym for diffusion.)

black hole

(Black holes are very bright. Higher priorities, necessary to making sense of it, are why things orbit other things and why ordinary stars shine.)

laser

(Everyone knows it produces a very intense light. Explaining it is something else.)

that "everything is made of invisibly tiny pieces that are continually moving and banging into one another, and that this view explains many diverse natural phenomena," far more is contributed to the readers' understanding of what students need to know. In all of this, therefore, the purpose is to take care that fancy language does not supplant or get in the way of plain language used to state learning goals clearly. (Goal statements also imply, of course, what language is reasonable to expect of all students.)

Designs on Disk contains a list of topics and technical terms found in representative science and mathematics textbooks for different grades. Based on the recommendations in *Science for All Americans, Benchmarks for Science Literacy,* and the *National Science Education Standards*, the list suggests which topics and terms all students need to learn and which are not essential.

A Process for Trimming Technical Vocabulary

Again, faculty teams can be set up to look for topics that seem to be overburdened with technical language and recommend which terms can reasonably be avoided. As suggested in the box on the opposite page, a list of topics can be considered to include three categories: (1) the concept and the technical term for the concept are both recommended for basic science literacy; (2) the concept is recommended, but not the technical term; (3) neither the concept nor technical term is recommended. As the faculty teams study the terminology associated with a topic, they can question the judgment expressed in the list and modify it if they wish, but only after discussion and then only if persuasive arguments for including the technical terms are made. The burden is on having to show why technical words that go beyond what is needed for science literacy should be included, not on having to argue for their exclusion.

As before, teachers should try teaching and assessing the selected topics without the terms that have been tentatively placed on the list of nonessential technical terms. That involves making sure that students know which words are not required for them to earn satisfactory scores on any tests. Instruction should focus instead on what the phenomena are, explaining them in familiar terms, what their importance is, and where else they will show up, but only incidentally on the technical term to use—when talking to other people who know the technical term. Each participating teacher should write an evaluation of the experience for the investigative team.

Weighing the helpfulness of technical terms is one step in Project 2061's procedure for analyzing curriculum materials, which asks whether a material:

- Provides a sense of purpose
- Takes account of student ideas
- Engages students with phenomena
- Develops and uses scientific ideas
- Promotes student thinking
- Assesses progress along the way
- Promotes other benefits

Sharing this information, the teams can collaborate in making districtwide recommendations, and the process can continue the progressive reduction of emphasis on memorizing technical terms.

Reducing Wasteful Repetition

Overloading the curriculum with topics, overloading topics with detail, and having students learn words and terms they don't need are not the only ways to waste instructional time. Another waste is the unnecessary repetition of topics—the same ideas in the same contexts, often with the same activities and the same questions. But deciding what is necessary and what is not is not always an easy matter. The common student complaint that the same topics appear in successive grades, often in the same way, is matched by the common teacher complaint that the students did not learn what they were supposed to before, and so previous topics have to be "reviewed" or, to be frank about it, taught all over again. This situation leads to frustration on the part of both teachers and students and to the loss of opportunities to take up other topics or the same topic in a new and more advanced context.

Considering Redundancy

On the other hand, deliberately revisiting the same concepts can be a valuable instructional strategy. Students' understanding of new ideas does not typically occur in single instructional bursts, but grows gradually over time, often with setbacks and the appearance of new misunderstandings. Many important ideas do have to be revisited in different contexts at different levels of sophistication before they are grasped well by students. But the curriculum is rarely thought out over spans of many grades, and so there is little opportunity to rationalize it by deliberately tailoring repetition.

The understanding achieved by students does not always proceed topic by topic but comes through their assembling ideas from quite different areas. Making sense of the fossil evidence for evolution, for example, requires putting together knowledge of soil erosion and sedimentation, the radioactive transformation of elements, rates of radioactive decay, variation within species, changing proportions, geological change in climate, DNA control of development, and so on. Identifying, coordinating, and sequencing all those components requires an investment of time and cooperation across grade levels that is available only through districtwide support and planning.

A Process for Reducing Unnecessary Repetition

One approach to the problem of wasteful repetition is to use the Project 2061 strand maps found in *Atlas of Science Literacy*. The maps represent the kind of thinking required for planning the fruitful repetition of topics over 13 years of school. The maps illustrate which ideas within and across conceptual strands need to precede others and converge to yield student growth of understanding over the years.

A few maps also appear in *Benchmarks on Disk* and on the Project 2061 Web site at www.project2061.org.

Cross-grade teacher teams should conduct an informal survey to see which topics appear to be frequently repeated in the K-12 curriculum. Choosing from the resulting list of topics likely to have excess redundancy, the teams should analyze one for which a growth-of-understanding map exists. By comparing entries on the map to the profile of the topic given in the district curriculum, the team can locate differences. By studying these differences, the team can think through just what component ideas may be learned and when, with what level of understanding, and with what means to demonstrate that understanding. Note that this recommendation is for a collaborative investigation of what it takes for students to learn, not for high-school teachers to instruct middle-school teachers, nor for middle-school teacher to instruct elementary-school teachers, in what they should accomplish with students.

The Challenge

Before wholesale easing of the curricular burden can be attempted or accepted, educators will have to believe that reducing the number of topics, pruning ideas within topics, cutting technical vocabulary, and avoiding needless repetition are worth doing and possible. The small-scale team efforts described above are all within reach. The first steps can improve the curriculum and help colleagues become better disposed to and ready for reform on a more ambitious scale. The more such experiences educators can share in conversation, at conferences, and in newsletters and journals, the closer they can get to a critical mass for the systemic and lasting improvement of science education.

The main point of this chapter has been to make time for teaching the most important ideas more successfully. But knowing how to expand the treatment of a smaller set of topics is not a trivial challenge. To some extent, all teachers know places where there is not enough time to do what they know needs to be done. In other places, it is not at all clear what additional instruction should be done, if more time were made available for it. Even so, it is important to avoid the temptation to include new topics or more details on included topics rather than stretching to improve students' understanding of the core ideas.

In the long run, the effective use of time may be the responsibility of block developers, and teachers' curriculum role will be chiefly to choose an appropriate array of curriculum blocks wisely. In the short run, guidance on how to use time more effectively can be found in the criteria for evaluating lessons and materials found in *Resources for Science Literacy: Curriculum Materials Evaluation*.