
Learning About Seeds
We planted our seeds on Wed. April 26th
We have been growing our garden for this many days:

Chapter 2

How Do Children Construct Understanding in Science?

CHAPTER LEARNING PERFORMANCES

- *Explain the difference between inert and meaningful knowledge.*
- *Describe the three types of knowledge—content, procedural, and metacognitive.*
- *Critique examples of teaching to determine if they represent receptional or transformational approaches to teaching and learning.*
- *Explain what is meant by social constructivism and describe the various features of a social constructivist model of teaching.*
- *Develop a lesson based on the social constructivist model of teaching.*
- *Apply the idea of scaffolding to help children accomplish a difficult learning task.*
- *Discuss how authentic tasks help women and minorities participate and stay interested in science.*

INTRODUCTION

Children face an increasingly scientific and technological world. Information and access to information are growing at an exponential rate. Schools need to prepare our youth to learn and apply all of this scientific knowledge to solve real-world problems. Do students in our schools develop understandings that help them use science? What is a *usable understanding of science*? How can teachers help students develop usable science understanding?

This chapter examines the educational literature that anchors project-based science in the social constructivist theory of learning. We'll consider a social constructivist model of teaching that focuses on active engagement with phenomena, using and applying knowledge, multiple representations, use of learning communities, and the role of authentic tasks. We'll examine types of knowledge and ways to help students develop integrated understandings through the construction of knowledge in social situations. Finally, we will explore a number of techniques to help teachers scaffold students' learning of science. First, however, let's develop a working definition of *understanding.*

STUDENT UNDERSTANDING

> ***Key Idea***
>
> School science often results in students developing inert knowledge—disconnected, unusable fragments of ideas.

What kinds of science understandings do students develop in school? Does school help them develop understandings that are useful for their lives? Unfortunately, a number of research studies (Osborne & Freyberg, 1986; Rutherford & Ahlgren, 1989; AAAS, 1993; and Linn, 1998) indicate that students at the elementary, middle, and high school levels do not develop an understanding of science that is useful for their everyday lives. Most students memorize science terms without understanding, and they memorize how to solve problems (Eylon & Linn, 1988; Osborne & Freyberg, 1986). Students learn bits of factual information and how to solve problems at the end of chapters by using formulas. Scientific facts and algorithmic problem solving make up much of the science curriculum taught in U.S. schools. Most children do not develop rich understanding and cannot apply what they learn to explain scientific phenomena. This kind of knowledge has been defined as *inert knowledge.* The learner with **inert knowledge** lacks connections and relationships between ideas, and cannot retrieve or use knowledge in appropriate situations (Perkins, 1992). For example, a fifth grader might be able to define *atom* but not know how to use the definition to explain properties of matter.

Students' decreased interest in science appears to be a contributing factor to decreased understanding of science. Although most elementary children start school with an interest in the physical world, they soon lose interest in learning about science. As students transition to middle school, their interest in science decreases further and students lose motivation to continue their learning of science. Yager and Penick (1986) summarized the data from various national studies and concluded that "the more years our students enroll in science courses, the less they like it." This conclusion is also supported by the Third International Mathematics and Science Study (TIMSS, 1998), which indicates that interest in science decreases from elementary grades to high school. One possible reason for this decrease in motivation stems from the predominant use of textbooks to teach science and the emphasis on memorizing science facts. Most students need to experience science as an active process of engagement for interest to be high.

Let's examine three scenarios that illustrate the variety of understandings students have of scientific ideas.

Scenario 1: What Is Alive?

The first scenario comes from a common biology topic: What is alive? Mr. Ramirez asked his second graders if a seed, such as that from an apple, is alive. Most of his students responded, "No." When Mr. Ramirez probed them to explain their answers, many said that a seed does not move and so cannot be alive.

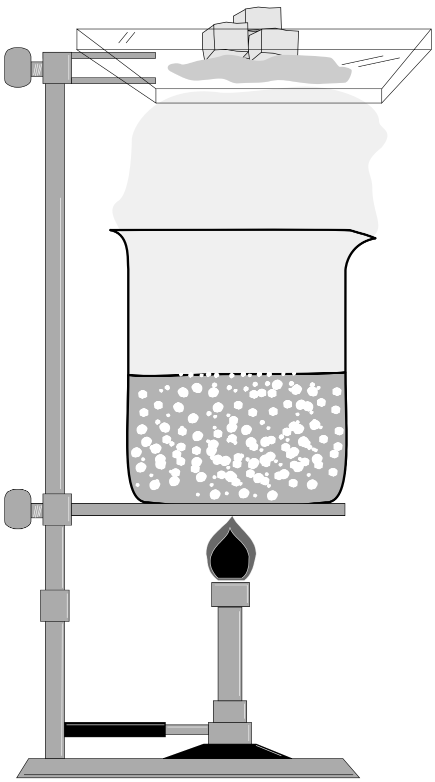
Young children tend to categorize *alive* and *not alive* according to superficial physical characteristics and to the presence or absence of locomotion (Carey, 1985; Driver, Squires, Rushworth, & Wood-Robinson, 1994). Older students and students more knowledgeable of biology retain aspects of this categorization scheme but seem to broaden their criteria for *life* to include more carefully differentiated ideas of function (autonomous movement is distinguished from simple movement) and ideas about additional functions (growth, metabolism, and reproduction). If we ask older children (seventh or eighth grade) if an apple seed is alive, many will say that it has the "potential" to grow but that it is not alive. This example shows how students do not develop rich ideas about basic biological phenomena.

Scenario 2: Boiling Water

The second scenario centers on a common physical science topic: the boiling and condensing of water. Ms. Beacher asked two of her fourth-grade students, Kristen and Shawn, to make observations of and explain a laboratory setup in which water was boiling in a beaker and condensing on a cool glass surface held above the beaker. Figure 2.1 shows the experimental setup. Kristen said that the water was boiling. Ms. Beacher asked how she knew, and Kristen answered, "Because of the bubbles in the water." Shawn added that water was condensing on the glass surface. Ms. Beacher probed them further to elicit more in-depth responses. She asked, "What is inside the bubbles?" Kristen responded, "Air," and Shawn agreed. Then Ms. Beacher asked, "Well, if there is air in the bubbles, where does the air in the bubbles come from?" Both Kristen and Shawn looked at Ms. Beacher with blank faces. She then asked them, "Shawn, you mentioned that water was condensing on the glass surface. Where does that water come from?" Shawn responded, "It evaporated from the beaker." Ms. Beacher probed further: "Can you tell me what it means to evaporate from the beaker?" Shawn replied, "You know; it came from the beaker."

This scenario shows that the children were able to use scientific terms, but they could not use the terms to explain some everyday phenomena. Children might use terms such as *evaporate, condense,* and *boil.* However, if we use probing questions to elicit from them more in-depth descriptions and explanation of the phenomena, we find that many students don't have a very rich understanding of the terms they use. As the example illustrates, many of them cannot go beyond just using vocabulary terms (Osborne & Cosgrove, 1983). Interestingly enough, the responses of eighth graders are not very different from those of these fourth graders. In their explanation of boiling, some eighth-grade students say that the bubbles in the water are made of air or hydrogen and oxygen gas instead of explaining that the bubbles are filled with water molecules in the gaseous phase.

Figure 2.1

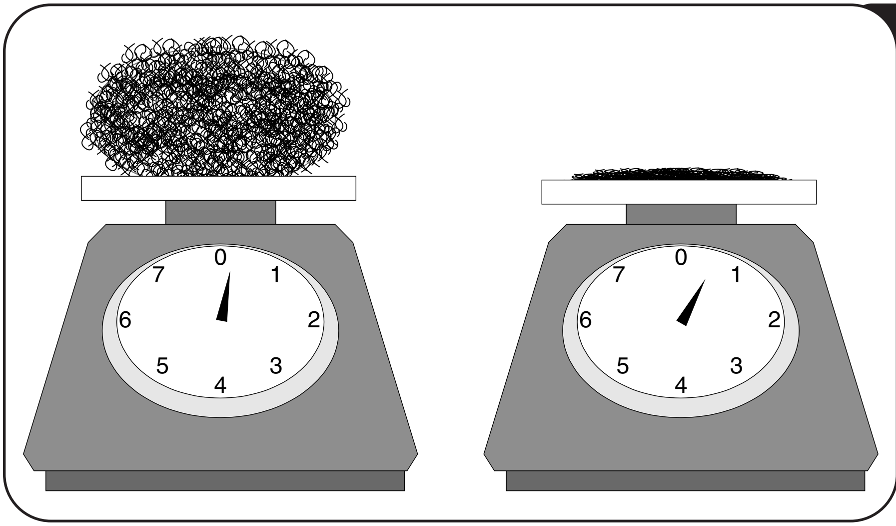


Children cannot frequently explain simple phenomena such as the boiling and condensing of water.

Scenario 3: Burning Steel Wool

The third scenario centers on a common chemistry topic. Ms. Jackson's sixth graders observed a piece of steel wool burning in air. Many of the students explained that a chemical reaction was occurring. However, when Ms. Jackson asked them to predict how the original mass of the steel wool would compare to the mass of material remaining after burning, almost all of the students predicted that the mass of the material remaining after burning would be less than the original mass of the steel wool. Ms. Jackson then asked the students to explain why they thought the mass would decrease. Many of them said that it turned to ash, like paper or wood, when it burned. Next, the students measure the mass of steel wool before burning and then measured it again after burning. They noticed that the mass did not decrease and, in fact, increased (see Figure 2.2). Most children, and adults too, would be surprised at these results. When Ms. Jackson asked the students to explain the increase in mass, some said that the steel wool turned into carbon, which is heavier than steel wool (Anderson, 1986).

Figure 2.2



Children believe that the residue that remains after steel wool is burned will weigh less than the steel wool.

Once again, the responses of eighth graders do not differ substantially from those of these sixth graders. The example illustrates that students lack understanding of combustion, in which a substance chemically combines with oxygen to form a new substance, iron oxide.

These scenarios illustrate that, when we ask students to qualitatively explain scientific phenomena, students typically use the "correct" words such as *evaporation, condensation,* or *reaction,* but they lack understanding of the underlying scientific concepts (Driver, Squires, Rushworth, & Wood-Robinson, 1994; Osborne & Cosgrove, 1983).

How would you have answered the questions in the three scenarios? Qualitative explanations of scientific phenomena are a challenge, not only for many elementary and middle school students, but also for many high school, undergraduate, and even graduate students. When the three scenarios were replicated in science methods classes and in graduate courses, even students with backgrounds in science had a difficult time giving solid, qualitative explanations of the observed phenomena. Many college students were surprised that the residue of burning the steel wool had more mass than the steel wool, even though they had successfully completed introductory college chemistry. Take time now to complete Portfolio Activity 2.1.

> ***Key Idea***
>
> Students have meaningful understandings when they can use their knowledge in a variety of different situations to solve problems.

What is *your* reaction to the fact that the mass of a tree comes primarily from carbon dioxide found in the air and water taken from the environment? Many students, even biology majors, seem surprised by this information. Yet this is the basic premise of photosynthesis—a concept that is found in every elementary book and covered in every basic biology class in high school and college.

To learn more about scientific understandings, talk with some children about common physical, chemical, or biological phenomena. Having conversations with children of

THINKING ABOUT YOUR OWN UNDERSTANDING

Materials Needed:
- Something to write with
- If available, the *Private Universe Project* tapes (Presidents and Fellows of Harvard College, 1995)

A. Picture a tree seed. Next, picture an entire tree. How did the tree get its mass? Where did it come from? Answer these questions in your portfolio.

B. Contrast your answers with those of a few classmates. What ideas do you and your classmates have about where the mass came from? Try to come to a consensus.

C. Look up the word *photosynthesis* in a science book and read about it. What are your thoughts now about how a tree gets its mass? How do these differ from your initial thoughts? How are they alike?

D. If available, watch some of the episodes of the Harvard *Private Universe Project* series. One of them centers on how a seed grows to be a tree. What are your reactions to students' understandings of science concepts?

E. Think about the types of understandings you have developed about science concepts. How often have you used your science ideas to explain phenomena in your daily life? List as many examples as you can in your portfolio.

INVESTIGATE YOUNG LEARNERS' IDEAS

Materials Needed:
- Something to write with
- Baking soda
- A 250 ml beaker
- Vinegar
- Water
- Two students of different ages to talk with

A. Set up a conversation with two students of different ages to learn about how they understand some science concepts. You might want to tape your interview. Make sure to find out the following information:

   - Age of student.
   - Current grade.
   - What science topics they remember studying in school or at home.

   NOTE: Probing a child to determine his or her conceptual understanding is a difficult process. It is a good idea to practice with a classmate or a friend before you conduct these interviews with students. Tape these practice sessions and study the way you asked questions. In general, observe the following guidelines when interviewing your learners:

   1. Avoid using leading questions that suggest responses. For example, don't say, "How do you think this will react?" By saying *react,* you lead the students to think something is going to happen.
   2. Avoid praise or negative comments. For example, don't say, "Good." Rather, say, "I see."
   3. Use phrases that allow a learner to clarify and expand on his or her ideas. Be sure to probe when scientific or technical terminology is used. For example, if the student says, "It will evaporate," ask, "What do you mean by 'it will evaporate'?" To clarify ideas, say things like, "Could you tell me more about what you mean?" Here are other phrases:
      - "Please describe that further."
      - "What do you mean by…?"
      - "Tell me more about…?"
      - "Is this what you mean…?"
      - "Please explain that further."
      - "Hmm. That's interesting. Tell me more about that."
      - "What else would you like to tell me about what you observed?"
   4. Listen to the learner—use active listening techniques. For example, look at the child when he or she is speaking. Paraphrase what the student says. For example, if the child says, "I think it will disappear," you might say, "Do you mean you wouldn't be able to see it?" Ask for explanations. Summarize what you think the student said.

different ages and comparing their responses can help you discover some surprising things about what they know. Portfolio Activity 2.2 is designed to help you begin talking to children about their science ideas.

Meaningful Understandings

Instead of developing inert knowledge, project-based science helps students develop meaningful understandings. **Meaningful understanding** results from the learner building relationships and connections among ideas and blending personal experiences with more formal scientific knowledge (Bransford, Brown, & Cocking, 1999; Krajcik, 2001). Imagine a child who understands from a prior lesson the relationship between molecules in gaseous, liquid, and solid states. The child learns a new concept about sound vibrations traveling through different substances. The child notices during some activities that sound travels best through solids, next best through liquids, and least well through air. The teacher asks, "Why do you think sound travels best through the solid and least well through the air?" The child answers, "Well, it probably has something to do with what it is made of." The teacher replies, "What did we learn about what all matter is made of?" The child says, "Atoms." The teacher prompts the student by saying, "What do you know about

5. Use the learner's language to rephrase and further probe the learner's response. For example, if a student says, "I won't be able to see it," say, "Why can't you *see* it?" Don't say, "Do you mean it will dissolve?"
6. Provide the learner with ample time to construct a response. Wait at least three to five seconds after asking a question before you say anything more.
7. Establish a calm and accepting atmosphere. Don't rush the conversation by talking hurriedly or being judgmental about responses.
8. If a learner cannot answer a question, try rephrasing the question to find out what the student does know and what his or her thoughts are. For example, if you first ask, "What do you think will happen?" and the child doesn't respond, rephrase the question to say, "What do you think will happen when I put this baking soda into this water and stir it?" However, be careful; don't add more than what the student said.

B. Complete the following tasks with the two students:

Dissolving Change Task. In this task, you will mix a teaspoon of baking soda in 100 ml of water. The baking soda will dissolve in the water.

- Show students a teaspoon of baking soda and a 250 ml beaker with 100 ml water. Ask students to predict what will happen if you mix the baking soda in the water.
- Place the baking soda in the beaker of water and stir. Ask the students to describe what they see. Ask the students to explain what they observe. Find out what the students mean by the words they use. For instance, if they say, "It dissolved," ask them what they mean by *dissolved.*
- Ask the students what they might see if they could magnify the contents of the beaker 100 million times. Ask the students to draw what they think they would see.

Chemical Change Task. In this task, you will mix a teaspoon of baking soda in vinegar. This is a chemical change; the baking soda will react with the vinegar to form new products.

- Show students a teaspoon of baking soda and a 250 ml beaker with 100 ml of vinegar. Ask students to predict what will happen if you mix the baking soda in the vinegar.
- Place the baking soda in the beaker of vinegar. Ask students to describe what they see. Ask students to explain what they observe. Find out what the students mean by the words they use. For instance, if they say, "It reacted," ask them what they meant by *reacted.*
- Ask what they might see if they could magnify the contents of the beaker 100 million times. Ask the students to draw what they think they would see.

C. Process what you found. Combine your data with the data from other students in your class. Summarize your data. What conclusions can you draw? What educational implications do your conclusions indicate? Record these in your portfolio.

the molecules in different states of matter?" The child answers, "Well, the molecules are close together in solids and far apart in gases." The teacher questions, "And what might this tell you about sound travel?" The child says, "Oh, I get it. In solids the molecules are close, so vibrations happen because the molecules can bump into each other. And that's not true in gases; the molecules can't bump into each other as well because they are too far apart." This student has meaningful understandings: she used her understanding of molecules in different states of matter to come up with a new explanation of the effect of states of matter on sound travel.

Students who have meaningful understandings can use those understandings to solve problems. For instance, a child with meaningful understanding might use Newton's laws of motion to explain why a person needs to wear seat belt when riding in a car. Newton's First Law of Motion states that an object will stay at rest or continue in motion unless acted upon by a force. Therefore, we wear a seat belts so that our bodies don't continue in motion (hit the windshield or get thrown out of the car) if the car comes to a sudden stop.

Figure 2.3, created by Valerie Talsma, illustrates the difference between inert and meaningful understanding. The cell in the lower left corner, Cell A, represents a learner who has very little understanding and whose understandings are not connected to each other. This learner has inert knowledge—disconnected, unusable fragments of facts. The cell in the lower right corner, Cell B, represents a learner with some understanding that is tightly integrated. This learner has the type of understanding we want a student to develop at the third- or fourth-grade level, where their understandings, although limited, should be integrated. The cell in the upper left corner, Cell C, represents a learner who has accumulated knowledge but has not integrated the knowledge. This is the type of understanding that often emerges in schools. The cell in the upper right corner, Cell D, represents a learner who has accumulated knowledge and developed meaningful understandings. This is the rich, integrated understanding that learners achieve in project-based science.

Types of Knowledge

One way to think about integrated and meaningful knowledge is to think about three types of knowledge: content, procedural, and metacognitive (Anderson & Krathwohl, 2001; Perkins, 1992). All three types of knowledge are needed for understandings to become integrated and meaningful.

Content knowledge refers to the central concepts, principles, and theories in an area of study. One example of a central science concept is *force.* An example of a principle is Newton's First Law of Motion. A learner who understands why an object stops moving once it is given a push, for example, has a better foundation to understand central concepts and principles of physics such as *force, acceleration, velocity,* and Newton's three laws of motion.

Content knowledge, however, is only one type of knowledge that students need to develop (Perkins, 1992; Krajcik, 2001). Understanding also depends upon accumulating supporting knowledge that helps the learner know how to learn. This supporting knowledge includes procedural knowledge and metacognitive knowledge. **Procedural knowledge** is essential in helping a student engage in inquiry and in finding solutions to problems. A child uses procedural knowledge to find solutions to questions, design an experiment, and

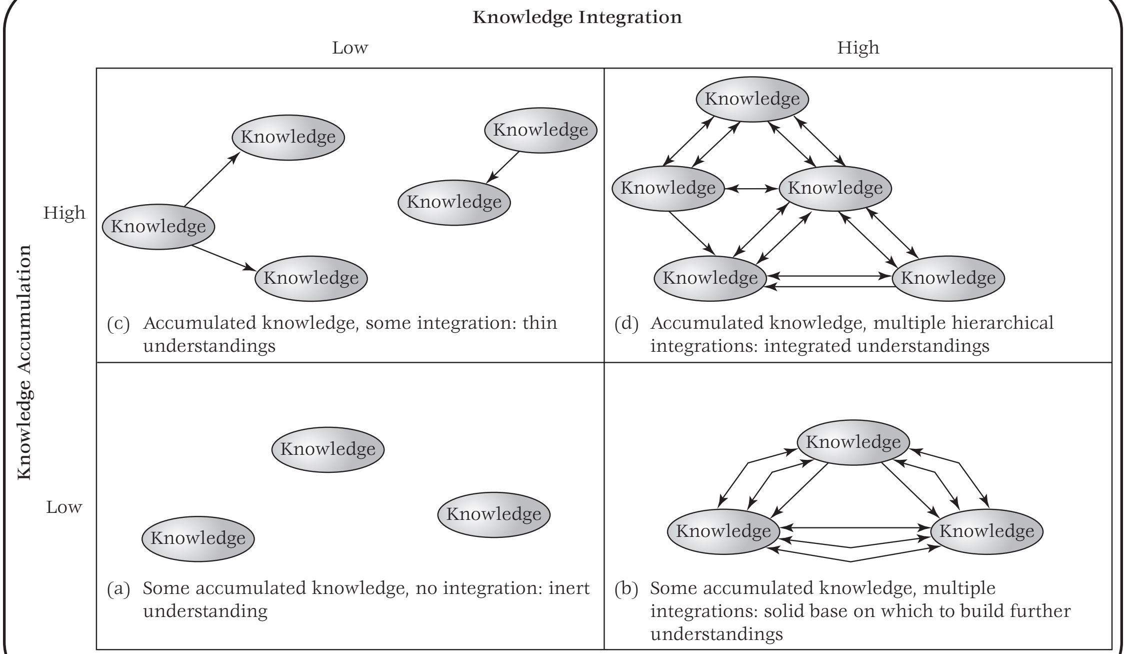


Figure 2.3

Understanding is a function of knowledge accumulation and knowledge integration. Theoretically, it is possible to accumulate a large number of discrete bits of knowledge without creating relationships between those pieces of knowledge or with only a few weak relationships (Cells A and C). It is also possible to have a limited amount of knowledge of which each piece is well integrated or linked to other knowledge, perhaps in multiple ways (Cell B). Rich, integrated understandings are achieved as knowledge becomes both structured and integrated (Cell D).

(Talsma, 1998).

find and evaluate background information related to a question. For instance, knowing how and when to control variables is procedural knowledge. (Chapter 4—"How Are Scientific Investigations Developed?"—discusses the control of variables in more detail.) Procedural knowledge also involves knowing when the evidence is sufficient for a person to draw a valid conclusion.

Metacognitive knowledge (Anderson & Krathwohl, 2001) is knowledge about cognition in general as well as awareness and knowledge about one's own cognition. Anderson and Krathwohl describe three types of metacognitive knowledge: strategic knowledge, knowledge of cognitive tasks, and self-knowledge. *Strategic knowledge* refers to knowing different strategies for learning such as knowing how to use search terms to find information on the World Wide Web. *Knowledge of cognitive tasks* refers to the

Table 2.1

THREE TYPES OF KNOWLEDGE

Type of Knowledge	Definition	Examples
CONTENT	Knowing the central concepts and principles in a domain	In biology, understanding predator and prey relationships; in chemistry, understanding physical and chemical change; in physics, understanding inertia
PROCEDURAL	Knowing how to solve problems and design and carry out investigations	Knowing how to design an experiment; knowing how to analyze data; knowing strategies for monitoring one's progress
METACOGNITION	Knowing different strategies for learning; knowing the difference between different cognitive tasks; knowing one's own strengths and weaknesses in learning	Knowing different strategies for solving problems; knowing that memorizing definitions of terms is not as difficult as explaining what a term means; knowing that one finds it difficult to write careful observations

understanding that cognitive tasks are different such as understanding that data analysis might include transforming the data into a different representation. *Self-knowledge* refers to knowing one's own strength and weaknesses in learning. For instance, a child might realize that he has difficulty spelling science words, so he might need to spend extra time on them.

A child uses metacognitive knowledge to monitor her progress on a report or to decide when to seek help with a procedure. A student with strong metacognitive strategies will be able to track how well he is completing a task, such as following procedures, that is part of an investigation that extends over time. A child with metacognitive knowledge will know when she has collected enough information to make a conclusion.

We present this summary of the three types of knowledge because all three are essential for students to develop the integrated and meaningful understanding needed for continued learning. Limiting a student to content knowledge robs the learner from learning more. Meaningful understandings will occur only if content knowledge is developed in the process of engaging in inquiry. For example, if a child knows only definitions of molecular states, she will not be able to use the understandings and apply them to a new situation related to sound travel. Table 2.1 summarizes the three types of knowledge.

MODELS OF TEACHING

You can think of teaching on a broad continuum from transformational approaches to receptional approaches.

Transformational approaches to teaching and learning involve teachers supporting students to make sense of material. Project-based science is one example of a transformational approach to teaching and learning. In contrast, **receptional approaches** to teaching and learning involve teachers transmitting information and students receiving it. Receptional approaches to teaching and learning have long dominated our school systems. Armstrong (1994) writes, "For most Americans, the word *classroom* conjures up an image of students sitting in neat rows of desks facing the front of the room, where a teacher either sits at a large desk correcting papers or stands near a blackboard lecturing students" (p. 86).

Key Idea

Receptional approaches to teaching and learning involve teachers transmitting information and students receiving it. *Transformational approaches* to teaching and learning involve teachers supporting students to make sense of material.

A Receptional Approach to Teaching

Marie, a sixth-grade teacher, believes that children need to be quiet and in their seats to learn the information she is telling them. In a recent lesson in which she taught about sound, she first had the students read from the textbook the chapter on sound. Students read out loud one paragraph at a time. Marie indicated to students what the important concepts were by writing them on the board as they were read. Students wrote definitions of the important vocabulary words—frequency, pitch, amplitude, waves, rarefaction, and compression—in their science journals. Marie attempted to prove to the students that sound is produced by waves by demonstrating the waves that are created by striking a tuning fork and placing it in water. Next, Marie showed the children the different frequencies produced by tuning forks of various pitches. Finally, Marie reinforced the important concepts by showing a videotape covering the same ideas. Students received a homework assignment: They had to answer three questions at the end of the textbook chapter. Marie evaluated the students with a quiz at the end of the week. On this quiz, students were asked to choose the correct definitions for words such as pitch, amplitude, and frequency.

A Transformational Approach to Teaching

Roberta, another sixth-grade teacher, introduced the same sound lesson as Marie in a very different manner. Roberta was investigating with her class the driving question "What Makes Music?" She introduced a benchmark lesson to help students understand basic concepts of sound. First, she handed each child in the class a balloon, a rubber band, and a ruler. The students were instructed to spend the next ten minutes exploring ways to make sounds with each of the objects. At the end of the exploration time, students were asked to discuss their findings with each other in small groups and later share with the whole class what they had discovered about sound. Roberta did not evaluate these ideas but listed all of them on the board. One child said that the balloon was louder than the rubber band. Another said that the ruler changed sound as it was hung off the table at different lengths. A third student said that a loud sound was created when she snapped Randy, her neighbor, with the rubber band. (Oops—the teacher forgot to set some basic ground rules for behavior! See Chapter 10 for more information about classroom management.) Yet another child said that all the objects were moving when the sounds were produced. Roberta wrote the word *vibration* on the board and told the children that that is the term scientists use for such movement.

Then she asked the class to stop and compare each object again. She asked, "Is it true that all the objects need to be moving to produce sound?" The students debated the

Science Education Program Standards
Student understanding is actively constructed through individual and social processes. In the same way that scientists develop their knowledge and understanding as they seek answers to questions about the natural world, students develop an understanding of the natural world when they are actively engaged in scientific inquiry—alone and with others (p. 29).

evidence supporting this conjecture. One student asked how the sounds made by a thick rubber band would differ from those made by a thin one, just as the strings on his guitar made different sounds. Roberta encouraged the students to explore this idea. Through questioning, she guided the students through a comparison of the lengths, thicknesses, and stretched widths of the various objects and a comparison of the pitches. She asked students to think about why the pitch would be different—was there anything different about the vibrations? Using the materials, students explored the question in small groups. By analyzing the evidence they collected, the students explained that the differences in pitch seemed to be caused by variations in how fast the rubber bands were moving.

Roberta introduced the class to the term *frequency* and helped students see how their findings matched the definition of this term. Students were encouraged to think about their own experiences that would support the concept that sound is caused by vibrations and that pitch is caused by variations in the frequency of the vibrations. A student mentioned the digital monitors on her stereo system that visually displayed the frequency of vibrations. Another told about a time that he dropped salt on the top of the TV; the salt "danced" up and down and vibrated while the TV was turned on but was still when the TV was turned off. A third student discussed how she would place her fingers and move her lips to play her clarinet. Yet another talked about watching the pictures on her brother's wall vibrate when he turned up his rock music. Roberta consistently asked students to elaborate on their examples and to explain how the examples supported the question asked. Students were frequently asked to confirm or refute comments made by others in the class. Finally, to evaluate what students learned, Roberta asked them to write down in their journals what they had learned in the lesson.

What can be done to help children develop integrated and meaningful understanding of science? How can we help children apply scientific concepts and principles to solve real world problems that are of interest to them? What can be done to help children develop content, procedural, and metacognitive knowledge? Research findings from the last two decades have shown growing support for the notion that integrated and meaningful types of knowledge are best learned when what occurs in schools is less receptional and more transformational.

SOCIAL CONSTRUCTION OF KNOWLEDGE

How do students come to make sense of material rather than only memorize it? Brown, Collins, and Duguid (1989) argue that "knowledge is . . . in part a product of the activity, context, and culture in which it is developed and used" (p. 32). These researchers see knowledge as contextualized. By **contextualized** they mean that knowledge cannot easily be separated from the situation in which it is developed. Blumenfeld and colleagues (1998) reiterate this notion: "Knowing and doing are not separated; knowledge is not an abstract phenomenon that readily can be transferred from how it is learned in the classroom for use in other situations." This learning model, which suggests that learning cannot be separated from the social context in which it takes place, is often referred to as **social constructivism.**[1]

Unlike the receptional approach to teaching, the transformational approach is consistent with social constructivist theory and project-based science. What are the similarity and differences between the two approaches? Can you identify a constructivist lesson? Portfolio Activity 2.3 will help you explore this idea on your own.

The Influence of Jean Piaget

Jean Piaget

Jean Piaget (1970), arguably the most influential developmental psychologist of the twentieth century, believed that a person's reasoning and intelligence developed like other biological systems—through maturation, or innate biological changes, as well as through the process of equilibration. According to Piaget (1970), an individual actively modifies what he/she knows through interactions with the environment and others. Maturation, in addition to environmental and social interactions, influenced how an individual's reasoning and intelligence developed. **Equilibration** refers to the process of modifying one's mental structures, or schemas, to fit new experiences. **Schemas** can be thought of as blueprints that guide behavior and reasoning but that can be modified.

Piaget tested his ideas about intellectual development on his own and other children and identified four "forms" of thought. These are not lock-step stages tied to specific ages but rather types of thought more or less pronounced at various developmental levels. Even adults learning something new will progress through the various forms of thought. Piaget's four forms of thought are **sensorimotor intelligence** (in which the child interacts with the environment through sensory and muscular activity), **preoperational thought** (characterized by the development of language and rapid conceptual development focused on mastering representations without thorough understanding), **concrete operations** (in which children develop the ability to apply logical thought to problems they come across in their environment), and **formal operations** (in which the child becomes able to apply logical thought to all types of problems—including ones he or she cannot actually experience directly).

Piaget's ideas about biological maturation and interaction with the environment and others had important consequences for curriculum and instructional activities. If an individual does not reach a particular maturation point, it will be impossible for him to develop understanding; similarly, if he lacks appropriate experience, he will not be able to develop the appropriate understanding. Hence, according to Piaget, curricular materials should fit the cognitive development of the student. If, for example, the curriculum aims at exploring abstract ideas, then students whose cognitive development is still at the concrete operational stage may lose their motivation and not succeed in their learning.

Key Idea

Adaptation refers to actively creating an accurate view of world. Adaption occurs through two pricipals: assimilation and accommodation.

Piaget's ideas about adaptation also play a key role in his theory of reasoning and intellectual development. **Adaptation** refers to an individual's attempt to create an accurate view of the world so that she can continue the process of development. Two basic principles allow adaptation to occur: assimilation and accommodation. **Assimilation** refers to

[1]This book adopts a social constructivist perspective. Other forms of constructivism are radical constructivism and contextual constructivism. For more information on other variants of constructivism, see Tobin, K., ed. 1993, *The practice of constructivism in science education,* Washington, D.C.: American Association for the Advancement of Science. Also consult Shapiro, B. 1994. *What children bring to light: A constructivist perspective on children's learning in science.* New York: Teachers College Press.

Portfolio Activity 2.

RECOGNIZING AND EVALUATING A SOCIAL CONSTRUCTIVIST LESSON

Materials Needed:

- Something to write with

A. Read the following classroom descriptions.

1. Marquette, a kindergarten teacher, asks her students to tell her what they want to know about pets. Three students want to know more about dinosaurs, two students want to know how they can get pet rabbits, one inquires about a lizard, and two want to learn more about kittens. As students suggest these animals, she writes the words *dinosaur, rabbit, lizard,* and *kitten* on the board. Marquette does not tell the three students that dinosaurs are not pets; instead, she asks the students what they think about the pets suggested. Quickly a number of students point out that dinosaurs are not pets. Marquette asks the students to elaborate on their reasons for this belief, and then she asks the students who originally suggested dinosaurs what they think. Two agree that they are not pets, but one, Tyrone, says that he has a whole collection of them. Marquette asks this student to explain what he thinks it means to have a pet; he says that a pet is an animal you collect. She asks him if he has ever been to a pet store. He has. She asks whether he has ever seen dinosaurs for sale at the pet store. He agrees that he hasn't. Another student quickly quips that the pets must be alive, and you need to feed and care for them. Tyrone agrees and says that he would like to learn more about lizards that look like the dinosaurs in his collection.

   Marquette leads the class in a discussion about what students would like to know about each animal, and she asks them to suggest how they might learn these things. From this discussion comes the idea that veterinarians and pet store owners would be able to answer a number of their questions. Carlos, a boy in the class, says that his mother is a veterinarian and that he will ask her to come to school to talk. Marquette agrees, and she calls the mother to make arrangements. Mrs. Hernandez comes to school the next week and teaches the students about the nutrition necessary for various types of pets—particularly the lizard, rabbit, and kitten suggested by the students. She also discusses dogs, guinea pigs, hamsters, and gerbils, as instructed by Marquette. The next day, Marquette passes out a worksheet with pictures of animals and the foods they eat. The children are evaluated on their ability to match the proper food with the animal that eats it.

2. Ron, a third-grade teacher, is very interested in space flight and astronomy. He has shared with the students in his class many artifacts, including photographs taken on vacations and trips to the Kennedy Space Center at Cape Canaveral in Florida and the Neil Armstrong Center in Wapakoneta, Ohio. He has shown many movies and videos on space travel, and he has even brought his telescope to school for the students to look through. His students have become quite interested in astronomy and space travel. During science class, a student in the class shares with the others that his parents took him to a planetarium at a nearby university over the weekend. Ron decides this would be a great trip for his class and schedules it. On the trip, students learn about the constellations and apparent movement of stars in the sky throughout the year. Ron finds an activity in a teacher book with a star locating device in it. He has his students make the star finder and asks the students to look for certain constellations in the sky over the next month. Daily, he has students share information they have discovered about the stars and various constellations. At the end of the month, he gives the students a quiz in which they match the constellations with their names. He also quizzes students on the definitions of *star, constellation, sun, orbit, revolution, rotation,* and other important words that are in the textbook.

B. Using the following chart, evaluate the two lessons in terms of how well they meet the criteria for social constructivist lessons. Record the results in your portfolio. Then meet with teammates to discuss your evaluations. Come to a consensus.

C. Neither of these two lessons has all the features of a social constructivist classroom. How could they be revised to contain more of the features?

D. Meet with your classmates to come to a consensus on improving the lessons.

E. Record the results of your meetings and thoughts in your portfolio.

Scale for Evaluating Degree of Constructivist Learning

Active Engagement with Phenomena

Students ask and refine questions related to phenomena.
often ______ ______ ______ ______ ______ ______ ______ seldom

Students predict and explain phenomena.
often ______ ______ ______ ______ ______ ______ ______ seldom

Students mindfully interact with concrete materials.
often ______ ______ ______ ______ ______ ______ ______ seldom

Use and Application of Knowledge

Teachers and students use prior knowledge.
often ______ ______ ______ ______ ______ ______ ______ seldom

Students identify and use multiple resources.
often ______ ______ ______ ______ ______ ______ ______ seldom

Students plan and carry out investigations.
often ______ ______ ______ ______ ______ ______ ______ seldom

Students apply concepts and skills to new situations.
often ______ ______ ______ ______ ______ ______ ______ seldom

Students are given time for reflection.
often ______ ______ ______ ______ ______ ______ ______ seldom

Students take action to improve their own world.
often ______ ______ ______ ______ ______ ______ ______ seldom

Multiple Representations

Students use varied evaluation techniques.
often ______ ______ ______ ______ ______ ______ ______ seldom

Students create products or artifacts to represent understanding.
often ______ ______ ______ ______ ______ ______ ______ seldom

Students revise products and artifacts.
often ______ ______ ______ ______ ______ ______ ______ seldom

Use of Learning Communities

Students use language as a tool to express knowledge.
often ______ ______ ______ ______ ______ ______ ______ seldom

Students express, debate, and come to a resolution regarding ideas, concepts, and theories.
often ______ ______ ______ ______ ______ ______ ______ seldom

Students debate the viability of evidence.
often ______ ______ ______ ______ ______ ______ ______ seldom

Learning is situated in a social context.
often ______ ______ ______ ______ ______ ______ ______ seldom

Knowledgeable others help students learn new ideas and skills that they couldn't learn on their own.
often ______ ______ ______ ______ ______ ______ ______ seldom

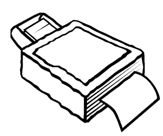
Role of Authentic Tasks

Driving questions focus and sustain activities.
often ______ ______ ______ ______ ______ ______ ______ seldom

The topic or question is relevant to the student.
often ______ ______ ______ ______ ______ ______ ______ seldom

Learning is connected to students' lives outside school.
often ______ ______ ______ ______ ______ ______ ______ seldom

Science concepts and principles emerge as needed to answer a driving question.
often ______ ______ ______ ______ ______ ______ ______ seldom



fitting new information into existing mental structures or schemes. For instance, a child who has goldfish will think of a fish as an animal that lives in water. When he learns about whales in school, sees a picture of a whale in a book, or sees a video about whales, he classifies the whale as a fish because it lives in water. **Accommodation** refers to making a permanent change in a mental structure. For instance, as the child gains more knowledge about fish and mammals, he changes his mental structure of a fish as an animal that lives in water. He now has schemas for fish that live in water and mammals that live in water.

Piaget's theory of intellectual development had a major influence on the development of the inquiry-focused curriculum of the 1960s such as the Elementary Science Study (ESS) program. ESS asked young students to interact with materials to build mental structures of key science ideas. For instance, in the *Battery and Bulb* unit, students were given a wire, a bulb, and a battery and were asked to light the bulb. Based on this experience, a student would be better able to build a cognitive structure for a circuit.

Piaget's theory of intellectual development also profoundly influenced Robert Karplus's notion of the learning cycle (Karplus, 1977). The **learning cycle** is an instructional model used in a number of curriculum projects developed in the 1960s and 1970s. According to Karplus, the learning cycle consists of phases of instruction that help students learn by providing them with direct experiences with concrete materials, opportunities to construct understandings about concepts, and chances to apply their understandings to new situations. The learning cycle phases are explored more thoroughly in Chapter 7.

Many psychologists refer to Jean Piaget as the "founder of constructivism." Piaget's ideas on how environment and social interactions influence knowledge construction have had a major impact on the constructivist theories at the foundation of new inquiry-oriented curricula of the 1990s and 2000s and on the use of collaborative learning strategies in science. Piaget regarded socialization as significant in the development of reasoning (Piaget, 1959). He argued that, when learners discuss ideas with their peers, they become aware of the different views of a problem. This confrontation requires them to seek new information and formulate new hypotheses and, over time, to structure a new way of thinking. We discuss collaboration thoroughly in Chapter 6.

The Influence of Lev Vygotsky

Although influenced by Piaget, social constructivist theories in education developed primarily from the works of Lev Vygotsky, a Russian psychologist, who concluded that children construct knowledge or understanding as the result of thinking and doing in social contexts (Vygotsky, 1986). Vygotsky believed that development depends on biological factors (such as brain growth and maturation) and on social and cultural forces (such as the influence of others at home, in school, or on the playground). He also believed that learning takes place in social contexts (such as during playtime with peers, in conversations with classmates, or while parents or teachers are speaking) and that children internalize information they gather in those contexts to form understanding. Children gradually become more independent and autonomous through social interactions with others such as teachers and other adults. Researchers in science education have found evidence to support the social constructivist viewpoint about how children learn science (Brown & Campione, 1994; Driver, 1989; Roth, 1995).

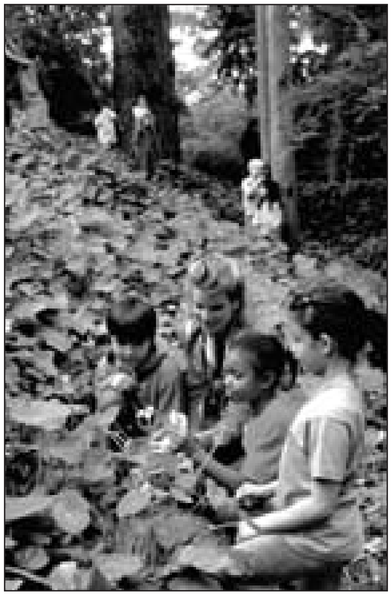
> ***Key Idea***
>
> Social constructivism holds that children learn concepts or construct meaning through their interactions with and interpretations of their world, including essential interactions with others.

Social constructivism holds that children learn concepts or construct meaning through their interactions with and interpretations of their world, including essential interactions with others. From the moment a child is born, she (supported through interactions with others) is constructing knowledge of her environment. Knowledge is not something that is simply memorized; it is constructed by the learner according to her experiences in the world. For example, a child may learn that leaves fall from trees after they turn colors during the autumn by observing this happen several years in a row. Discussions with family members or peers may influence his understanding. For example, a parent might explain that leaves fall when the weather becomes cold. Knowledge is the result of individual interpretations (the child notices they fall after they turn color) and constructions of reality as it occurs in a social context (a parent says this happens when it gets cold).

Children receive information, interpret it, and relate it to other **prior knowledge** and experiences. As a result, they come to school already holding concepts related to concepts teachers will be expecting to help them learn. These prior experiences and conceptions will influence any new knowledge they attempt to acquire. For example, a teacher who attempts to teach a class about why trees drop leaves will encounter any number of prior ideas about this phenomenon in the minds of her students. Some might think the leaves drop because they are dead. Some might think the tree runs out of food. Others might think that the color of the leaves causes them to fall. Some might think trees sleep in the winter. Still others might think that the cold winter winds blow the leaves off. These prior beliefs will affect the teaching and learning going on in the classroom. Because prior knowledge and experiences influence the learning of new knowledge, it is important to reflect frequently on prior experiences. You probably have already noticed that the chapter titles in this book are questions, each chapter begins with reflective questions, and many activities ask you to think about your own experiences. These questions help *you* reflect on *your* ideas.

Key Idea

Prior experiences and knowledge influence the learning of new knowledge.



Children learn about their environment by interacting with others.

Because children come to school with prior understandings about their world, their concepts and theories are not always the same as those developed over the years by scientists. As a teacher you might try, for example, to teach elementary students that air is matter and that matter is something that takes up space and has mass. A typical activity in many elementary textbooks demonstrates to children that two deflated balloons will balance on a scale but that one deflated and one inflated balloon will result in the tilt of the inflated balloon toward the ground.[2] This activity provides students with some evidence that air has mass and takes up space—the balloon filled with air has more mass than the one without air.

What if, before showing children the result of this activity, a teacher asked them to predict the event? What do you think young children would predict? Think about some of the prior experiences elementary children may have had with air. Air (helium) in a balloon causes it to float away. Air in a raft or beach ball causes it to float on water. Air cannot be seen. These prior experiences may have convinced students that air is nothing or that air has no mass. They may predict, therefore, that nothing will happen—air is a nonentity, so the

[2]When doing this demonstration, the balloon must be filled with a source of dry air, so do not blow up the balloon using your mouth. Your lungs and mouth contain much moisture and will add water vapor to the balloon as well as other gases. Instead, use a bicycle pump to blow up the balloon.

Key Idea

Learning requires many new experiences in which students can construct and reconstruct knowledge by interacting with others and materials.

inflated and deflated balloons should still balance. Perhaps they will predict that the inflated balloon will float upward and the empty balloon will sink. Young students will probably not be convinced otherwise by a teacher's demonstration.

The teacher needs to create a learning environment that encourages students to revise their own concepts to accept these new formulations. This is not an easy task. Learning is a continuous process that requires many new experiences in which students can construct and reconstruct knowledge by interacting with others and materials. Children need many opportunities to express and explore their ideas. These ideas about social constructivism have a number of implications for teaching science and are the foundations for project-based science.

A SOCIAL CONSTRUCTIVIST MODEL OF TEACHING

The social constructivist theory asserts that children take an active role in constructing meaning; they cannot construct meaning by passively absorbing knowledge transmitted from a teacher. An ancient Chinese proverb captures this idea in three simple lines:

Tell me, and I forget.

Show me, and I remember.

Involve me, and I understand.

Accordingly, teaching based on social constructivist theory focuses on the child as an active builder of knowledge in a community of learners. Social constructivist theory has implications for the way a teacher creates the learning environment, sets up lessons, asks questions, reacts to students' ideas, and carries out lessons. Lorsbach and Tobin (1992) suggest that teaching science using a constructivist approach means that teachers do *not* teach science as "the search for the truth." Instead, they teach science more as scientists really do science—by actively engaging children in the "social process of making sense of experiences." This approach differs greatly from much of what can be seen in "school science" today, where science teaching consists of asking students to memorize terminology and find correct answers.

Table 2.2 lists the main features of this model of learning. We will now explore each of these in depth.

Key Idea

Children construct understanding in science by actively engaging with phenomena.

Active Engagement with Phenomena

Children construct understanding in science by actively engaging with phenomena. **Active engagement** describes several experiences: Students ask and refine questions related to phenomena, they predict and explain phenomena, and they mindfully interact with concrete materials. Active engagement, then, is both mental and physical.

Students Ask and Refine Questions and Predict and Explain Phenomena

To actively engage students intellectually, teachers must create a learning environment in which students can *ask questions* freely, *dialogue* with classmates and more knowledgeable others to *refine questions,* and *predict and explain phenomena.* Such cognitive

Table 2.2

FEATURES OF THE SOCIAL CONSTRUCTIVIST MODEL OF LEARNING

ACTIVE ENGAGEMENT WITH PHENOMENA

- Students ask and refine questions related to phenomena.
- Students predict and explain phenomena.
- Students mindfully interact with concrete materials.

USE AND APPLICATION OF KNOWLEDGE

- Teachers and students use prior knowledge.
- Students identify and use multiple resources.
- Students plan and carry out investigations.
- Students apply concepts and skills to new situations.
- Students are given time for reflection.
- Students take action to improve their own world.

MULTIPLE REPRESENTATIONS

- Teachers use varied evaluation techniques.
- Students create products or artifacts to represent understanding.
- Students revise products and artifacts.

USE OF LEARNING COMMUNITIES

- Students use language as a tool to express knowledge.
- Students express, debate, and come to a resolution regarding ideas, concepts, and theories.
- Students debate the viability of evidence.
- Learning is situated in a social context.
- Knowledgeable others help students learn new ideas and skills that they couldn't learn on their own.

AUTHENTIC TASKS

- Driving questions focus and sustain activities.
- The topic or question is relevant to the student.
- Learning is connected to students' lives outside school. Technology tools can help connect learning to life outside of the school.
- Science concepts and principles emerge as needed to answer a driving question.

activities help students make connections and develop in-depth understandings (Brooks & Brooks, 1993). It is through discourse (asking questions, having discussions about important questions, making predictions, and providing explanations) that students come to understand what they know. (The role of questioning and ways to set up project-based learning environments that support questioning are covered in several chapters. Chapter 4 explores the role of predicting and explaining phenomena.)

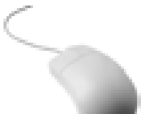
Imagine a second-grade teacher asks, "How could we find out if the apple seed is alive?" She is stimulating the students to ask questions. Students might ask in return, "Could we plant it?" "Can we cut it open to see if something is growing inside?" "Could we ask a farmer?" The teacher has the students work in groups to discuss and refine these

Science Teaching Standards
An important stage of inquiry and of student science learning is the oral and written discourse that focuses the attention of the student on how they know what they know and how their knowledge connects to larger ideas, domains, and the world beyond the classroom (p. 36).

questions. They might debate the fact that cutting open the seed could kill it and, therefore, defeat the purpose of their investigation. This thought might lead them to settle on planting the seed to see if it is alive. If the students planted the apple seed, they could predict what would happen next. This could lead to more refined questions such as "Why isn't it sprouting yet?" and "Do we need to water it more?" If the apple seed began to sprout, students could explain that the seed was alive. However, a lively debate could still take place about whether the seed was alive before being planted. It is through the process of asking and refining questions, making predictions, making observations and providing explanations about the apple seed that students begin to understand whether the seed is alive.

Students Mindfully Interact with Concrete Materials

One hallmark of social constructivist teaching is that students mindfully interact with concrete materials. Children retain more of what they are taught if they engage in more active, concrete types of learning. In fact, it is estimated that the more active and concrete their learning, the more they retain (Bruner, 1977).



Dale's Cone of Experience

Dale's Cone of Experience (Dale, 1969) provides teachers with a tool for thinking about teaching strategies. This categorization is not a prescription for determining how actively students are engaged cognitively because, for example, even active reading strategies[3] can make reading about science far less passive. Rather, it provides a framework for thinking about how a particular strategy might use concrete materials. Notice where demonstrations fall on the scale of Dale's Cone of Experience[4] in Figure 2.4. A demonstration is visually oriented; students do not work directly with materials but rather watch the teacher work with materials. Demonstrations, thus, are moderately abstract compared with activities in which students work with concrete materials themselves. Some instructional tools, such as computer applications, can provide different levels of direct student interaction. Thus, computer applications (which were not yet widely used in schools at the time Dale proposed this hierarchy) can fall into several categories. Some computer programs are very abstract—requiring mostly reading or symbol interpretation. However, computer *simulations* fit into the Contrived Experiences category, and programs with interface devices permitting students to investigate with temperature and light probes provide Direct Experiences. Take time to complete Portfolio Activity 2.4.

Key Idea

Students develop meaningful understanding when they use and apply ideas.

Use and Application of Knowledge

To develop meaningful understandings, students need to use and apply their knowledge. This use and application of knowledge is supported by six strategies:

1. Teachers must consider students' prior knowledge.

[3]See, for example, Carr, E. M., and L. E. Aldinger. 1994. *Thinking works: Using cognitive processes in the language arts classroom.* Ann Arbor, Mich.: Exceptional Innovations.

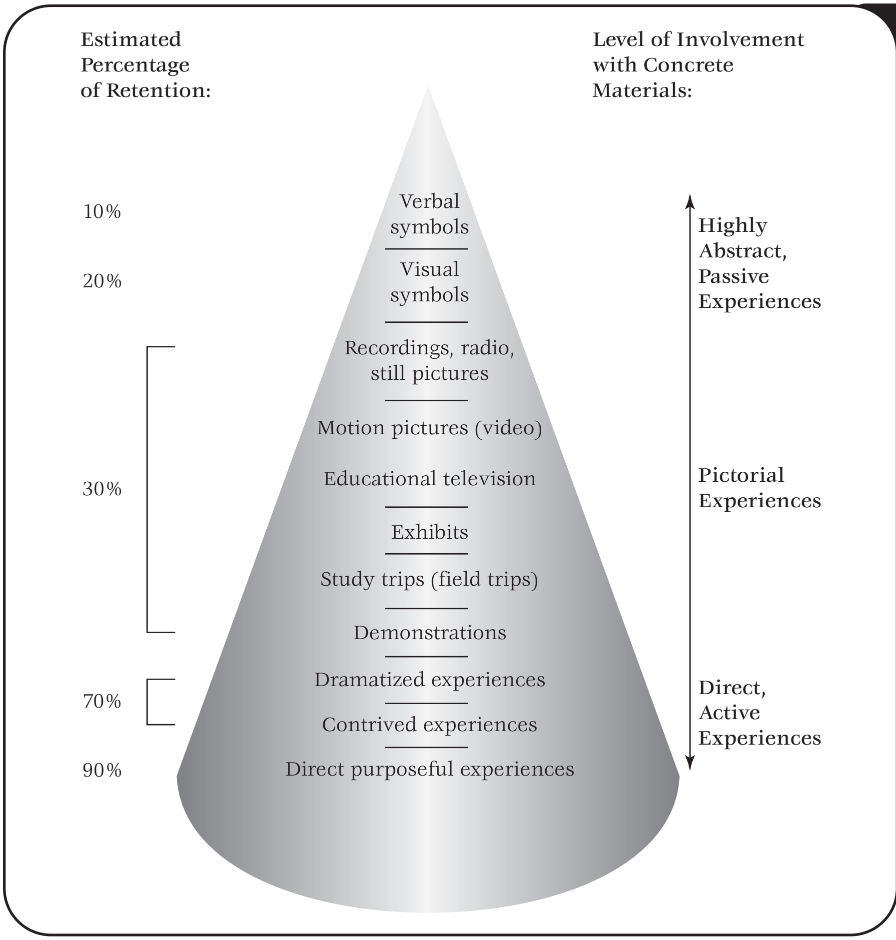
[4]Edgar Dale's Cone of Experience pictured in Figure 2.4 was modified by a personal friend, Rolinda LeMay, to include comments pertaining to level of involvement and percentage of retention.

2. Activities must encourage students to identify and use multiple resources.
3. Activities must involve students in planning and carrying out investigations.
4. Learned concepts and skills must be applied to new situations.
5. Students should be allowed time for reflection.
6. Teachers must help students take action to improve their own world.

Science Education Program Standards

Learning science is something students do, not something that is done to them. In learning science, students describe objects and events, ask questions, acquire knowledge, construct explanations of natural phenomena, test those explanations in many different ways, and communicate their ideas to others (p. 18).

Figure 2.4



Dale's Cone of Experience.

Portfolio Activity 2

DETERMINING LEVELS OF CONCRETENESS AND ABSTRACTNESS

Materials Needed:
- A copy of Dale's Cone of Experience (Figure 2.4)

A. What follows is a list of a number of strategies for teaching about recycling. Rank each strategy's level of abstraction on a scale of 1 to 5 (1 being very concrete and 5 being very abstract).

1. Watching a television documentary about landfill problems.
2. Watching the teacher sort aluminum, glass, and plastic into three recycling bins.
3. Visiting a recycling center.
4. Burying a piece of plastic, a glass cup, a banana skin, a piece of bread, and an aluminum can; watering the items weekly; and periodically uncovering the items to see if they are decomposing.
5. Painting a poster to promote recycling.
6. Writing a rap song about recycling.
7. Coloring a picture about the ways to limit litter (reuse, recycle, reduce).
8. Starting a compost in the school playground.
9. Arranging in sequence pictures about how long it takes some items to biodegrade.
10. Reading a newspaper article about recycling.
11. Listening to a guest speaker from the local recycling center.
12. Writing a story about the future if people fail to solve landfill problems.
13. Creating a poem about recycling.
14. Sorting items from the school lunch into aluminum, glass, and plastic bins.
15. Starting a school paper recycling program.
16. Keeping track of the amount of waste produced in the classroom for the week and estimating how much would be produced in a year.
17. Role playing what to do if a friend drops a candy wrapper on the ground.
18. Looking at photographs of landfills.

B. Convene with some of your classmates to share your rankings of the teaching strategies. Try to come to a consensus about the rankings.

C. Obtain a variety of teacher resources and activity books. Look in them for lessons to teach about plant growth. In your portfolio, make a list of lessons, activity ideas, or investigations that would be more concrete than the ones in the books. How could you make any abstract strategies more concrete?

Teachers and Students Use Prior Knowledge and Experience

In order for a teacher to help students use and apply their knowledge, she or he must consider what it is that students already know. The following paragraph serves as an illustration of this point:

> It is really actually simple. First, you arrange things into different groups depending upon their makeup. Of course, one pile may be enough depending on how much there is to do. If you have to go somewhere else due to a lack of equipment, that is the next step; otherwise, you are pretty well set. It is important not to overdo any particular part of the job. That is, it is better to do too few things at once than too many. In the short run, this may not seem important, but trouble from doing too many can easily arise. A mistake can be expensive as well. Working the equipment should be self-explanatory, and we need not dwell on it here. Soon, however, it will become just another facet of life. It is difficult to see an end to the necessity for this task in the immediate future, but then one can never tell (Bransford, 1979).

What is this paragraph about? You probably had difficulty understanding it because you were not given any clue about its topic. If you had known from the start that it was about washing clothes, you would have understood it instantly. Reread the paragraph now that you know what it is about. Doesn't it make more sense? In this case, activating your prior knowledge clearly would have enhanced your ability to understand new material.

Constructivist teaching approaches focus on the learner's prior knowledge, because it is the learner who must integrate new ideas into his or her current understandings. Shapiro (1994) writes,

> The role of the teacher [in a constructivist view] is not to simply present new information, correct students' "misconceptions," and demonstrate skills. It is to guide the learner to consider new ways of thinking about phenomena and events. In order to do so, the teacher must have some understanding of what the learner brings to the learning experience, that is, his or her prior ideas, and thoughts (p. 8).

To help students integrate their understandings, teachers must know about their prior understandings. Recall the examples earlier in this chapter of the role played by prior knowledge and experience in learning. Children have had years of experience with leaves falling or with air (blowing, in balloons, in balls) before they come to school to receive formal instruction about these concepts. When teachers attempt to teach students that air has mass, prior experiences may conflict with the new ideas as students try to integrate the new understandings into their conceptual framework of "air." With some awareness of students' past experiences, teachers can help students reconcile what seem to be conflicts between those experiences and new learning. Without this awareness, teachers will still be able to ensure that teaching takes place but not that learning does.

There are many ways to probe for students' prior knowledge. For example, in the washing clothes scenario, a teacher could provide students with a mental organizer (such as telling them they are about to read about washing clothes) and discuss what they know about washing clothes before students read the paragraph. Another strategy is to remind students of an activity or investigation done earlier in the year that has some connection to new learning.

Students Identify and Use Multiple Resources

An important strategy in helping children construct understandings in science is having them identify and use multiple resources. **Multiple resources,** which might be used in the course of answering a driving question, include books, journals, science equipment, supplies, and computers. They reinforce student understanding through different presentation and through emphasis of different information. While a book might explain via text and photographs how a landfill works, a Web page might present a slightly different explanation through illustrations and through interactive charts of statistics on landfill usage and cleanup efforts. When students analyze and synthesize this different information presented in these different ways, they create more solid, integrated understandings.

Students Plan and Carry Out Investigations

The cycle of asking a question, making observations, designing an investigation, collecting data, analyzing results, and asking new questions, which is a key feature of project-based science, requires children to use and apply their understandings. (The investigation web is further explored in Chapter 4.) Assume a class is exploring the question "Where does all our garbage go?" To explore this driving question, students might set up a decomposition column (or other organic matierial), which is a small composter in a 2-liter pop bottle filled with leaves, dirt, banana peels, and worms. Students ask questions such as "Why do worms help the materials in our pop bottles decompose faster?" or "How does moisture affect how fast decomposition occurs?" Students gather information related to their questions from multiple resources such as books, journals, and the World Wide Web. Students plan investigations to answer these questions, considering the materials they will need, how they will collect and analyze the data, and how they will present their findings to the class. They make predictions about what will happen to the items in the bottle. Then students carry out their investigations. They debate whether two pop bottles can provide ample evidence for whether moisture affects the rate of decomposition. Students create artifacts such as posters or multimedia products to represent their understanding of decomposition. Finally, students share and explain ideas about the problem of decomposition as it relates to landfills. This process of asking and refining questions, debating ideas, making predictions, designing experiments, gathering information, collecting and analyzing data, drawing conclusions, and communicating ideas and findings to others helps students construct a solid, integrated understanding of the topic and related concepts.

Students Apply Concepts and Skills to New Situations

Students develop rich, meaningful understandings when they apply their knowledge to new situations. This phenomenon is illustrated as the change in understanding from Cell C to Cell D in Figure 2.3. By applying concepts and skills to new situations, students elaborate on their understandings, form new connections with old ideas, and build connections between new ideas and old ideas. For instance, in the decomposition example, students can apply their knowledge of how oxygen affects decomposition to real world situations such as landfills. Through discussions with others, students can make connections between the understanding that oxygen is needed for decomposition and the awareness that materials don't decompose quickly in a landfill.

Students Are Given Time for Reflection

In science, **reflection** involves thinking about alternative questions, considering hypotheses, contemplating a variety of answers, speculating on outcomes, deliberating on steps that can be taken, and meditating on conclusions found. Reflection takes *time.* Teachers cannot rush through topics, lessons, and examples and expect students to learn new material thoroughly. For this reason, constructivist teachers present fewer topics in the curriculum and spend more time on them. Teachers provide students with time in class to discuss ideas with others, write about experiences, and revise ideas and products. Recall the teacher who had students discuss whether the apple seed was alive. During discussions teachers use the technique of wait-time: They wait three to five seconds after asking a question before calling on a student. In addition, teachers ask *probing* questions, which are questions designed to elicit more details. (Wait-time and probing questions are discussed in more detail in Chapter 7.) Brooks and Brooks (1993) write,

> Classroom environments that require immediate responses prevent these students from thinking through issues and concepts thoroughly, forcing them, in effect, to become spectators as their quicker peers react. They learn over time that there's no point in mentally engaging in teacher-posed questions because the questions will have been answered before they have had the opportunity to develop hypotheses (p. 115).

Students Take Action to Improve Their Own World

The idea of taking action to improve the world has become popular in science education in the last few decades. The Science Technology Society (STS) movement that was popularized in the 1980s is one example. STS focuses on topics such as health, population, resources, pollution, and environment—topics that people must understand in order to become active citizens who make decisions and take actions related to society or to improving their lives.

Children are particularly interested in studying questions that can be applied to their own lives and improve their own world. Adolescents see themselves as emerging adults and feel a particular urgency about the future. Many adolescents are interested in ecological topics and environmental issues (Barnes, Shaw, & Spector, 1989). Adolescents see exploration of these topics as a way of taking action to improve their world. Middle grade students may be interested in more far-reaching *local* issues, such as the health of a local stream. They may be interested in monitoring the quality of the stream and reporting it to a local governmental agency. Young elementary students have less global concerns. They are interested in more personal concerns such as improving the living conditions and nutrition of their pets at home. Children of all ages care about improving the school environment. They can put up bird feeders, plant wildflowers, and organize a litter pickup day. When learning includes taking action to improve their world, children see the importance of it, and the action solidifies their knowledge.

Science Education Content Standards K–4

As a result of activities in grades K–4, all students should develop understanding of personal health, characteristics and changes in population, types of resources, changes in environments, and science and technology in local challenges (p. 138).

Science Education Content Standards 5–8

As a result of activities in grades 5–8, all students should develop abilities of technological design and understandings about science and technology (p. 161).

Multiple Representations

Constructivist theory asserts that learning involves developing **multiple representations** of ideas that integrate understanding. In the decomposition activity described earlier, students constructed a decomposition column, wrote about their investigation, and built a poster to express their ideas. Writing, building a poster, and manipulating materials are examples of different representations. These three activities require the translation of understandings into three different formats—concrete, textual, and graphical representations. When students make connections among these representations, they develop integrated understandings that can be applied to new situations.

Key Idea

When students make connections between various representations, they develop integrated understandings that they can apply to new situations.

Teachers Use Varied Evaluation Techniques

There are two reasons to use varied evaluation techniques. First, different types of evaluation techniques can better assess different types of understanding formed through a variety of intellectual activities. Second, multiple forms of assessment help different learners succeed in demonstrating their understandings.

In project-based science, students develop different types of understandings that each must be assessed, and these understandings may be assessed in a variety of ways. (Assessment and evaluation are covered in detail in Chapters 8 and 9.) For example, how might students demonstrate understanding about water quality in a stream? They might write reports, present artifacts to classmates, take photographs, or create multimedia products that document a stream cleanup effort.

Because different learners will respond to different assessment techniques in different ways, using a variety of assessment techniques ensures that all students are evaluated appropriately. Whereas one child might flourish on a written exam, another might present her ideas more effectively with a poster or three-dimensional model, and yet another might express his ideas better through a written journal. By using a variety of forms of assessment, teachers let students express their understandings in ways consistent with their individual strengths.

Because constructivist theories focus on students' prior experiences to frame teaching and learning, multiple paths (from different students' ideas) to learning emerge. Therefore, assessment also needs to include students' interpretations of their learning. Students' interpretations can be captured with self-evaluation techniques. Teachers can interview students about how they think they have progressed in learning about a topic or skill. Students can also keep journals to track their own progress throughout a project.

Students Create and Revise Products or Artifacts to Represent Understanding

Another approach to helping students create understanding is through the building and revision of artifacts. Artifacts are tangible representations of student understanding that answer a driving question. They include models, reports, videos, and computer programs. They can be thought of as external, intellectual products. Papert (1980, 1993) refers to artifacts as "objects-to-think-with" because they are concrete and explicit and serve as tools of learning. Students build understanding by constructing artifacts and explaining to each other the meaning of their artifacts. Artifacts and products can be critiqued by others—students, teachers, parents, and community members. As a result, learners have many opportunities to reflect on and revise their artifacts, and so they have many opportunities to further enrich their knowledge.

Imagine that students decide to make a poster presentation to explain how they will explore the influence of fertilizer on plant growth. In the process of developing this artifact, students need to select plants and explain their selections, and they need to determine the amount of fertilizer. The students need to provide answers to questions such as "How many plants?" "How much fertilizer?" and "How often?" All of these decisions focus the students' thinking and help develop deeper understanding. Students again have an opportunity for enhanced understanding when their teacher and classmates give them feedback on their poster.

> **Key Idea**
>
> Social constructivism stresses that students learn in a social context and that language serves as a tool to develop understanding.

Use of Learning Communities

The social constructivist model holds that students learn in a social context—a learning community. Within such learning communities, language is a primary tool for developing understanding. In this section, we explore five aspects of **learning communities:**

1. students using language as a tool to express knowledge,
2. students using language to come to a resolution about science ideas and theories,
3. students debating the viability of evidence,
4. students learning in a social context, and
5. students learning from knowledgeable others.

We will also discuss ways that knowledgeable others can use scaffolding to help students learn.

Students Use Language as a Tool to Express Knowledge

Children (and adults) learn best when they can talk about and share their ideas with their peers and with concerned adults. Hence, meaningful learning develops as an interplay between the child thinking about ideas (an *intra*personal use of language) and talking with others (an *inter*personal use of language). This interplay helps the child build connections among ideas, integrating understanding. When a child uses the words push or pull to describe force to another child, a learner demonstrates his or her understanding of the concept.

Teachers can help students use language in a variety of ways. One, students can debate ideas. For example, they can debate whether temperature affects the growth of seeds. Two, students can share information in written form. For example, students can create reports to share the results of their investigations with others or exchange journals so that others can read about their investigations. Three, students can learn through oral language. For example, many teachers have students explain their investigations to classmates using artifacts or products.

Students Express, Debate, and Come to a Resolution Regarding Ideas, Concepts, and Theories

Healthy debates are a critical aspect of developing understanding in science. Constructivists define *science* as knowledge that has been publicly debated and accepted by scientists (Shapiro, 1994). Scientists continually obtain new information from investigations, and they debate ideas based on this information. Similarly, in science classrooms, teachers want students to debate ideas, concepts, and theories and come to resolutions about them. The student who believed dinosaurs were pets because he collected them debated this idea with classmates, who offered reasons that dinosaurs were not pets. Finally, all students came to the resolution that dinosaurs were not pets.

Students Debate the Viability of Evidence

Scientists constantly debate the viability of evidence. One group of scientists may speculate that mutations being found in frogs around the world are the result of depleted ozone. Another group of scientists argues that the deformations are a result of pollutants in the environment. The viability of evidence is debated until one supposition or another is supported by most in the scientific community. Just as scientists debate the viability of evidence, students

Science Education Program Standards

Thinking critically about evidence includes deciding what evidence should be used and accounting for anomalous data (p. 145).

need to do this in science classrooms. For example, students might debate whether the height of a plant is a good indicator of growth. Some students might argue that number of leaves and color are more important indicators than is height, because height might only indicate that the plant is stretching to reach sunlight (a tropism).

Learning Is Situated in a Social Context

Children do not construct understanding in isolation but in a social context. Parents, friends, teachers, peers, community members, books, television, movies, and cultural customs all affect the construction of student understanding. For example, students learning about decomposition share with classmates their findings from various experiments performed on decomposition columns. They visit local landfills or recycling plants and talk with the managers. They connect to the World Wide Web to talk with other students around the country about the problem of landfills in their region. They talk with peers to see if any use composts at home. Each of these social interactions helps students build integrated understandings. In isolation, these understandings might not be connected, but through social construction of ideas, students link new understandings with old ones.

Knowledgeable Others Help Students Learn New Ideas and Skills That They Couldn't Learn on Their Own

A basic idea that stems from these ideas about language, culture, and community is that more competent others can assist children in accomplishing a more difficult cognitive task than they otherwise could on their own. The development of understanding occurs as a result of social interaction with more knowledgeable others and with peers. Even second graders are able in learning communities to carry out sophisticated investigations under the guidance of a classroom teacher.

Vygotsky (1978) developed the construct of the **zone of proximal development** to represent the hypothetical space between assisted and unassisted performance of a learner, or the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers (1978, pp. 85–86). He studied the difference between concepts learned spontaneously, or out of school, with those learned in school, and he concluded that children learned more when the teacher or more knowledgeable adults assisted them. The presence of a more knowledgeable other appeared to foster the discussion and debate of ideas. Vygotsky concluded that the social interaction between students and teachers or other adults is an important aspect of intellectual development, because the zone of proximal development allows learners to take part in more cognitively challenging tasks and problem solving than they could on their own.

Others have expanded Vygotsky's ideas to include collaborative interactions with peers. Researchers have found that students learn more effectively when working in collaborative groups with advanced or knowledgeable peers than they do working alone. Forman (1989) coined the term **bidirectional zone of proximal development** to describe the expertise levels in collaborative groups and the fluctuations among group members—sometimes members are the teacher and sometimes they are the learner. A collaborative classroom thus becomes an environment that comprises what Vygotsky called multiple zones of proximal development. Students are exposed to overlapping zones as they learn by interacting with many different people—the teacher, peers, and community members. Each person with whom the student interacts can become a support that will enable the student to climb to the next level of learning. This is one reason that collaborative learning is stressed in constructivist classrooms. We discuss collaboration in detail in Chapter 6.

By identifying the learners' zones of proximal development, a teacher can provide the assistance that is needed to move a learner to a higher level of understanding than would be possible without the support. Good teachers have always provided this support by doing things such as modeling ideas for students. The zone of proximal development simply serves to name these types of support so we can talk about them.

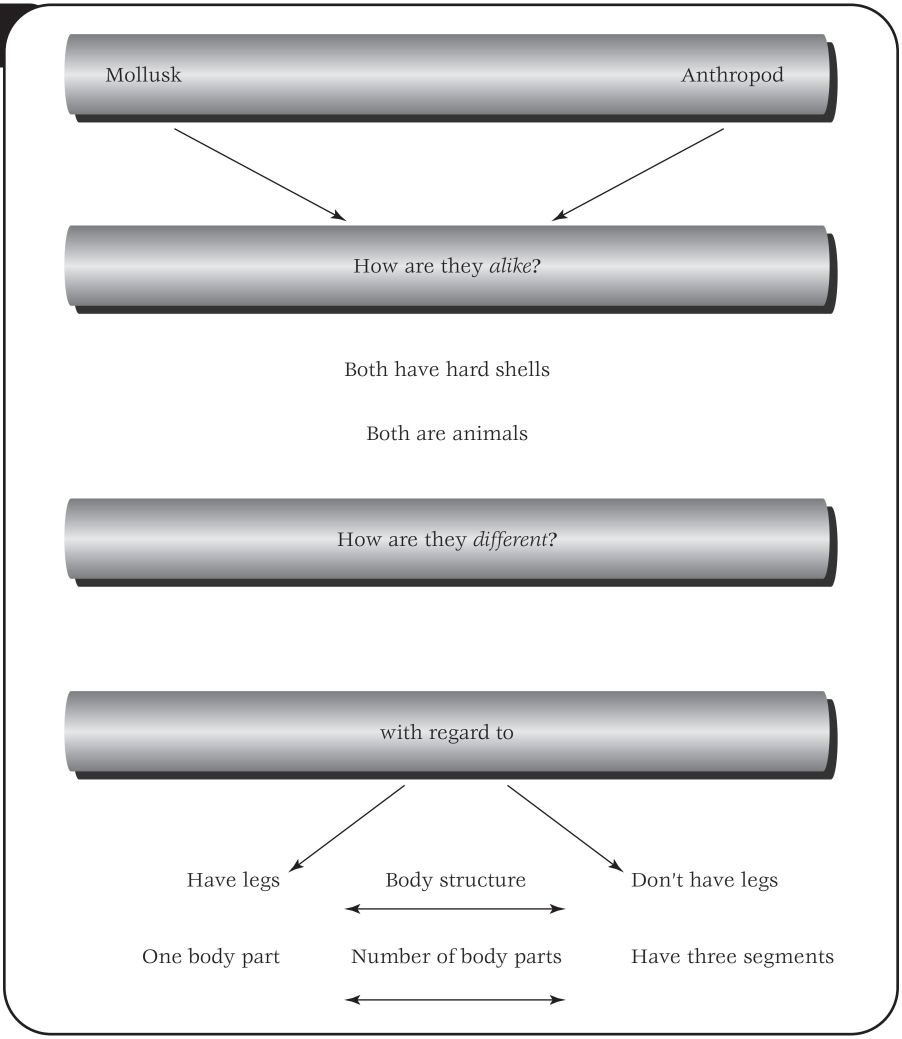
Scaffolding. The concept of scaffolding stems from Vygotsky's notion of the zone of proximal development. **Scaffolding** (Bruner, 1977; Wood, Bruner, & Ross, 1976) is a process in which a more knowledgeable individual provides support to another learner to help him or her understand or solve a problem. In scaffolding, the more knowledgeable other directs those aspects of the intellectual task that are initially beyond the capacity of the learner. This allows the learner to take part in intellectual activities that otherwise would be unwelcoming, activities that he or she doesn't completely understand. Imagine a parent helping her child put together a Lego structure. The parent might say, "Let's find all the pieces that are blue." Next the parent might suggest snapping all the blue pieces together. Although the child might not see how the individual steps fit together to build a castle, because the parent has structured the activity, the child can participate in building the structure.

> *Key Idea*
>
> A more knowledgeable individual provides a scaffold to support a learner by helping him or her to take part in intellectually demanding tasks just out of his or her developmental level.

Scaffolds used by knowledgeable others (parents, teachers, other adults, or peers) include modeling, coaching, sequencing, reducing complexity, marking critical features, and using visual tools. In the Lego example, the parent has provided a very important aspect of instruction that is known as *sequencing.* Sequencing, which is just one of the many types of scaffolds that can be used in a classroom, breaks a difficult task into much smaller, manageable subtasks. What follows is a summary of scaffolding strategies that teachers can use to support learning:

- **Modeling** is the process through which a more knowledgeable person illustrates to the learner how to complete a task. For example, a teacher could demonstrate how to use the concept of *average* to analyze data or how to read a scale. Many science processes can be modeled for students. Some of these processes are *asking questions, planning and designing investigations,* and *forming conclusions.*
- **Coaching** involves providing suggestions to help a student develop knowledge or skills. For example, a teacher might make suggestions to a student about how to make more precise measurements when reading a spring scale. The teacher might suggest, for instance, that the student make sure the scale is calibrated to start at zero before beginning to use the scale. Other forms of coaching include asking thought-provoking questions (such as "How do your data support your conclusion?"), giving students sentence stems (such as "My data support my conclusion because . . ."), and supplying intellectual or cognitive prompts (such as asking students to write down predictions, give reasons, and elaborate answers).
- **Sequencing** is breaking down a larger task into subtasks so a child can focus on completing just one subtask at a time rather than worry about the entire task at once. A teacher might break down the process of investigations into

Figure 2.5

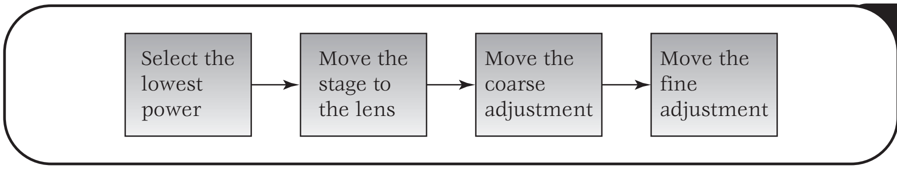


Compare and contrast diagram to represent a concept.

various components, not allowing the learner to proceed to the next step until completing a step. For example, the teacher could require the learner to complete a rough blueprint plan before moving on to building an apparatus.

- **Reducing complexity** involves withholding complex understandings or tasks until the learner has mastered simpler understandings or subtasks. The classical example is helping a child learn to ride a bicycle by using training wheels. In science classrooms, a teacher might use an analogy to reduce the complexity of a concept. For instance, a teacher might compare DNA to the instructions for building a model airplane.

Figure 2.6



Visual tool to represent steps in a task

- **Marking critical features** is highlighting the essential elements of a concept or task. For instance, a teacher might point out to young students that animals called *mammals* all have hair. In teaching a student how to focus a microscope, a teacher might point out that it is important to always start with the lowest-power lens first.
- **Using visual tools** (pictorial prompts) can help students understand their own thinking, processes, concepts, or tasks (Hyerle, 1996; Parks & Black, 1992). Visual tools make abstract ideas more concrete by organizing them or illustrating relationships among them. Although there are many kinds of visual tools, we illustrate two: one designed to help students understand a concept (Figure 2.5) and another designed to help students understand a task (Figure 2.6). *Compare and contrast diagrams* (Parks & Black, 1992) are visual tools that illustrate the relationships among the characteristics of two different objects. Learning the classifications of various animals, for example, requires students to understand similarities or differences among animals. Figure 2.5 is a sample compare and contrast diagram that depicts the similarities and differences between mollusks and arthropods. Steps provide a simple pictorial representation of a task, helping students to visualize it. Figure 2.6 is a simple pictorial representation of the steps to focus a microscope.

Graphic Organizers

Often, it is the teacher who provides the scaffolds during instruction. Other vehicles for scaffolding are peers (same age or older), community members, parent volunteers, and technology. Many teachers find that, at first, they (or knowledgeable others) must provide much support and structure in the classroom. However, gradually, the learner can take more and more responsibility for structuring his or her own learning.

For example, at the beginning of the year, a teacher might model for students how to ask good questions and demonstrate why they are appropriate questions. However, as the year progresses, the teacher expects students to ask their own questions and give justifications for why they are good questions. When students have reached this point, it is still critical that the teacher provide feedback.

For scaffolding to be beneficial to the learner, the following conditions must be present.

- Support must be relevant to the student and the student's task. To be relevant, the support must be related to a task a student needs to complete. For instance, the teacher can reduce the complexity of data analysis by providing a chart for collecting data.
- Support must correspond to the level of help needed by the student. If the support is geared too high for students, it will not match their understanding. If it is too low, it will not be useful. The analogy that DNA is like a set of instructions

for putting together a model airplane might be appropriate for a fifth grader who has put together an airplane. Comparing DNA to the instructions in a computer program, however, would be beyond most fifth graders' experience.

- The support must be given in close proximity in time to the student's request for help. Delaying support might mean that an educational opportunity is lost and that support is not given until a student no longer needs it.
- The student must take action on the opportunity (or apply what he or she has learned). For example, a student needs to apply her understanding of finding averages to her own data.
- Scaffolds need to be **faded**—This means that the support must decrease over time. A child first learning to ride a bike uses training wheels. The training wheels are gradually raised. Next, the training wheels are removed, and the child tries to ride the bike with an adult running alongside the bike. Finally, the child rides the bike on his or her own. In science class, a teacher might start by showing students how to create a bar graph. Next, the class and the teacher co-construct bar charts. After that, students working in groups construct bar graphs with the teacher merely giving them feedback.

> NSES
>
> **Science Education Program Standards**
> Teaching Standard B—at all stages of inquiry, teachers guide, focus, challenge, and encourage student learning (p. 33).

Authentic Tasks

Social constructivism also points to the need for students to learn by addressing problems that they see as authentic (Brown, Collins, & Duguid, 1989; Newman, Griffin, & Cole, 1989; Resnick, 1987). To develop meaningful understandings, students must develop knowledge related to real situations. Because deep learning occurs only when a task is situated, tasks must take on meaning beyond what occurs in the school. **Authentic tasks** are those that have meaning for the child beyond the classroom. We'll explore four aspects of authentic tasks: the driving question, the relevance of a question or topic to students, the connection of learning to students' lives outside of school, and the emergence of science concepts and principles when they are needed.

Driving Questions Focus and Sustain Activities

Driving questions are a vehicle for bringing authentic tasks into classrooms. (Chapter 3 explores the driving question in greater detail.) In project-based science, the driving question contextualizes learning experiences in the lives of learners, organizes concepts, and drives activities. As students pursue solutions to a driving question, they develop meaningful understandings of key scientific concepts. For instance, the question "What is the pH of rainwater in our city?" allows students to explore concepts such as acids and bases, pH, and concentration. The

> NSES
>
> **Science Education Program Standards**
> Teaching Standard A—Inquiry into authentic questions generated from student experiences is the central strategy for teaching science (p. 30).

question also organizes the activities involved in planning and carrying out investigations of the acidity of rainwater and of the impact acid rain has on living and nonliving things. A question such as "How do you light a structure?" allows students to explore principles such as parallel and series circuits, voltage, resistance, current, and power. Activities might be organized around students designing and building structures that they can light.

The Topic or Question Is Relevant to the Student

A guiding principle of constructivism is that problems, questions, and topics must be relevant or pertinent to children. Greenberg (1990) suggests that relevant questions are testable by children, involve the use of equipment in testing ideas, are complex enough to elicit problem-solving approaches, and can be solved through group efforts. Haberman (1995) argues that many students' misbehaviors in schools are caused by not being involved with meaningful learning activities. He stresses that project-based methods can make learning relevant and meaningful. Similarly, Blumenfeld and colleagues (1991), in a summary of the literature, argue that student interest is enhanced when (a) tasks are varied and include novel elements, (b) the problem is authentic and has value, (c) the problem is challenging, (d) there is closure through the creation of an artifact or product, (e) there is choice about what and/or how work is done, and (f) there are opportunities to work with others.

Some people criticize the idea of relevance, arguing that a certain curriculum, whether pertinent to students or not, must be covered in schools. Brooks and Brooks (1993) write that, "relevance does not have to be preexisting for the student. . . . Relevance can emerge through teacher mediation" (p. 35). (For this reason, Chapters 3, 4, and 10 discuss ways teachers can stimulate curiosity and develop relevant investigations.) Few children will come to school interested in the topics of force, momentum, and acceleration. However, a teacher can help make these topics relevant to students by turning the topics into driving questions such as "How do we stay on a skateboard?" or "Why do I have to wear a helmet, knee pads, and wrist protectors when I'm rollerblading?"

> ***Key Idea***
>
> Authentic tasks have meaning for the child beyond the classroom.

Learning Is Connected to Students' Lives Outside School

Children (and adults) usually exert greater effort to study questions that relate to their own lives outside of school. If a lesson being presented to students is not connected to their lives, it is not uncommon for an upper elementary or middle school student to ask, "Why do we need to know this?" Unfortunately, teachers sometimes reply, "Because it is in the book" or "You will need it when you get older." Few children have the patience to study something simply because it is in the book, and most children do not have the cognitive capacity to accept or care that they will need something far in their future. Research on women's and minorities' involvement in science also points out the need to connect science to children's lives outside of school (Barton, 1998; Haberman, 1995). The lack of relevance to life outside of school is believed to be a strong factor in leading girls and minorities away from science.

Most topics in elementary and middle grades curriculum can be situated in students' lives. For example, teachers can connect the concept of insulation to students' lives by emphasizing the role of insulation in coats and gloves, thermos bottles that keep drinks hot or cold, and coolers that keep food from spoiling.

Portfolio Activity 2.5 DEVELOPING A SOCIAL CONSTRUCTIVIST LESSON

Materials Needed:

- A video of an elementary or middle grade science lesson or a classroom that you can observe in person
- Materials to develop and teach a lesson
- Video equipment and video
- The rating scale from Portfolio Activity 2.3

A. Obtain a video of an elementary or middle grades science lesson or observe a teacher teaching a science lesson. Use the rating scale from Portfolio Activity 2.3 to evaluate the teaching. What could the teacher do to make the lesson more consistent with the social constructivist view?

B. Prepare your own lesson to teach a new concept to a child or to a group of peers. Make a video of yourself teaching the lesson. Use the rating scale found in Portfolio Activity 2.3 to analyze how well you employ constructivist approaches to teach the concept.

C. How would you improve upon your lesson if you were to reteach it? Record your ideas in your portfolio.

Science Concepts and Principles Emerge as Needed to Answer a Driving Question

In constructivist classrooms, the concepts and skills presented are used to answer driving questions rather than presented for their own sake. When concepts and principles emerge on an as-needed basis, students can more easily integrate them into their understandings. For example, students learn to read a thermometer so that they can measure the temperature in their decomposition column. They learn about oxygen so that they can understand why worms help the decomposition process. In each of these examples, students aren't learning something because it's in the textbook; they are learning it so that they can solve a problem or apply it to a particular situation. Before continuing, complete Portfolio Activity 2.5.

USING TECHNOLOGY TOOLS TO EXTEND LEARNING

Technology tools extend learning by helping students perform cognitive tasks. Humans have always used cognitive tools to help them learn, engage in intellectual tasks, and make work easier (Salomon & Perkins, 1991). For example, humans used the abacus as early as 500 B.C. for counting and performing calculations. Adding machines and calculators are more modern technological tools for helping us calculate. Concept maps, or diagrams to visualize relationships among ideas or concepts, are used widely in schools to clarify concepts. New technology tools also serve as cognitive tools. Electronic spreadsheets allow accountants to collect and analyze numbers. Graphs allow them to visualize and interpret data.

In science classes today, a wide variety of technology tools are available to help students learn. For example, computers can be used to access data on the World Wide Web, calculate data on spreadsheets, visualize concepts on a diagram or picture, and express ideas as written words. Palms or PDAs can be used to acquire, process, organize, and visually represent information. Temperature, light, and motion probes can help students conduct investigations and learn important concepts that are more difficult to understand without the use of technology. Because technology tools have assumed such an important role in science teaching, we devote Chapter 5 to a more thorough review of technology tools.

CHAPTER REVIEW **www.mhhe.com/krajcik2e**

Go to the Online Learning Center at **www.mhhe.com/krajcik2e** to review important content from the chapter and key terms, take a chapter assessment, and link to the chapter's websites.

ONLINE LEARNING CENTER

CHAPTER SUMMARY

In this chapter, we discussed student understanding and examined several scenarios of student understanding. Students need to construct content, procedural, and metcognitive knowledge to develop understanding. Project-based science strives to create meaningful understandings.

The chapter reviewed the historical roots of constructivism and outlined a social constructivist model of teaching. The first feature of this model is active engagement of students with phenomena. In a constructivist classroom, students ask and refine questions, predict and explain phenomena, and engage with concrete materials. The second feature is student use and application of knowledge. In constructivist teaching, teacher and students consciously address prior knowledge, and students identify and use multiple resources, plan and carry out investigations, apply concepts and skills to new situations, devote time to reflection, and take action to improve their own world. The third characteristic is the use of multiple representations of understandings. Multiple representations include varied evaluation techniques and student products or artifacts. The fourth characteristic is the use of learning communities. Learning communities are created when students use language to express knowledge; express, debate, and come to a resolution regarding ideas, concepts, and theories; debate the viability of evidence; learn in a social context; and obtain help from knowledgeable others in learning new ideas and skills that they couldn't learn on their own. The fifth characteristic is the focus on authentic tasks. What makes learning authentic are driving questions that focus and sustain activities, topics or questions that are relevant to the student, learning that is connected to students' lives outside school, and science concepts and principles that emerge as needed to answer a driving question. These five characteristics characterize a transformational as opposed to a receptional approach to teaching.

We discussed the important role teachers play in scaffolding student learning. Scaffolds allow learners to take part in cognitive activities just beyond their reach of cognitive development. Teachers can scaffold learners by modeling, coaching, sequencing, reducing complexity, marking critical features, and using visual tools.

Tasks in school need to be authentic for children to find them meaningful. Four aspects of authentic tasks are driving questions, the relevance of questions or topics to students, the connection of learning to students' lives outside of school, and the emergence of science concepts and principles when they are needed. Technology tools play an important role in making connections to students' lives in science classrooms today.

CHAPTER HIGHLIGHTS

- Meaningful understanding results when learners have built relationships among ideas, can explain these relationships, and can use their ideas to explain and predict phenomena.
- School science often results in students developing inert knowledge—disconnected, unusable fragments of ideas.
- Project-based science leads to students developing meaningful understandings.
- To develop meaningful understanding, students need to develop content, procedural, and metacognitive knowledge.
- Children construct meaning through their interactions with and interpretations of their world, including essential interactions with others.
- The features of social constructivist teaching include
  - active engagement in phenomena,
  - use and application of knowledge,
  - multiple representations,
  - use of learning communities, and
  - authentic tasks.
- Language serves as a tool to develop understanding.
- Teachers scaffold students so they can engage in tasks just out of their cognitive reach.
- Teachers can scaffold learners by
  - modeling,
  - coaching,
  - sequencing,
  - reducing complexity,
  - marking critical features, and
  - using visual tools.
- Tasks in school need to be authentic to have meaning.
- Four aspects of authentic tasks are
  - the driving question,
  - the relevance of a question or topic to students,
  - the connection of learning to students' lives outside of school, and
  - the emergence of science concepts and principles when they are needed.
- Technology tools extend learning in science classrooms.

KEY TERMS

Accommodation (52)
Active engagement (54)
Adaptation (49)
Assimilation (49)
Authentic tasks (68)
Bidirectional zone of proximal development (64)
Coaching (65)
Concrete operations (49)
Content knowledge (44)
Contextualized (48)
Equilibration (49)
Faded (68)
Formal operations (49)
Inert knowledge (38)
Learning communities (62)
Learning cycle (52)
Learning technologies (70)
Marking critical features (67)
Meaningful understanding (43)

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