Content

What science content should I teach? That is a question that all science teachers must consider as they design their lessons. And if we want our lessons to be of high quality, we must ensure that the content is rigorous, appropriate, and worthwhile. Rigorous, meaning that it challenges students and moves them forward in their learning; appropriate, it aligns with the standards and benchmarks for their grade level; and worthwhile, the learning is essential for students and worth the time to teach it. The strategies associated with the “Content” aspect of our framework help keep us focused on the question “Why am I doing this?” Clearly, we need to know and be able to articulate why we are addressing particular content in our lessons and how that content is related to the important learning goals established for students.

In this section, you will

- learn how to clarify what students should understand about science concepts, as the first step in a new method for planning effective lessons;
- practice identifying rigorous, appropriate, worthwhile content; and
- participate in a reflective process to check your units and lessons to make sure they are focused on important learning goals.

Table 2.1 (Identifying Important Content, p. 24) gives an overview of the six strategies recommended in this chapter to help us get the content right.
### Content Strategy 1: Identifying “Big Ideas” and Key Concepts

When planning instruction, effort on our part is needed to establish clear learning goals. Once established, we need to give students a chance to understand the goals in positive classroom settings. From the 1999 TIMSS video study of 8th grade science teaching (Druker et al. 2006) in the United States, observers discovered that in 22% of classrooms, students were doing activities with no content, in 44% of classrooms, students were learning content with weak or no conceptual links, and in only 30% of the classrooms did the content have strong conceptual links. Each higher-achieving country engaged students with core science concepts and ideas and, except in the Netherlands, linked concepts and activities.

This tells us that before we walk into our classrooms to teach, we must determine the important content that students will learn and be clear about the “big picture” and key concepts. Planning a unit of study is like creating a book. There is a clear beginning, then the content storyline develops, and at the end we want our students to understand the “moral of the story.” Identifying the big ideas—the concepts, themes, or issues that give meaning and connection to discrete facts and skills (Wiggins and McTighe 2005)—in the early stages of unit planning helps us focus the students and ourselves on the learning we want to occur. An idea is "big" if it helps students make sense of lots of confusing ideas and experiences and seemingly isolated facts. It’s like the picture that connects the dots and reveals the image (big idea) by connecting the component pieces (key concepts). And keeping the overall goals in mind is necessary when preparing individual lessons that connect the concepts into a logical progression and lead students to conceptually understand the big ideas.

At the elementary level, the idea that we are all part of a “food chain” of living and nonliving things is big because it links seemingly different (and isolated) animals and plant matter into a bigger, comprehensible “ecosystem” of energy exchange. We then see the role of predators, trash, and the relationship of humans to nature in a completely new and meaningful way than before. At the middle and high school levels, Newton’s laws of motion are three of the biggest ideas ever posed. Suddenly, thousands of seemingly unrelated facts and phenomena—apples falling, the motion and cycle of tides, seasons, the Moon’s orbit—have a meaningful explanation and can be seen as part of a huge coherent system (Wiggins 2008).

### The Issue

Teachers rely on textbook activities, often aren’t clear about their lesson goals, and, even if they are, do not share these learning goals with their students. As a result, students are unclear about what they are supposed to learn and focus their learning on details and memorization of facts rather than on in-depth understanding of science concepts. Much of what students learn in science classrooms is new to them—they are science novices. Without thinking explicitly about all of the concepts that underlie the big ideas of science, teachers, who are science experts, might forget to address and connect all of the concepts that science novices must experience to learn science.

### The DEBSI Approach

This is really about reflecting on the big ideas and key concepts that form the content storyline in our units and clarifying the learning goals for ourselves and our students. This involves aligning the curriculum with the standards for our grade levels or grade bands (e.g., grades 6–8); identifying the “big ideas” and important concepts that organize the science knowledge our students are to learn; and “unpacking” the standards, benchmarks, and key concepts to identify the finer details of content to be addressed by the learning targets for individual lessons within units of study. “Unpacking” involves taking the big ideas and listing the key concepts that when
taken together, connect into a big idea. Once we identify the big idea and key concepts, the learning targets for individual lessons can be written in student-friendly language. Doing so helps ensure that students are working toward clearly defined objectives that focus on essential, conceptual understandings.

Selected Research Related to the Strategy

1. According to *Classroom Instruction That Works* (Marzano, Pickering, and Pollack 2001), there are two types of knowledge: declarative and procedural. Declarative knowledge comprises what a learner knows and understands, and procedural knowledge is what a learner does with that knowledge, i.e., processes and skills. Declarative knowledge includes organizing ideas, details, and vocabulary terms and phrases related to ideas (see Figure 2.1). Big ideas and key concepts fall under the category of organizing ideas and are, therefore, an integral part of the declarative knowledge that students learn in science class.

Brain research reveals that students must have multiple experiences with declarative knowledge—big ideas, concepts, vocabulary—to learn it at an adequate level (Nuthall 1999; Rosee-Collier 1995). More than one experience is needed because declarative knowledge is stored in long-term memory through a complex process that involves the hippocampus and the cerebral cortex (Marzano et al. 2001).

2. Setting objectives is a strategy that is highly likely to improve student achievement (Marzano et al. 2001). Marzano and his colleagues indicated that use of this strategy resulted in an average gain of 23 percentage points in student achievement. These researchers also noted that when students know the instructional goals, they focus on the most important information. They cautioned that these goals should not be too specific, lest they focus student learning too narrowly. The research supported the idea that teachers should encourage students to personalize the academic goals identified by the teacher.

3. By taking the time to study a topic before planning a unit, teachers build a deeper understanding of the content, connections among concepts, and effective ways to help students achieve understanding of the most important ideas and skills (Keeley 2005).

What Is the Strategy?

The focus of this strategy is on designing lessons within a unit of study that present science as a coherent body of knowledge, organized around big ideas that connect and give meaning to other concepts, facts, and details. Though science textbooks are a central source of information in the classroom, we cannot rely on textbooks alone when identifying "big ideas" and key concepts around which to design lessons. In fact, in recent years, evaluations have revealed that, for the most part, textbooks are not organized coherently around important science concepts. Instead, they include many topics with little guidance about how students should think about science ideas (Kesidou and Roseman 2002). Similarly, science kits provide correlations to national standards, but they do not always include teacher notes which talk about the big ideas and important concepts around which to base the learning targets for each lesson.

For this strategy, we want to identify big ideas and the concepts that compose them. As a first step, we must align curricular content with science standards to
ensure that the focus is on the important content that students are to learn. This can be accomplished by reviewing national, state, and district standards and making a list of the standards and benchmarks that will be taught and assessed in the unit. Many states and districts are already working on curriculum alignment activities. As a result, you may have curriculum framework documents that identify the essential learning and big ideas related to standards and benchmarks for particular units. Once you have a clear idea about the content that you will include in the unit, we should think about how well we understand the content. If necessary, use science-related resources that you have available (including online information) to review the big ideas and key concepts. This will ensure that the content we teach will be worthwhile (relevant to understanding the science, significant for science literacy and subsequent learning) and accurate (based on recent science research findings).

Standards and benchmarks are often written in general terms or include multiple ideas in one statement. It might not be obvious which concepts, facts, vocabulary, or processes are included in the standards and benchmarks. As part of identifying the content of lessons, you can systematically analyze, or "unpack," the standards and benchmarks to pinpoint the specific knowledge and skills that the content, you can create a curriculum map that clearly shows how the content within the unit is connected. The map should include the big ideas, key concepts, facts, vocabulary, skills, and processes that the students are expected to learn. To finish the process, share the curriculum map with students (and parents) in a format that makes it easy for them to understand what students will be learning and how the various ideas within the unit are connected.

As a thought experience, consider the following big idea from a unit on climate change:

The unequal heating of the surface of the Earth between the equator and poles, Earth's rotation, and the distribution of land and ocean generate the global wind patterns that affect climate and climatic changes.

To unpack this into key concepts and ideas, try to answer this question: What would students need to experience to understand this big idea? The idea of unequal heating would be one idea that students wouldn't be able to grasp without opportunities to observe it, talk about it, and look at evidence. So when we unpack the big idea we would want to include lessons about unequal heating. Additional concepts that we would want to plan for include:

- Land and water retain heat differently.
- The temperature near the ground depends in part on the angle of the sunlight hitting the Earth.
- Higher elevations above sea level have cooler temperatures.
- The thickness and composition of the atmosphere of the planet affects heating and cooling at the surface.
- Sunlight is the primary source of heat for Earth.

What other important concepts can you think of to add to the list that would help students understand the big idea of the unit?

Exploring the Strategy

In this section, we will look at an example that takes you through a four-step approach. Because of the availability of research on children's ideas on matter and atomic and molecular theory, we will use the research findings to think about how to implement this strategy. Research has shown that this content provides a rich source of information for teachers at grades K-8 (Smith et al., 2004). The example below is explained in detail in the full study. To learn more about the study and the learning progressions identified for the atomic-molecular theory of matter, read chapter 8 in Taking Science to School: Learning and Teaching Science in Grades K-8 (NRC 2007). We will revisit the idea of learning progressions that occur vertically across grade levels and learning progressions that exist within a course during our discussion of Content Strategy 6.

Step 1. Align the curricular content for the unit of study with science standards to focus on the important content.

This includes identifying the big ideas. Below is a list of big ideas that align with national standards and benchmarks that address matter and atomic and molecular theory:

1. Properties of Matter—Matter and the materials that they make can be studied through measurement, classification, and descriptions of the objects based on their properties.
2. Conservation of Matter—Matter can be changed and transformed but not created or destroyed either by chemical or physical means.
3. Atomic-Molecular Theory—All matter is made up of about 100 kinds of atoms, which bond together in different ways to form a wide variety of molecules.
4. Transformations of Matter—Changes in matter involve both changes in atoms and changes in their alignment and orientation in the molecules that are formed.

In this example, the big ideas were identified by the research team that wrote the Project 2061 Benchmarks for Science Literacy. It is not easy to come up with the big ideas yourself but it can be done. Think about the unifying concepts and represent it to the most important 2–3 sentences that contain the key concepts and represent the unifying concepts of the unit. No one said it would be easy but you practice writing big ideas.

Step 2. Develop your content knowledge and understanding related to science topics.

Any or all of the following resources are likely to become indispensable in helping you increase your knowledge and understanding of science education and a range of science topics. You may not have these references in your library but many of them are available online. Don’t forget to use your local resources such as mentors and local experts. What we are trying to avoid is passing along misconceptions that we might have to our students. Setting a goal of developing our own understanding will help us relate the content to our students. Full citations for the end of this book, are found in the references at the end of this book.

- **Atlas for Science Literacy, Volumes I and II (AAAS 2001, 2007).** This is a two-volume collection of conceptual strand maps that show how students’ understanding of the ideas and skills that lead to literacy in science, mathematics, and technology might develop from kindergarten through 12th grade.

- **Benchmarks for Science Literacy (AAAS 1993).** This is a national standards document that discusses what science students should know and be able to do in science, mathematics, and technology.

- **Designs for Science Literacy (AAAS 2001).** This is a companion document to the Project 2061 Benchmarks and includes information about curriculum design, discusses ways to unburden the curriculum, and offers a variety of options for restructuring time, instructional strategies, and content.

- **Making Sense of Secondary Science** (Driver et al. 2005).—Research into children’s science ideas are presented in this book. These ideas, right or wrong, form the basis of all that children subsequently learn. Research has shown that teaching is unlikely to be effective unless it takes into account the ideas with which children come to class.

- **National Science Education Standards** (NRC 1996).—This book contains the goals for achievement that are appropriate for all members of the science education community. Included are standards for content, professional development, teaching, systems, programs, and assessment.

- **Science Curriculum Topic Study** (Keeley 2005).—The Curriculum Topic Study (CTS) is a professional development resource developed to help K-12 educators deepen their understanding of the important science and mathematics topics they teach. CTS builds a bridge between state and national standards, explores research on students’ ideas in science, and provides opportunities for teachers to improve their practice.

- **Science Matters: Achieving Scientific Literacy** (Hazan and Treff 1991).—Organized as a compilation of basic facts and concepts that teachers need to understand the scientific concepts they teach, this book offers a quick read on scientific fundamentals.

- **Textbooks and teacher’s manuals**

- **Online resources by topic containing current and emerging science content**

Deepening your knowledge about a topic will make it easier to determine the big ideas and key concepts. A good resource that helps with this process is the Science Curriculum Topic Study mentioned above. It takes the wonder out of where to find information about topics and the research into student’s ideas about these topics. We can use this resource by ourselves, but it makes more sense when we work with collaborative groups of science teachers and with the support of administrators. For our example, attached is a list of the “big ideas” for matter and atomic and molecular theory broken into grade-level bands. This will also clarify the progression of learning from K–2, 3–5, and 6–8. This study did not include the high school level so it is not included (Smith et al. 2004).

**Grades K–2 Learning Related to Big Ideas**

Students’ experiences at this age have prepared them to learn and think about what things are made of and some of the properties of matter. Therefore, grades K–2 students are able to understand the following big ideas:
Content

- Objects are made of specific materials and have certain properties. The properties of objects can be carefully described, compared, and measured.
- Some properties change and some stay the same when objects are transformed in simple ways.

**Grades 3-5 Learning Related to Big Ideas**

When building on their earlier learning, older elementary students are able to go beyond knowledge of kinds of material and begin to use graphical representations and measurements to study the quantifiable properties of materials. They can also make predictions and design investigations to determine if objects contain the same materials. Therefore, grades 3-5 students can understand the following version of big ideas related to matter and atomic and molecular theory:
- There are some properties that characterize all matter; others characterize specific types of materials.
- Matter is conserved across certain transformations that radically change appearance.

**Grades 6-8 Learning Related to Big Ideas**

At this age, students are able to engage in abstract thinking so that they can understand the particulate nature of matter and represent that understanding using atomic-molecular models. Students can also use mathematical representations to understand the properties of matter such as density. They can design and conduct experiments to study the physical changes and chemical changes that occur when matter is transformed. Thus, grades 6-8 students can understand the following version of big ideas:
- There are properties that characterize all matter, specific materials, and phases of matter than can be quantified and related.
- Some transformations involve chemical change (e.g., burning, rusting) in which new substances are created. In other changes (e.g., changes of state, thermal expansion), materials may change appearance, but the substances in them remain the same.
- Matter and mass are conserved across both types of changes.
- All matter is made up of discretely spaced particles (called atoms) which are far too small to see directly through an optical microscope. There are empty spaces (vacuums) between atoms.

- Microscopic properties can be explained in terms of atoms and molecules.
- Macroscopic transformations can be explained in terms of atoms and molecules.
- All properties of atoms and changes in atoms can be distinguished from the macroscopic properties and phenomena for which they account.

**Step 3. Unpack the standards and benchmarks to identify the concepts, facts, vocabulary, and processes to include in the individual lessons that compose the unit of study.**

In most instances, we have to unpack the big ideas to determine the key concepts, subconcepts, and factual knowledge that are embedded. Since a big idea pulls together a large number of ideas into a coherent explanation, a single scientific concept is a piece of a big idea that links at least two ideas together. We have already identified the big ideas; next, we must be clear about the concepts that underlie the big ideas and then design lessons that will help students learn those concepts. If our goal is that students understand an idea as a concept, then we must provide learning experiences that help them develop in-depth understanding rather than a surface understanding of the concept as represented by a word or phrase. When students understand a concept, they are able to talk about the key characteristics of the concept and generate a number of examples that illustrate each characteristic. For example, if students understand ecosystems as a concept, they understand that two characteristics of ecosystems are that (1) they provide a one-way flow of energy and (2) matter within an ecosystem is recycled. They are able to demonstrate their understanding by explaining, predicting, and analyzing what happens to the matter and energy in different ecosystems such as rainforests, temperate deserts, or midlatitude grasslands. If students understand ecosystems only as a vocabulary term, they have a general, but less accurate, understanding of what the concept means. In other words, they aren’t as able to generate mental images of the word (as a concept) or connect it to experiences in which the word applies.

Unpacking the big ideas of matter and atomic and molecular theory makes it clear that there are many concepts and facts that students must learn in order to grasp the big ideas. Table 2.2 (p. 34) identifies the concepts, facts, and vocabulary—revealed by unpacking standards and benchmarks—that are related to the big ideas of matter and atomic and molecular theory at grade levels K-2, 3-5, and 6-8.
## Table 2.2
**Key Concepts, Facts, and Vocabulary Related to Matter and Atomic and Molecular Theory**

**Grades K–2**
- Materials and objects can be classified based on appearance.
- Matter can be distinguished from nonmatter because matter is anything that has mass and takes up space.
- Materials can either be made of matter that is made of the same substance or a mixture of different substances.
- Different materials have different appearances and different properties which can be measured or observed using our senses.
- Matter can change form and appearance when it undergoes transformations.

**Vocabulary:**
- Matter
- Materials
- Objects
- Transformation

**Grades 3–5**
- Matter takes up space and has weight. Nonmatter does not.
- Air is matter and takes up space and has weight.
- There can be pieces of matter that are too small to see with the naked eye.
- Materials have characteristic properties that are independent of the size of the sample (e.g., color, texture, hardness, heaviness for size, bendability).
- Matter continues to exist across transformations in which it no longer is visible (e.g., dissolving).
- Amount of matter and weight are conserved across melting, freezing, and dissolving.
- Materials can be changed from solid to liquid form by heating, but are still the same kind of material.

**Vocabulary:**
- Solid
- Liquid
- Gas
- Heat
- Cool
- Dissolve
- Evaporate
- Condense
- Solidify
- Vaporation
- Sublimation

**Grades 6–8**
- Mass measures the amount of matter. Weight is the amount of mass and varies with the gravitational field.
- Materials have quantifiable properties such as melting point, boiling point, and density.
- Density is quantified as mass/volume.
- Conservation of mass is a fundamental law.
- Heating changes the volume of materials but not the mass of the object.
- Boiling, phase change, and chemical change involve conservation of mass but not volume.
- There are more than a hundred different kinds of atoms. Each kind has distinct properties, including mass and the way it combines with other atoms or molecules.
- Atoms can be joined to form molecules—a process that involves forming chemical bonds between atoms. Molecules have different characteristic properties from the atoms of which they are composed.
- In solids, atoms or molecules move rapidly, but usually within spaces constrained by their neighbors. In liquids, atoms or molecules are closely packed but move more freely, and constantly collide as they move past one another. In gases, atoms or molecules move freely in straight lines except when they collide with each other or their container.
- Changes in matter include physical changes, in which molecules change arrangement and motion but remain intact, and chemical changes, in which atoms are rearranged (disconnected and reconnected) into new molecules, but the atoms remain intact.

**Vocabulary:**
- Physical change
- Chemical change
- Mixture
- Compound
- Phase change
- Atoms
- Molecules
- Elements
- Chemical bonds
- Density


These facts, concepts, and vocabulary were identified in the NRC report and if they are taken together as a whole, then they represent the big ideas identified earlier. When unpacking the big ideas into the separate concepts, these should always be statements of understanding, not just phrases or one or two words. This will help us focus the subsequent student lessons on important content.

**Step 4. Create a curriculum map or planning template outline that shows how the content is connected.**

"Strand maps" produced by the American Association for the Advancement of Science (AAAS) can be used to visualize what a curriculum map might look like. A portion of the strand map related to transformation of matter and energy is included in Figure 2.2 (p. 36). For the conceptual information provided in our example, you would create a separate curriculum map for each grade band to show the connections and guide instructional planning.

**Planning for Classroom Implementation**

As we think about using this strategy in our classrooms, keep in mind that big ideas represent the central principles of the science disciplines and are the underlying understandings embedded in science standards. Our first task is to identify the big ideas at the overall course or grade level. This helps us connect the goals for student learning into a coherent framework. Next, identify the big ideas and key concepts for each unit. We’ll focus on the unit of study level throughout this book. To fully implement this strategy, we must complete another step: analyze the big ideas to identify the key concepts, facts, and vocabulary that are embedded in them. Although taking all of these steps might seem like a lot of work, there are good reasons for taking them. Organizing teaching around big ideas provides coherence to the curriculum. It also helps us align the curriculum with student learning so that what students should know and be able to do directly relates to the learning performances.

To uncover the big ideas, key concepts, and vocabulary for your own unit of study, go back to the four steps in the process. Use the resources mentioned as well as online resources to begin the process. A template is provided in the appendix for Content Strategy 1 for you to record the big ideas and key concepts for your unit of study. Also, an example of a completed planning template outline for a ninth-grade unit on evolution is included in Figure 2.3 (p. 37). This is a practical teacher example; keep in mind that different teachers focusing on the same big idea may create very different unit plans, depending upon the course and grade level in which the content will be taught.
Figure 2.2
Strand Map

Chemical Reactions

- An atom's electron configuration, particularly the outermost electrons, determines how the atom can interact with other atoms. Atoms form bonds to other atoms by transferring or sharing electrons. 4D7

- The configuration of atoms in a molecule determines the molecule's properties. Shapes are particularly important in how large molecules interact with others. 4D8

- Atoms may stick together in well-defined molecules, or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances. 4D1

- When substances interact to form new substances, the elements composing them combine in new ways. In such recombinations, the properties of the new combinations may be very different from those of the old. (SFAA, p.47)

- About 100 different elements have been identified...out of which everything is made. 4D6

3-5

- A lot of different materials can be made from the same basic materials. 4D4

- When a new material is made by combining two or more materials it has properties that are different from the original materials. 4D4

K-2

- Objects can be described in terms of the materials they are made of (clay, cloth, paper, etc.) and their physical properties (color, size, shape, weight, texture, flexibility, etc.). 4D1

- Things can be done to materials to change some of their properties, but not all materials respond the same way to what is done to them. 4D2


Figure 2.3
Completed Planning Template Outline for Evolution Unit

<table>
<thead>
<tr>
<th>Title: Evolution</th>
<th>Grade: 9</th>
<th>Length:</th>
</tr>
</thead>
</table>

Step 1: Content

**Big Idea**
Natural selection provides a scientific explanation for the fossil record and the molecular similarities among the diverse species of living organisms.

**Key Concepts**
Modern ideas about evolution provide a scientific explanation for three main sets of scientific observations about life on Earth:

- There is an enormous number of different life forms that exist today, 99% of which did not exist in earlier times on earth.
- The systematic similarities in anatomy and molecular chemistry seen within that diversity are a result of common ancestry of organisms.
- The sequences of changes in fossils found in successive layers of rock that have been formed over more than a billion years show the changes that have occurred as organisms have descended from common ancestors.

The scientific explanation for the theory of evolution is based on a large body of evidence that explains the process of biological change over time that is occurring among living organisms. Species acquire many of their unique characteristics through biological adaptation over many generations.

Fossilization is the process that turns a once-living thing into a fossil.

**Knowledge**
- Fossils are the remains of animals and plants, or the record of their presence, preserved in the rocks of the Earth.
- Extinction is a naturally occurring process where all individuals in a species die out.
- Variations exist within all populations.
- Scientific theories are explanations of natural phenomena built up logically from testable observations and hypotheses.

**Skills**
- Application of timelines to rock layers
- Microscope skills
- Classification based on characteristics of fossils, or internal and external structure of animals and plants
- Preparation and participation in debate and discussion
- Use of evidence in supporting conclusions
What Works in Science Classrooms: Implications for Teaching

**Recommendation 1:** Our challenge is to ensure that our lessons are designed to help students learn important content. When you ask yourself the guiding question for the content element of the framework ("Why am I doing this?"), you should be able to respond, "This content is important for students to learn because it addresses the big ideas of science." If the lesson doesn’t help students make progress toward learning the big ideas and key concepts of the discipline, then redesign the lesson so that you make the most of instructional time. Remember, worksheets that do not help students understand concepts, important facts, or vocabulary related to the big ideas of science can be a waste of student time; they do not support student learning and achievement of essential science content.

**Recommendation 2:** Examine the learning goals (key concepts) you have defined from the perspective of a novice learner. Ask yourself, "Will these learning goals help novice learners focus their thinking and learning on the important science concepts in this unit?" Research studies have shown that novice learners don’t know what is important to learn and tend to focus on memorizing facts and vocabulary. As a result, they develop only a superficial understanding of the content.

**Recommendation 3:** Ensure that each lesson focuses on an important science concept and provides appropriate opportunities for students to learn the concept. Remember, concepts connect several ideas. In order to learn concepts, students need multiple opportunities to think about the ideas and apply them in meaningful ways. If you decide to teach an idea as a vocabulary term or phrase as one of the opportunities for student learning, there are strategies you can use. *Teaching Reading in Science* (Barton and Jordan 2001) is one resource that provides many vocabulary strategies. Online resources are also readily available. Using a vocabulary strategy would be one opportunity, to which you would then want to add additional experiences, to help students retain and incorporate what they learned into their existing mental frameworks.

**Content Strategy 2: Unburdening the Curriculum**

**The Issue**

When science teachers are asked about the biggest issue that they face each year, time is always one of the top concerns. How will we find the time to teach everything included in the standards and have time to prepare students for state assessments? This drive for coverage stems from two fronts. First, because of new scientific discoveries, new content is being added all the time. Second, we are expected to prepare all students to perform at a proficient level on state assessments. To meet both of these goals, teachers struggle to provide enough opportunities for students to really learn.

**Table 2.1**

<table>
<thead>
<tr>
<th>Identifying Important Content</th>
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<tbody>
<tr>
<td>Strategy 1: Identifying Big Ideas and Key Concepts</td>
</tr>
<tr>
<td>Strategy 2: Unburdening the Curriculum</td>
</tr>
<tr>
<td>Strategy 3: Engaging Students With Content</td>
</tr>
<tr>
<td>Strategy 4: Identifying Preconceptions and Prior Knowledge</td>
</tr>
<tr>
<td>Strategy 5: Assessment—How Do You Know That They Learned?</td>
</tr>
<tr>
<td>Strategy 6: Sequencing the Learning Targets into a Progression</td>
</tr>
</tbody>
</table>

**The DESI Approach**

The original TIMSS (Third International Math and Science Study) report released in 1997 found that teachers often try to teach too much and there isn’t enough time for students to learn everything. U.S. schools teach so many science topics that the concepts are covered in superficial detail and employ technical language that exceeds most students’ understanding. The consequence of superficial student learning is lack of retention of the learning in a durable way. Durability of learning is the degree to which students are able to transfer information or skills learned in one content to new contexts across time. The *How People Learn* report (Bransford et al. 1999) summarizes how we can promote durability of learning with our students. Key findings are...
More than one context is needed. Teachers need to help students understand abstract, general principles and provide multiple contexts for students to apply them.

Learners need to know under what conditions, or when, to apply the knowledge or skill. It is necessary to explicitly teach students when, where, and why the skill or concept is to be applied—not just how.

In science classes, it is important that students experience and learn the science concepts through exploring, considering explanations, learning to think scientifically, and showing they understand through developing, presenting, revising, and defending their conclusions. Developing this level of scientific understanding takes time, and lack of time and opportunity to learn are well-documented and well-understood by teaching professionals. Unburdening or pruning the curriculum can help teachers fit it all in. In the pruning process we need to decide what is essential so that there is adequate time to teach the content.

**Selected Research That Addresses This Issue**

1. Developing durable student understanding happens only if units focus on a few, rather than too many, concepts and if each lesson focuses squarely on one concept (NRC 1999). This can be accomplished by pruning. Pruning helps focus instruction and improve understanding in classrooms where, too often, quantity takes precedence over quality and coverage wins out over student understanding. If we focus on essential learning, then supplemental learning needs to be eliminated.

2. According to Why Schads Matter (Schmidt 2001), there is powerful evidence that textbooks exert a strong influence on the content that teachers teach. Textbook coverage is important both for what topics (and concepts) are taught and for the levels of performance and understanding expected of students. However, we know that textbooks are not the curriculum and standards themselves are also not the curriculum. Standards and science frameworks from national, state, and local documents must be unpacked so that the appropriate concepts to be taught at each grade level can be identified. As we learned in Strategy 1, unpacking the big ideas means identifying the key concepts (organizing ideas from the standards), facts, and vocabulary that become part of a student’s enduring knowledge.

3. Teachers are experts and students are novices when it comes to understanding science concepts. Science teachers know the structure of the knowledge in their disciplines; know the conceptual barriers that are likely to hinder learning; and have a well-organized knowledge of concepts, inquiry procedures, and problem-solving strategies (Brandford et al. 1999). They notice features and patterns that students don’t. An expert and a novice perceive the same content differently. In a sense, experts have learned what to look for. From a sea of data, they pinpoint the important, useful information. Novice learners, on the other hand, don’t know what to look for and can lose focus trying to learn lots of facts and details without developing conceptual understanding. Novices need to learn the concepts; otherwise, they will never be able to make meaning out of the rest of the information that we teach (Donovan and Bransford 2005).

**What Is the Strategy?**

Pre-pruning. Before beginning the pruning process, let’s look at some criteria we can use. Designs for Science Literacy (AAAS 2000) specifies that the two primary reasons for pruning content are (1) there was no compelling argument that it is essential for science literacy or (2) the amount of time and effort needed for all students to learn was out of proportion to its importance. In the appendix for Century Strategy 2 you will find one possible process to use if your school or district wants to practice a pruning process for their curriculum framework.

Pruning is important work that is best accomplished by teams of teachers with the support of schools and districts. However, if time and resources for pruning are not available, individual teachers can still do this on their own. It takes a significant amount of time to prune units and revise lessons, so we recommend working on one unit and the related lessons during the first semester and another one during the second semester. The next year, two more can be revised, and so on. Another strategy is to have a team of teachers divide up the units within a course of study and each teacher work on one unit; teachers then share their revised units with one another.

Using the two criteria already mentioned, we can also look at pruning topics and units that have already been taught and eliminate wasteful repetition. So what can and should we prune? Teachers and curriculum developers decide what science concepts and skills must be learned. If you are lucky enough to go through the pruning process as a school or district team, then reaching consensus or what to eliminate is itself an effective way for us to clarify in our own minds what is important. Some districts have already generated curriculum maps that include the key concepts. We can use these as a guide to what to keep.
As you decide what to keep, make sure to analyze conceptual strands by using the Atlas of Science Literacy (volumes 1 and 2 or the online resources). Conduct cross-grade surveys to determine what is being taught both before and after your course. Refer to district curriculum maps and guides if they are available. Districts often produce their own curriculum maps and guides, so refer to those if they are available to determine grade-level expectations. Remember, it is important to offer learning that is not too advanced or too easy, but appropriate for the developmental level of your students.

If you end up doing the pruning process by yourself, we suggest sharing your concept map or paragraph explaining the big idea(s) with a colleague to get feedback. This also allows you to reflect on your choices. There is no one set of objectives/concepts that works in every context, and variation is to be expected when teachers prune individually. What's more important is finding the time—for teacher and students—to focus on learning goals and providing students with multiple opportunities to learn the concepts and supporting knowledge they need to know.

Exploring the Strategy
For this example, we will use a standard statement from the National Assessment of Education Progress (National Assessment Governing Board 2005) as our big idea:

Energy can be converted from one form into another. Kinetic energy can be converted into potential energy, and potential energy can be converted into kinetic energy. Thermal energy is often one of the forms of energy that results during energy conversion. When energy is converted from one form to another, the quantity of energy before the conversion equals the quantity of energy after conversion. (Grade 8)

- This big idea is basically about energy transformations and conservation. Write a paragraph that elaborates and explains what this big idea means, or draw a concept map that details the relationship between the key concepts and knowledge embedded in the statements.
- Then, take each idea from your paragraph and match it to the concepts and objectives from the list below. Decide which statements you think are high priority and cross out those which should be pruned. In other words, if it does not clearly relate to the big idea above, then it is a candidate for pruning. This doesn’t mean that the pruned ideas wouldn’t be taught in other courses or at other grade levels, but it should clarify what to include in this unit on energy transformation and conservation.

List of Assessment Statements for Energy Concepts, Knowledge, and Skills:
1. Recognizes that things that give off light often also give off heat
2. Explains that energy is needed to do work
3. Identifies uses of energy
4. Understands that sound is a form of energy
5. Relates kinetic energy to the speed of an object
6. Recognizes that heat can move from object to object by conduction
7. Compares ability of materials to conduct heat
8. Makes predictions about the transformation between kinetic and potential energy
9. Describes the transformations of energy that may occur in electrical systems
10. Explains that a turbine is a machine that transforms mechanical energy to electrical energy
11. Explains that energy cannot be created or destroyed, only changed from one form to another
12. Defines kinetic energy and gives examples
13. Classifies examples of heat transfer as conduction
14. Understands that heat flows from warmer to cooler objects until both reach equilibrium
15. Gives examples of energy transfer through radiation
16. Explains that when energy is converted from one form to another, heat is often produced as a by-product
17. Recognizes the major forms of energy
18. Defines potential energy and gives examples

As you look at the statements that come directly from a state standards document, you’ll notice that some of the statements relate directly to the four main ideas in our big idea. Those ideas are energy conversion, transforming kinetic to potential energy and the reverse, energy conversions resulting in heat energy, and conservation of energy. If we keep the bolded targets and plan instructional activities with these goals in mind, then we can prune away most of the other
goals. With more time for learning the concepts, we can provide opportunities for inquiries into energy conversions and energy conservation.

Now, let’s look at pruning the technical vocabulary in the following list from the same source. According to Design for Science Literacy (AAAS 2001), if we include lots of technical vocabulary, then students focus on the terms rather than learning the science ideas (concepts). The key vocabulary that we do include has to be at the appropriate level for our students. Remember that some of the terms will already have been introduced in earlier classes or units so we are only talking about new vocabulary. The rule of thumb is no more than 3-5 new terms for elementary students per unit, 6-8 new terms for middle level students, and 8-10 for high school students. If we look at our state and national science standards documents and create vocabulary lists for the grade-level bands, the total number of vocabulary words will work out to the recommended number per unit. In the example below, there are lots of terms that can be pruned. Reflect on what this means for your current practice.

Vocabulary List from a State Science Standards Document:

| direct sunlight | neutral | vocal cords |
| electrical conductor | neutron | chemical energy |
| electrical energy | Newton | circuit tester |
| conduct | parallel circuit | correction |
| conductor | positively charged | dimmer switch |
| conversion | prism | dry cell battery |
| electrical current | potential energy | electrical shock |
| electrical insulator | radiate | explosion |
| electron | radiator | heat transfer |
| filament | series circuit | infrared |
| flow of heat | sound energy | radiation |
| fluctuate | light energy | energy transformations |
| insulator | mechanical energy | visible spectrum |
| kilowatt hours | spectrum | wavelength |
| kinetic energy | stationary | alternating circuit |
| material | thermos jug | law of conservation of |
| minimize | transfer | energy |
| molecular motion | turbine | nuclear energy |

Planning for Classroom Implementation

In summary, you just learned about pruning pass. This can be used with your understanding of what you need to learn. Recent research findings in The Impact of Science Practice on Classroom Learning and Teaching Science in Grades K-8 (NRC 2007) reveals that science teachers understand how much opportunity to learn than it is about students' innate abilities. Not including students with cognitive deficiencies, students' brains are pretty much alike and are able to process science ideas in similar ways. This is different about each of our students is the learning experiences that they have in our classrooms. It is all about having the time to engage students in meaningful ways with important science concepts and ideas.

What Works in Science Classrooms: Implications for Teaching

**Recommendation 1:** Determine the essential learnings or key concepts students need to learn. Use the resources that you have (including those mentioned in Content Strategy 1) to figure out what constitutes essential learning. Supplemental learning, wasteful repetition, and technical vocabulary all need to be pruned. Only then will we have the time needed to engage students with important concepts.

**Recommendation 2:** Since students are novice learners when it comes to most science concepts, provide opportunities for them to engage in the context in ways that help them make sense of the ideas. This includes providing multiple opportunities to learn the key concepts and develop understanding of the big ideas.

**Recommendation 3:** Pruning is a process that we need to practice to develop proficiency. Ask yourself this question before the start of each lesson: “What is the important concept that students should be thinking about today?” To create that focus in the lesson, it makes good sense to eliminate others ideas and vocabulary that would distract students.
Content Strategy 3: Engaging Students With Content

The Issue

Students in secondary science classrooms complain that science is boring. Why? Probably because they either don’t understand it or it seems irrelevant to their lives—or both. In any event, if students are not interested, they will not learn. So the key to successful science learning is “to be providing students an opportunity to engage with important science concepts and ensuring that they in fact make sense of these concepts” (Weiss et al. 2003).

Making science interesting must begin in elementary classrooms, where, thankfully, the amount of time given to learning science has increased recently, with the mandatory implementation of science assessments in each state. To engage students, think about what students like most about learning science. They like inquiry investigations and demonstrations; things that teach how things work. Most students love a mystery—and science is filled with puzzles and mysteries.

Table 2.1 Identifying Important Content

<table>
<thead>
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<tr>
<td>Pure extraneous subtopics, technical vocabulary, and wasteful repetition.</td>
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<th>Strategy 3:</th>
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<td>Create essential questions that engage students with the content.</td>
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<th>Assessment—How Do You Know That They Learned?</th>
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<td>Develop assessments that consist of the conceptual understanding and related knowledge and skills.</td>
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<tr>
<th>Strategy 6:</th>
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<tr>
<td>Clarify and sequence the learning targets into progressions to focus instruction on building conceptual understanding, align learning activities with learning targets.</td>
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Why am I doing this?

What are the important concepts and scientific ideas included in the lesson?

How do we take advantage of students’ natural curiosity and engage them intellectually? One approach is by using well-designed questions. The idea of engaging students is the first step in the BSCS 5E instructional model (Bybee 2002). In Bybee’s instructional model he recommends engaging students with a new concept through the use of short activities that promote curiosity and elicit prior knowledge. The five features of inquiry (NRC 1999) also start with engagement—engaging students with scientific questions.

The DESI Approach

Using essential questions is a strategy that engages students in lively discussion, makes students think, and develops understanding as well as getting the students to ask even more questions. Essential questions directly relate to the key concepts and naturally recur every time the concepts are taught, but they are open-ended and have no obvious “right” answer. By carefully crafting questions ahead of time, we can make sure they are not too easy (and boring) and not too difficult (also boring) but challenge students to really think about what they understand and don’t understand. For example, ask yourself the following questions: “Can you see an apple in a totally dark room?” and “Is there life on Mars?” Upon hearing the question, we immediately start to think about what we know already. Using “good” essential questions helps students access their ideas about how nature works and, just like us, students can’t help but think about their thinking. Some of the science literature describes essential questions as conceptually rich problems or questions (Bell and Purdy 1985; Bransford et al. 1999). One example would be, “How does a tree get to be so big from a tiny seed?” These kinds of questions connect students to the content. Using probing or conceptually rich questions as a part of formative assessment will be discussed as part of Understanding Strategy 2.

Posing essential questions are easy for some teachers and challenge others. To generate essential questions, follow the advice provided by Wiggins and McTighe (2005) and others and practice writing some of your own.

Selected Research That Addresses This Issue

1. Essential questions are an innovative and effective element of the backward design model. Wiggins and McTighe propose that a question is essential if it meets a series of criteria. This information is contained in Table 2.3 (p. 48).

2. An important goal of using essential questions is student engagement with making sense of the science content. “Students’ inclination,
Table 2.3
Criteria for Essential Questions

1. Cause genuine and relevant inquiry into the big ideas and core content.
2. Provoke deep thought, lively discussion, sustained inquiry, and new understanding as well as more questions.
3. Require students to consider alternatives, weigh evidence, support their ideas, and justify their answers.
4. Stimulate vital, ongoing rethinking of big ideas, assumptions, and prior lessons.
5. Spark meaningful connections with prior learning and personal experiences.
6. Naturally occur, creating opportunities for transfer to other situations and subjects.

What Is the Strategy?

Drafting essential questions reminds us to ask ourselves, "What do we want students to understand?" One way to approach this strategy is to consider each concept that we will teach and come up with a question that really gets the students thinking. So to learn more about this strategy, in your own mind, which of the following questions are essential questions and why do you think so? Remember from the information in Table 2.3, they should not have an obvious right or wrong answer and they get at the heart of the conceptual ideas we want students to learn.

- Can a tree die of old age?
- How many legs does a spider have?
- What is "molecular bonding"?
- What makes a theory a "good" theory?
- What causes sound to echo?

If you look at the first question, it fits the criteria for an essential question. It engages students with the concept of aging and as a plant, how do trees age? Does it depend upon the conditions, kind of tree, climate? So this question prompts us to reflect on our knowledge and understanding of death and old age in plants and probably compare it to other organisms. The second question has an expected right answer of eight legs so does not meet our criteria for essential questions.

Reinforced over the years of school, to substitute memorization for understanding is all the more reason for teachers to help students get better at learning content that has greater utility and durability" (AAAS 2001, pp. 227-8).

Exploring the Strategy

Remember that essential questions are not just lesson objectives written in question form. A question like "What are the steps in cell division?" clearly has a specific right answer associated with it. But if we ask the question, "What causes cells to divide?" then with this essential question we can get students to start thinking about different kinds of cells, the conditions that might trigger division, and what about aging, or cancer cells. And how are stem cells different? Is the answer different for a plant cell, animal cell, or other type of cell?

In an elementary classroom, teachers expect students to know the answer to the question "What do living things need to survive?" This has a right answer, which would include components such as food, water, and shelter. But what if we asked these essential questions: "Do living things have the same needs?" "How are living organisms adapted to different habitats?" Because there is not just one response depending on the living organism, students think more about their ideas and their previous experiences.

There are many examples of essential questions that teachers have created and others that come right from their students. The strategy here is to practice writing essential questions that engage students in the learning, are arguable, raise important questions, and focus the students on the key concepts.

Table 2.4 contains some examples that you can use to think about your own questions. Try to keep the number of essential questions to only a few for each unit and try to match them to your big ideas and key concepts.

Because this is tough for most of us to do, when you have some draft essential questions prepared, share your responses with others. Be sure you share the criteria for essential questions with the reviewers. Based on their feedback, should any of the essential questions be revised? This process is one that requires practice. Just like anything else that is worthwhile, it takes effort. Using electronic resources is a helpful way to get started since many teachers are working on this also.
Planning for Classroom Implementation

Ultimately, essential questions are a way to get students to think about a topic and to connect to their ideas about how nature works. To craft essential questions that relate to each key concept, we need to engage in thinking about the concepts ourselves. What are some open-ended questions that invite multiple student ideas and relate to what you are teaching? Remember, these are not lesson objectives but questions designed to get students thinking “Hmm, that’s interesting. I wonder...” and answer the question and provide explanations. In this way, we get them to intellectually or understanding to accurately respond to the essential questions, the questions also invite opportunities for them to inquire and test their ideas. Try writing some essential questions that relate to your unit and compare them to criteria for essential questions. Get help! Some people are really good at “I wonder...” kinds of questions, so check out what others have created or get feedback on the ones you have written. You can even ask your students to create some “I wonder...” questions using the criteria provided. Remember that trying this for the first time is always the hardest but, with subsequent practices, it should get easier.

What Works in Science Classrooms: Implications for Teaching

Recommendation 1: Essential questions help engage students with the science concepts. There really aren’t any right or wrong answers for whether a question is essential or not, but try to make them open-ended enough so that students think and engage intellectually with the content—beyond just a superficial level. Draft a few essential questions for your unit of study. Try to create an essential question for each of your key concepts. Check your questions against the criteria provided.

Recommendation 2: If you have trouble writing essential questions, use whatever resources you have available to you. Further thought and interactions with element of planning high-quality science lessons doesn’t go smoothly at first. Imagine questions that you have always wondered about and see if they can be revised into essential questions.

Content Strategy 4: Identifying Preconceptions and Prior Knowledge

The Issue

How do we know what students know? Each student has prior conceptions about the natural world and how it works, which come from a wide variety of learning opportunities both in and out of school. The challenge is to determine answers to the following questions:

- What do students know and think about a particular concept?
- Why do they think that?
- How do teachers uncover prior knowledge and preconceptions?

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Identifying Important Content

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National Science Teachers Association

Designing Effective Science Instruction
The DESI Approach

Before teaching a new science concept in a unit of study, we must assess what our students already know and whether that knowledge is scientifically correct or incorrect. There is a wealth of information and research about student misconceptions that we need to review and use when planning lessons. But even before that, we must assess what we ourselves already know and whether our conceptual knowledge aligns with the scientific viewpoint. This was included in the Content Strategy 1. Once we have reviewed the concepts we are to teach and checked the research for information about common student misconceptions, then with this strategy the approach is to get students to reveal their ideas about the concepts that we will be teaching.

Selected Research That Addresses This Issue

1. “Knowledge-centered and learner-centered environments intersect when educators take seriously the idea that students must be supported to develop expertise over time; it is not sufficient to simply provide them with expert models and expect them to learn. For example, intentionally organizing subject matter to allow students to follow a path of ‘progressive differentiation’ (e.g., from qualitative understanding to more precise quantitative understanding of a particular phenomenon) involves a simultaneous focus on the structure of the knowledge to be mastered and the learning process of students.” (Donovan and Bransford 2005, p. 14)

2. “[Teachers] also must be skilled in helping students develop an understanding of the content, meaning that they need to know how students typically think about particular concepts, how to determine what a particular student or group of students thinks about those ideas, and how to help students deepen their understanding.” (Weiss et al. 2003, p. 28)

3. “The first thing to do is to consider the nature of any differences between children’s prevalent thinking and the science viewpoint. Various possibilities exist and learning science might therefore involve
   i. Developing existing ideas
   ii. Differentiating existing ideas
   iii. Integrating existing ideas
   iv. Changing existing ideas
   v. Introducing new ideas

Once the teacher has identified the nature of any differences between pupils’ thinking and the science viewpoint, then it becomes easier to plan activities which will support intended learning.” (Driver et al. 2005, p. 10)

4. “An assessment probe is a type of diagnostic assessment that provides information to the teacher about student thinking related to a concept in science... Probes are concerned less with the correct answer or quality of the student response and focus more on what students are thinking about a concept or phenomenon and where their ideas may have originated.” (Keeley and Eberle 2008, p.203–204)

What Is the Strategy?

“Preconception” is the term used in the meta-analysis How People Learn: Bridging Research and Practice (Donovan et al. 1999) to describe the initial understanding that students have about how the world works. Student preconceptions are sometimes accurate, but frequently they are not (Casey and Gelman 1991). In the appendix for Content Strategy 4 is a tool to remind you of the steps that should be part of the process for identifying student preconceptions.

One key finding in the study Looking Inside the Classroom (Weiss et al. 2003) was that 25% of lessons observed elicited student prior knowledge in some way, but the ideas students were asked to share were not well aligned with the learning goal of the teacher. Without the connection to the learning, students weren’t focused on the important ideas and as teachers, we therefore may not really know what students think. Once we know what ideas our students bring with them, then we can use our pedagogical content knowledge to know how to best present concepts, identify where students may go wrong in their thinking or have gaps in understanding, and determine effective methods to help our students engage meaningfully with their preconceptions and the science concepts.

Exploring the Strategy

To determine the prior knowledge of students, most teachers have used prewrites, KWL (What I Know, What I Want to Know, What I Learned) charts, brainstorming, and other strategies. You may want to think about what you have done in the past to gather evidence of student learning. As with any instructional strategy, students like variety and will become resistant if teachers use the same strategy for every unit. What follows is a sample brainstorming activity to determine what students know about photosynthesis. In this activity, we would provide the following instructions to the students.

Designing Effective Science Instruction
Prompt: How do plants make their own food? And what factors affect the process?

- In teams, use the piece of chart paper provided to record what you know and understand conceptually about the process of photosynthesis by answering the two questions listed in the prompt.
- Each member of the group should use a different color of marker to record his or her ideas.
- Take turns writing and proceed around the group in a clockwise fashion until all of the ideas you can think of have been recorded. The information can be scattered around the page in any way that the group decides.
- At the end of your group work, sign your name on the poster using the same colored marker that you used to record your statements of understanding.
- Be prepared to share with the whole group.

At the conclusion of the brainstorming activity, we would engage the class in a debriefing activity where each group shares their ideas one at a time without repeating any idea already shared by another group. We would record all of the ideas on another piece of chart paper, chalk board, white board, Smart Board, or other surface. We can ask clarifying questions of the teams and, at the end of the reporting out time, summarize the ideas that centered on the process of photosynthesis and the two questions for the class. This information then can be used to determine existing preconceptions that need to be addressed and allow us to set instructional goals for upcoming lessons. Because student ideas were recorded in different colors, we can use this information to group students into appropriate cooperative learning groups. A student example of this activity is provided in Figure 2.4.

A variation of this idea is included in an article on effective science instruction published by the Center on Instruction (Bantlow, et al. 2008). In the article, second grade students were provided with a blank sheet of paper and asked to write everything they knew about weather. The students could draw pictures that they labeled, create diagrams, or use words. The teacher asked each student to share one of their ideas with the class. As before, the teacher asked for clarification from the students and ended by summarizing for the class. The prior knowledge gathered from the student ideas then formed the launching point for a lesson on water.

You may want to investigate the use of student web that can be created using Inspiration software. The computer program includes organizational formatting.
a basic flow chart, and a drawing palette. The students can create their own or use visual tools that help students create visual representations of their concept-thinking (Hyerle 1996).

Another valuable strategy is to create a probing question or to create a formative assessment "probe." A process has been created "that links commonly held learning goals" (Keefee and Eberle 2008, p. 204). We can either create our own to determine prior knowledge, used during the unit to provide formative assessment understanding. If a probe is used to find out prior student knowledge, then the unit. The key goal is to be able to uncover students thinking about a science concept. This is different from pre-assessment tests, which sample for student (Note: There are currently four books that include dozens of examples of probes Earth and space science, and physical sciences. These resources are available from 2005-2009).

Planning for Classroom Implementation

Teaching for understanding requires that teachers have more than just science content knowledge. The many aspects of the art and science of helping students access develop an accurate understanding of the science concepts have been labeled pedagogical content knowledge, or PCK. Simply put, PCK means knowing your subject, your audience, and how to introduce one to the other in ways that result in conceptual understanding that addresses students ideas.

To be able to understand student thinking we need to gather and examine the evidence that students use to explain their points of view. One way to accomplish "Exploring the Strategy" section. Remember that there are not tasks to find out if students' thinking to determine where students are before we begin instruction. We must identify the gap that exists between student thinking and the science viewpoint to set instructional goals for each of our students. This process will reveal differences in individual student understanding. By encouraging students to ask questions as they think about their thinking, we can interpret responses from students and use this information when planning classroom teaching and learning experiences.

Depending on the grade level you teach, you may feel like an expert in science content or you may be a little uncomfortable yourself when it comes to understanding science ideas. But whether you are a master teacher of science content or a novice, you should always reflect on what you know yourselves as you go about the task of discovering the prior knowledge of your students. With scientific advances there is often emerging content that will inform our teaching. It is hard to be an expert in all areas of science and there is no reason to pretend that we know it all. To review this strategy, return to Content Strategy 1. There will always be questions from students that we, as learners, can't answer or concepts that we don't completely understand. To address students' ideas about science phenomenon, it is logical that we start with our own ideas. Remember that there is a tool that includes the steps to follow included in the appendix Content Strategy 4 document.

As we go about the process of eliciting students ideas, it is always helpful to have our resources close at hand that describe what students should know and be able to do. Some of the resources that we recommended during the first content strategy include national, state, and local standards documents and curriculum frameworks. There are books (e.g., the Stop Talking! series from NSTA Press), online professional development courses, internet resources, and virtual manipulatives that can be accessed electronically. Science Curriculum Topic Study—Bridge the Gap Between Standards and Practice (Keefee 2005) is an additional resource that aligns major topics in science with resources that identifies the key concepts and research on students' ideas related to the topics.

A second planning template is included in the Chapter 2 Appendix for strategy 4. The blank template can be used to gather background information and to plan for student misconceptions and prior knowledge.

What Works in Science Classrooms: Implications for Teaching

Recommendation 1: It is important to assess students' prior knowledge. Finding out what students ideas are is valuable, even if their thinking is consistent with scientific ideas. To learn science concepts, students must connect new ideas with prevailing ideas so getting students to explain their ideas is always a good plan. The key is to probe their explanations to reveal the experiences that they are using to make sense of the concepts.
**Recommendation 2:** Experience is one way that students learn, but it is not always the best way depending on how they make sense of their experiences. Without our help, many students use evidence from everyday experiences to come to incorrect conclusions about how the world works. Since learning is a social activity, opportunities that encourage kids to talk about their ideas and justify their explanations using evidence must be provided. When students discuss their ideas with one another and with our guidance, they have the opportunities that they need to make sense of the science concepts.

**Recommendation 3:** Students' ideas are not always consistent with the new ideas that they are learning. Research into how students learn indicates that to bring about conceptual change in students' ideas, we must first confront students with evidence that helps them formulate new ideas and become dissatisfied with old preconceptions. More about this will be discussed in Chapter 3, which focuses on developing student understanding.

**Content Strategy 5: Assessment—How Do You Know That They Learned?**

**The Issue**

If improved student learning is our primary goal, then summative assessments that align with important learning goals are logical and necessary. Unfortunately, most of us are not trained psychometricians (testing and assessment specialists). We rely on test banks of questions. Summative assessments in science are often based upon how much time has passed in a unit, not whether students are prepared to provide evidence of their conceptual understanding. With the role of science teachers moving away from the giver of grades to the facilitator of learning, summative assessments must match the learning goals and the criteria for success.

A second issue is depth of understanding. We often accept student responses that show apparent signs of understanding, such as students being able to provide the right word, definition, or formula. Changing the question or terms and probing further may cause our students to reveal that they really do not understand.

**Table 8.1**

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<tr>
<th>Strategy 2: Unburdening the Curriculum</th>
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</thead>
<tbody>
<tr>
<td>Prune extraneous subtopics, technical vocabulary, and wasteful repetition.</td>
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</table>

<table>
<thead>
<tr>
<th>Strategy 3: Engaging Students with Content</th>
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<tbody>
<tr>
<td>Create essential questions that engage students with the content.</td>
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</table>

<table>
<thead>
<tr>
<th>Strategy 4: Identifying Preconceptions and Prior Knowledge</th>
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<tbody>
<tr>
<td>Identify common preconceptions and prior student knowledge.</td>
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<table>
<thead>
<tr>
<th>Strategy 5: Assessment—How Do You Know That They Learned?</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Develop assessments that correlate to the conceptual understanding and related knowledge and skills.</td>
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</table>

<table>
<thead>
<tr>
<th>Strategy 6: Sequencing the Learning Targets Into a Progression</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarify and sequence the learning targets into progressions to focus instruction on building conceptual understanding; align learning activities with learning targets.</td>
<td></td>
</tr>
</tbody>
</table>
the concepts at all. They may even show a variety of misconceptions. If "correct" answers can result in insufficient evidence of understanding, then how can we learning to new contexts?

The DESI Approach

Summative science assessments help teachers, students, and parents determine how well students are learning. Assessments for formative assessments, planned and implemented to find out if students are learning. This feedback is feedback to formative assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom assessment experiences as part of a formative assessment process in classroom Assessment should focus on student mastery or non-mastery of core science concepts or subconcepts and examples related to the core concepts.”

(Vitale, Romance, and Dolan 2006, p. 5)

What Is the Strategy?

So where do we get well-designed summative assessment questions? And are grades based on evidence of student understanding? Summative assessment questions may not even be aligned with the big ideas and key concepts when we rely on test banks. So the question really isn’t “What do we go to get good questions?” but “Once learning concepts are clear, how do we design assessments that align with the learning goals and key concepts?” This has to be the next major step in our planning process after getting the content right—identifying big ideas and key concepts, pruning nonessential vocabulary and concepts, identifying possible student misconceptions and knowing where to start with students based on their prior knowledge. Continuing with a backwards design strategy we can now plan for summative assessments. In our own minds we must establish the criteria for success and what our students would need to provide as evidence of understanding. Only then can the instructional activity sequences be developed. First, we have to decide what is important to assess and what the best strategies to assess are.

Let’s look at the first part of that statement: “Decide what is important to assess.” There is a key distinction between science knowledge and conceptual science understanding. What is it? If we think about the hierarchy of declarative knowledge, what we know about a topic usually includes the facts and vocabulary and the concepts related to the topic. From the selected research, we know that asking students to demonstrate conceptual science understanding goes beyond
more recall. We will want to look at examples of current summative assessments (tests) we are providing for students that either come from test generators or that we constructed ourselves. tally the number of questions that measure recall; the apply information; and the number of questions that go beyond and ask students experimental inquiries (Marzano, Pickering, and Pollack 2001). If we do this test and what we will know about our students as a result of their performance. Part students need to provide to show a credible level of mastery of the concepts?

Exploring the Strategy

As we know from our previous strategy discussions, it is important to plan for assessment at the same time that big ideas and key concepts are determined. What and understanding that the students are gaining. To start this process, we have to have known. A sample is provided for you in Table 2.5 related to grade level concepts about matter and energy transformations.

In our minds, when we think about the learning targets (conceptual targets), we automatically start to talk about how they would demonstrate science knowledge and then insert a variety of verbs such as “list,” “define,” and “explain.” These learners will critique using evidence” or “The learner will inquiry; problem-solve, a template is provided in the appendix (Content Strategy 5a) to help you reflect on what is the important learning and how we will know that students are demonstrating understanding that goes beyond providing recall information. Are they applying their learning to a new situation? Are we asking them questions that if...?”

These kinds of higher-order thinking questions provide students with multiple possible responses and help us reveal student thinking. One example that will help bring this idea home is a question about ecosystems. A typical assessment question would be as follows: In the food chain shown below what would happen if all the mice disappeared?

Grasses ♦ Mice ♦ Snakes ♦ Hawks
a. Snake population would increase
b. Grass population would increase
c. Hawk population would increase
d. None of the above

What has happened in the question is that the scientific concept of interdependency, which is a key concept in our understanding about how ecosystems work, has been so simplified that we don’t really know what their answer to this question tells us about their understanding. Instead we may want to ask the students,

| Grade 4: Fourth-Grade Assessment Performances for Matter and Energy Transformations |
|----------------------------------------|-----------------|-----------------|
| **Application**                        | **Inquiry**     | **Knowledge of Benchmark Ideas** |
| Food is the source of energy and materials. | Classify things that people eat as food or not food. Identify uses that people make of food. Use tables to compare the calorie content and nutritional value of various foods and defend claims based on the data. Identify food as the source of animal growth (e.g., the weight of a lap, weight gain of an infant). |
| Animals need to take in air, water, and food. | Describe what happens to food that people and animals eat (some is used for repair and growth and some is eliminated). Based on collected data, compare weight gains of individual organisms with various diets. Identify materials that animals need to take in. |
| Plants need air, water, nutrients, and light. | Identify conditions for plant growth in different environments such as rainforests, deserts, or grasslands. Based on collected data, compare dry mass of plants grown in various conditions. Identify light, water, and air as essential to plant growth. |

(continued on pp. 64-65)

Designing Effective Science Instruction
Table 2.5 (cont.)
Sample Assessment Performance

### Grade 8: Eighth-Grade Assessment Performances for Matter and Energy Transformations

<table>
<thead>
<tr>
<th>Application</th>
<th>Inquiry</th>
<th>Knowledge of Benchmark Ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food provides the molecules that serve as fuel and building material for all organisms.</td>
<td>Explain how specific food substances are used for energy and growth by animal cells. Design a snack food that meets specified nutrition requirements.</td>
<td>Identify food as the source of both building material and fuel for both plants and animals.</td>
</tr>
</tbody>
</table>

| Plants use the energy from light to make sugars from carbon dioxide and water. This food can be used immediately or stored for later use. | Account for a plant's increase in mass from the molecular building blocks it makes. Explain why plants need light. Describe two possible fates of the sugars that plants make. | Criticize reasoning in arguments about claims that do not follow logically from data about plant growth under various conditions. Identify the inputs and the outputs of photosynthesis. |

| Organisms that eat plants break down the plant structures to produce the materials and energy they need to survive. | Explain what happens to food substances when animals gain and lose weight. Explain how animals digest and use food. Predict results of experiments involving animal nutrition or the effects of diet and exercise. | Criticize conclusions about likely consequences of consuming various diets based on flawed premises or flaws in logic of reasoning. Given a food web, predict the effects of a change in one population on another. |

| Then they are consumed by other organisms. | Trace food substances and energy through food webs. | Given a diagram of a food web, predict the effects of a change in one population on another. |

"What happens when an ecosystem becomes unbalanced?" We may also want to provide a more robust food web for a grassland that represents a wide variety of interrelationships. It is all about asking the right questions and using the right type of assessment.

---

Table 2.5 (cont.)
Sample Assessment Performance

### Grade 12: High School Assessment Performances for Matter and Energy Transformations

<table>
<thead>
<tr>
<th>Application</th>
<th>Inquiry</th>
<th>Knowledge of Benchmark Ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways.</td>
<td>Trace chemical elements through food webs. Describe the individual matter transformations that occur from one organism to the next in food webs. Explain how the law of mass conservation applies to ecosystems.</td>
<td>Compare alternative explanations about matter transformation and conservation in food webs in light of their consistency or lack of consistency with data. Distinguish between organic and inorganic compounds based on chemical formulas.</td>
</tr>
</tbody>
</table>

| At each link in a food web, some energy is stored in newly made structures, but much is released into the environment as heat. | Trace the path of energy in an ecosystem. Explain how the law of energy conservation applies to ecosystems. Criticize conclusions about likely consequences of consuming various diets based on premises or logic of reasoning about heat loss data. | Identify terms of energy found in living systems. |

| Continual input of energy from sunlight keeps the process going. | Explain why ecosystems need a continual input of sunlight in terms of the heat loss at each step in a food web. Use data about populations in ecosystems to construct possible food chains. | Identify sunlight as the ultimate source of energy for all living organisms. |

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Planning for Classroom Implementation

Remember that after we determine what to assess it is important to choose the right type of assessment. What are the different kinds of assessment? Look at the chart in Table 2.6 (p. 66) and think about these questions:

- When is it appropriate to use multiple-choice assessments?
- When is using a performance-based assessment worthwhile?
- What is the best way to assess conceptual understanding?
### Table 2.6: Assessment Methods

<table>
<thead>
<tr>
<th>Target to be Assessed</th>
<th>Assessment Method</th>
<th>Selected Response</th>
<th>Essay</th>
<th>Performance Assessment</th>
<th>Personal Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vocabulary</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Multiple choice, true/false, matching, and fill-in can sample mastery of vocabulary.</td>
<td>Essay exercises can tap vocabulary knowledge.</td>
<td>Not a good choice for this target</td>
<td>Can ask questions, evaluate answers, and infer mastery, but may be a time-consuming option</td>
</tr>
<tr>
<td><strong>Fact/Details</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multiple choice, true/false, matching, and fill-in can sample mastery of facts and details.</td>
<td>Essay exercises can tap knowledge of facts and details.</td>
<td>Not a good choice for this target</td>
<td>Can ask questions, evaluate answers, and infer mastery, but a time-consuming option</td>
</tr>
<tr>
<td><strong>Organizing Ideas</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Higher-order multiple choice questions can tap organizing ideas to some degree but are not the best choice.</td>
<td>Essay exercises can tap understanding of relationships among elements of knowledge.</td>
<td>Performance tasks that require the use of thinking and reasoning skills can tap understanding of organizing ideas.</td>
<td>Journals, learning logs, interviews, and discussions can provide information about students understanding of organizing ideas.</td>
</tr>
<tr>
<td><strong>Skills</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Can assess mastery of the knowledge prerequisite to skillful performance, but cannot rely on these to tap the skill itself</td>
<td>Can observe and evaluate skills as they are being performed (e.g., proficiency in carrying out steps in product development)</td>
<td>Strong match when skill is oral communication proficiency; also can assess mastery of knowledge prerequisite to skillful performance</td>
<td></td>
</tr>
<tr>
<td><strong>Reasoning Processes</strong></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>Can assess application of some patterns of reasoning</td>
<td>Written descriptions of complex problem solutions can provide a window into reasoning proficiency</td>
<td>Can watch students solve some problems or examine some products and infer about reasoning proficiency</td>
<td>Can ask student to &quot;think aloud&quot; or can ask follow-up questions to probe reasoning</td>
</tr>
<tr>
<td><strong>Dispositions</strong></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Selected response questionnaire items can tap student feelings.</td>
<td>Open-ended questionnaire items can probe dispositions.</td>
<td>Can infer dispositions from behavior and products</td>
<td>Can talk with students about their feelings</td>
</tr>
</tbody>
</table>


The key is to match the assessment type to the knowledge, skills, and conceptual understanding that should be assessed. To create a blueprint for a unit, use the template in Appendix Content Strategy 5b that provides spaces to make a list of the key concepts (learning targets), knowledge, and skills. Then determine which assessment tool maps to that learning target. In the template you can jot notes about how many questions to include on the summative assessment, what kind of performance assessment to use, or the actual essay question to ask. Include as much detail as possible.

Performance assessment prompts can be recorded on a separate sheet or on the back of the template. That completed, we need to make sure to include a certain percentage of questions that target:

- simpler ideas, facts, and skills presented during instruction;
- more complex conceptual understandings based upon what was taught in class; and;
- in-depth inferences and applications that go beyond what was taught in class.

Now is the time to go to assessment resource sites to find some conceptually rich questions. One source of assessment items would be the released NAEP assessment questions, which can be accessed online. Most state departments of education also have a place on their sites for released items and expected student responses. Finally, the National Center for Research on Evaluation, Standards, and Student Testing (CREST) is another good source for information.

When we are designing our own summative assessment tasks or problems, there are a few important questions teachers should ask:

1. **Does this assessment map to important, rigorous content?**
2. **Is the assessment task cognitively complex?**
3. **Is this assessment developmentally appropriate?**
4. **Is the assessment fair for all of my students?**
5. **Is this assessment meaningful and does it provide sufficient evidence of student understanding?**
6. **What are the consequences of the assessment?**
7. **What will I do with the data?**

In summary, summative assessments must be designed to reveal what students understand and the student responses must provide evidence of that under-
standing. To determine if learning with understanding has occurred, summative assessment must measure more than memorization of facts and vocabulary. Most widely used assessments don’t effectively assess the complex understanding and skills that cognitive science research indicates are important to determine levels of student understanding.

What Works in Science Classrooms: Implications for Teaching

**Recommendation 1:** As teachers we tend to design our tests (summative assessments) based upon the summative assessments provided with teachers resources or based on previous tests we have given. The important first step is to determine the key learning targets we want to assess from the broader learning goals and then determine the criteria for success. We have to be clear about what we are looking for and the students also need to know the criteria for success so they will know what they should be learning.

**Recommendation 2:** Assessment questions should be mapped to the learning goals and learning targets. Once we determine learning goals and targets for a unit of study step two is to create an assessment that assesses for each learning target. This is not something we hope happens but something that needs to be planned for by creating a blueprint for the assessment.

**Recommendation 3:** Assessment types must be matched to the learning targets. Think about it. Can multiple-choice questions reveal student understanding of concepts? The answer is sometimes yes and frequently no. Being thoughtful about the types of assessments we use is a strategy that should yield higher-quality student evidence of knowledge and conceptual understanding. We can only expect the data from the summative assessment to be as good as the questions, problems and tasks that we design.

### Content Strategy 6: Sequencing the Learning Targets Into a Progression

**The Issue**

Ideas in science are not taught in a coherent way. Evidence from science teacher interviews suggests that teachers rely extensively on textbooks and emphasize “coverage” as the way to occlude which learning activities to include in lesson design (Stigler and Heibert 1999). Concepts are stated rather than developed. We feel pressure to prepare students for state assessments, which means trying to cover more information than our students can reasonably learn in a year. This affects the quality of science lessons because the learning experiences often become superficial in order to address time constraints. Practical experience shows that direct teaching of concepts that results from too little time does not result in student learning beyond the definition level. Students do not always process this learning into their durable memory, so we are confronted with students who do not retain the learning. Many science ideas appear and disappear from science classes and

<table>
<thead>
<tr>
<th>Table 3.1</th>
<th>Identifying Important Content</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strategy 1:</strong> Identifying Big Ideas and Key Concepts</td>
<td>Identify “big ideas,” key concepts, knowledge, and skills that describe what the students will understand.</td>
</tr>
<tr>
<td><strong>Strategy 2:</strong> Unburdening the Curriculum</td>
<td>Prune extraneous autopairs, technical vocabulary, and wasteful repetition.</td>
</tr>
<tr>
<td><strong>Strategy 3:</strong> Engaging Students With Content</td>
<td>Create essential questions that engage students with the content.</td>
</tr>
<tr>
<td><strong>Strategy 4:</strong> Identifying Preconceptions and Prior Knowledge</td>
<td>Identify common preconceptions and prior student knowledge.</td>
</tr>
<tr>
<td><strong>Strategy 5:</strong> Assessment—How Do You Know That They Learned?</td>
<td>Develop assessments that correlate to the conceptual understanding and related knowledge and skills.</td>
</tr>
<tr>
<td><strong>Strategy 6:</strong> Sequencing the Learning Targets Into a Progression</td>
<td>Clearly sequence the learning targets into progressions to focus instruction on building conceptual understanding; align learning activities with learning targets.</td>
</tr>
</tbody>
</table>
the learning experiences do not progress in a coherent fashion. Water, for example, is introduced in a weather unit in an elementary class, then may appear again in a middle school physical science unit, and finally may be found in a high school biology unit. Or students may encounter an idea in second grade and then visit it again in fifth grade and finally in a tenth grade science course. As a result, students feel that they are learning the concepts for the first time each time it is presented and frequently answer our question, "Haven't you studied this before?" with the response, "No, I've never heard about this from my other science teachers." From their perspective, they are giving us accurate feedback: They really did not learn the concepts before and the knowledge and facts that they knew long enough to pass a quiz or test were never stored in their long-term memory.

The DESI Approach

Rather than jumping from topic to topic, teachers must first prune the curriculum (see Content Strategy 2) and then sequence the learning activities to allow enough time to support development of conceptual understanding. To build the conceptual understanding we have to take the learning goals and break them down into learning targets that we can sequence to form unit-based learning progressions. When the literature talks about learning progressions, they usually are referring to the development of student learning across grade bands from K-12 as they progress from novice learners to masters of the concepts. There are also horizontal learning progressions that exist in each of our units of study. Let's dig a little deeper into what learning progressions are, what is to be gained by sequencing learning targets (why we need them), and finally how we build them.

Selected Research That Addresses This Issue

1. Learning progressions are based on research into student learning, and they develop a student's conceptual framework by deepening their understanding in increasingly more sophisticated ways that move students from novice learners to more expert learners about to progress in their demonstrations of understanding. Learning progressions can track student learning across grade levels or they can map out the growth of students' knowledge and understanding within a single unit (Roberts et al., 1997; Wilson and Sloane 2001; Wilson 2005).

2. "A well-structured learning progression presents a number of opportunities to teachers for instructional planning. It enables teachers to focus on important learning goals in the domain, centering their attention on what the student will learn rather than what the student will do (i.e., the learning activity). In planning instruction the learning goal is identified first, and the sequence of activities or experiences that teachers will use to enable students to meet the goal is connected to the goal. Consequently, the all too common practice of learning being activity driven rather than driven by the learning goal is avoided." (Heritage 2008, p. 4)

What Is the Strategy?

For this strategy, there are some clear steps that need to be followed before we can sequence learning activities to develop conceptual understanding. Various parts of this process have already been addressed in the earlier content strategy explanations so this is not a completely new process. The steps are listed below in Table 2.7.

Remember that our goal here is to develop learning progressions that help plan useful and effective instruction. Work to build learning progressions for the big ideas in all of the disciplines of science is currently underway. While that work is taking place with the help of science education researchers, we can still use the AAAS Project 2061 strand maps contained in the two volumes of Atlas of Science Literacy as a starting point. Sequencing the learning targets can help close the learning gaps for students by providing a pathway for them to progress. The most important part of the process is aligning the learning activities with the learning targets. As a teacher who taught for almost three decades, I, like many other teachers, had files full of activities to choose from. For newer science teachers, review the activities that have been provided as part of the district curriculum and those activities provided in the kit-based materials and textbook-based materials and through online resources. As explained in the research from Gooding (1990) and Goodwin (2000), scientific concepts are never developed without participation in specialized forms of practice, such as creating instruments, inventing representational systems, or developing models. What they discovered is that the kinds of activities we provide can greatly enhance students' scientific knowledge. Engaging students Unpack the key concepts to identify the individual learning targets included in the key concepts for your unit of study (see Content Strategy 1).

Identify the criteria for success for each learning target by determining the student learning performance.

Sequence the learning targets to develop student comprehension of the learning goals (key concepts) in ways that build sophistication of student understanding.

Match learning activities to learning targets and monitor student learning performance.

Table 2.7 Steps for Sequencing Learning Targets Into Learning Progressions
Exploring the Strategy

Let's look at an example using a portion of the Diversity of Life strand map (AAAS 2007). Referring to the steps in the process listed in Table 2.7, we will start with the unit big ideas and the key concepts (learning goals) that are part of the topic of diversity of life. Remember that these are not the big ideas that are central to the science domains but rather these big ideas represent the conceptual understanding that we want for our students. For our example, the key concepts come from the Atlas strand map document shown in Figure 2.5, and the learning targets and learning activities criteria are adapted from the work of Cathie, Lehto, and Belser (2005), who proposed a learning progression for developing student understanding of evolution. The concepts related to diversity and survival are represented in Figure 2.6 (p. 74). Key to this document is the alignment of the learning activities that map to the sequenced learning targets.

Why do we need progression? Within this sample progression, the learning targets are sequenced to develop students' conceptual understanding of the broader key concepts (learning goals). First, lessons that are coherent and build from one lesson to the next help students learn. Second, creating the learning target progressions focuses the instruction in our own minds so that we can make the learning goals clear to both our students and their parents. Third, this allows us to prune away unnecessary learning targets and unnecessary or repetitious learning activities. Finally, when we find out what students already know by assessing their prior knowledge, then we know where to begin instruction with our students.

Planning for Classroom Implementation

We did a little bit of this work using Content Strategy 4, where we referenced resources to find out what students' prior understandings should be. The reason this is important now is to remind us that we are not just developing basic student understanding of an individual science concept. The larger goal is to link ideas from year to year to develop a deeper and more sophisticated conceptual understand-
**Figure 2.6** Concepts Related to Diversity and Survival

<table>
<thead>
<tr>
<th>Big Ideas</th>
<th>Key Concepts</th>
<th>Learning Targets</th>
<th>Learning Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diversity:</strong> Diversity of species, diversity within species, and diversity of habitats</td>
<td>The world contains a wide diversity of physical conditions, which creates a variety of environments: freshwater, marine, forest, desert, grassland, mountain, and others.</td>
<td>1. Different environments occur due to the physical conditions that exist (e.g., precipitation, temperature, elevation).</td>
<td>Students compare and contrast environmental conditions that exist in different ecosystems. Students predict how variations of a trait might affect an organism’s chances of surviving in an environment.</td>
</tr>
<tr>
<td>Survival: Populations of organisms are likely to affect other populations that live in that habitat. Changes in habitats affect the ecology and thus the chance that organisms will survive and reproduce.</td>
<td>In any particular environment the growth and survival of organisms depend on the physical conditions.</td>
<td>2. Organisms are adapted to living in particular environments based on their structures and the conditions.</td>
<td>Students identify competitors and analyze data that measures population levels to identify which species are competitors and for what resources.</td>
</tr>
<tr>
<td></td>
<td>Changes in environmental conditions can affect the survival of individual organisms and entire species.</td>
<td>3. Competition for limited resources (food, water, or space) can occur between organisms with similar needs.</td>
<td>Students analyze population level data and explain the changes over time due to the introduction of a new competitor in the environment.</td>
</tr>
<tr>
<td></td>
<td>Most species that have lived on Earth are now extinct. Extinction of species occurs when the environment changes and the individual organisms of that species do not have the traits necessary to survive and reproduce in the changed environment.</td>
<td>4. Competition occurs between kinds of organisms and within a population.</td>
<td>Students analyze data to discover changes in the distribution of the variations of a trait within a population, as the result of an environmental stress.</td>
</tr>
<tr>
<td></td>
<td>Some species and ecosystems emerge in a healthy environment; however, changes in the environment can disrupt the stability.</td>
<td>5. Such competition for resources remains stable in a healthy environment; however, changes in the environment can disrupt the stability.</td>
<td>Students construct and present defend an explanation about how an environmental stress will affect the variations of a trait in future generations of a population.</td>
</tr>
<tr>
<td></td>
<td>The variation between members of a population result in some organisms having an advantage over others and so survive to nature and reproduce.</td>
<td>6. The variation between members of a population result in some organisms having an advantage over others and so survive to nature and reproduce.</td>
<td>Students construct, revise, present, defend, and critique explanations about how the variations in traits of a single species give some individuals advantages over others in surviving environmental stress and in reproduction.</td>
</tr>
<tr>
<td></td>
<td>Changes in environmental conditions can introduce environmental stress or pressure on organisms, affecting survival of individuals or species.</td>
<td>7. Changes in environmental conditions can introduce environmental stress or pressure on organisms, affecting survival of individuals or species.</td>
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Recommendation 3: The learning targets should be sequenced to build the conceptual framework of a unit of study. Sequencing the learning targets is a critical step to support all of our students on the learning continuum. Some students will struggle with the first learning target in the sequence while others will be at learning target four. Identifying smaller steps that lead from one to the next breaks the learning goal down in ways that make the overall big ideas attainable. If we only share the big ideas and key concepts with students, many of them think that the science concepts are too hard and they give up. Knowing where they are heading and the steps they will take makes the learning more attainable for students and moves them along the trajectory (progression).

Recommendation 4: All activities are not created equally. Some merely ask students to fill in data charts and others ask them to identify facts and vocabulary without applying their work to learning about the important concepts. Every learning activity we select must be aligned to the learning targets and the conceptual understanding in the activity should help them think about the science ideas. So once again, the learning activities need to be more than activities for activities’ sake. Look at the lesson activities that you have available and think about how to change them so that the conceptual learning is the focus.

Understanding

This chapter focuses on strategies you can use as you work with your students to develop their understanding of science concepts. In Chapter 2 we learned about identifying the right content and in Chapter 4 you will learn about creating a collaborative learning environment in the classroom. After reviewing the research on effective science instruction, we are recommending six instructional strategies that help develop student understanding. Table 3.1 provides an overview of all of the strategies. Remember, these strategies help you focus on the question “Who is working harder?” Your lessons should be structured such that the answer is “The students”. As a result of this chapter, we hope you will understand the suggested strategies for developing student understanding and be able to apply them to your classroom. In thinking about what you do already to support a learner-centered classroom, we hope the ideas presented will be useful as you strive to improve students’ conceptual understanding.

Understanding Strategy 1: Engaging Students in Science Inquiry

The Issue

Learning science is often confusing for our students. Much of what we teach must be modeled for students because direct observations of the science phenomena are not possible. For example, studying the chemical and physical changes in matter can require sophisticated technology to provide direct observations, so we use models and diagrams to illustrate the science concepts. Studying populations of organisms and changes in the environment that happen over long periods of time often exceed the time we have with students so we provide sets of data for stu-