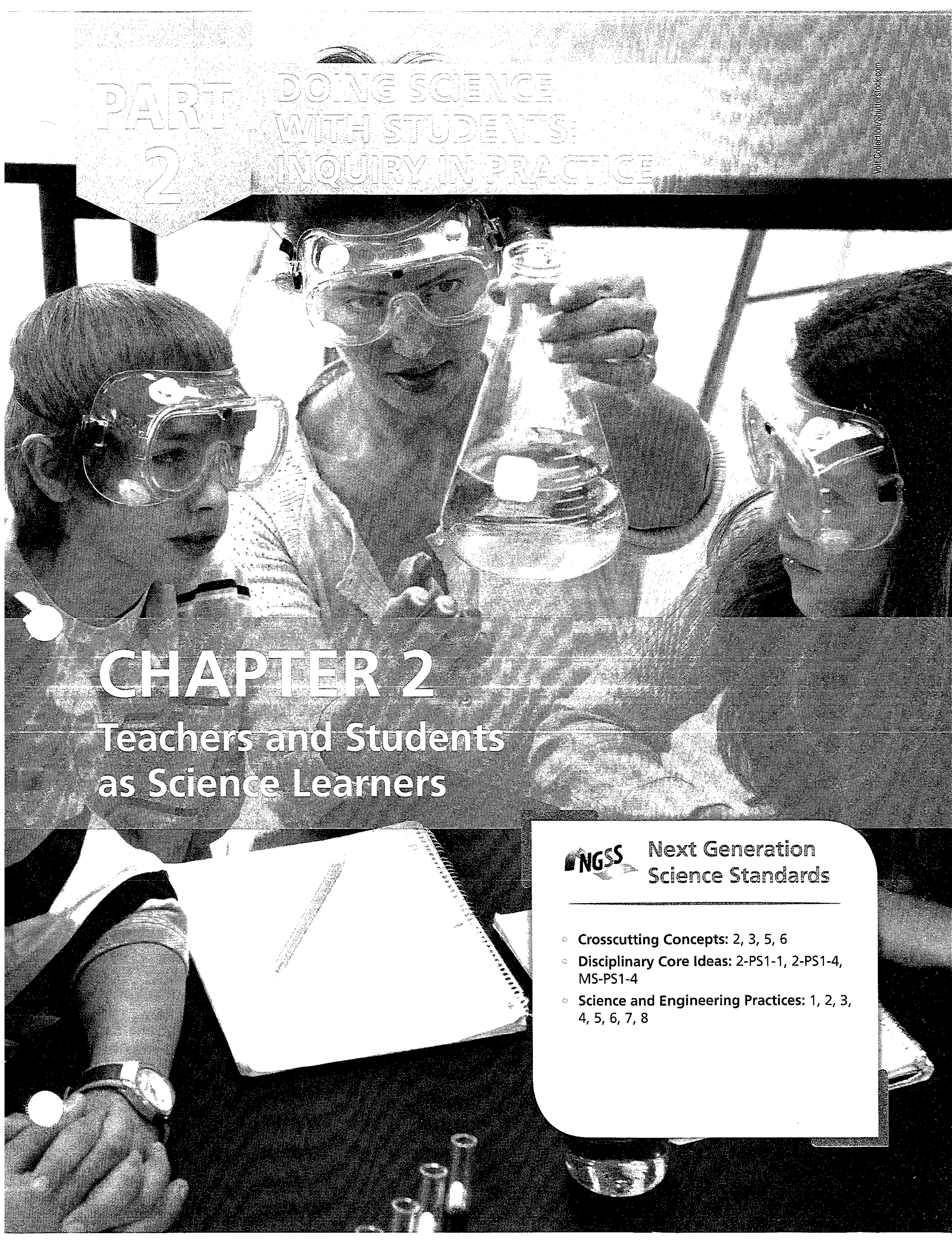

PART 2 DOING SCIENCE WITH STUDENTS: INQUIRY IN PRACTICE

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CHAPTER 2
Teachers and Students as Science Learners

NGSS Next Generation Science Standards

- **Crosscutting Concepts:** 2, 3, 5, 6
- **Disciplinary Core Ideas:** 2-PS1-1, 2-PS1-4, MS-PS1-4
- **Science and Engineering Practices:** 1, 2, 3, 4, 5, 6, 7, 8

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 2-1 Discuss how to help students make meaning of concepts for themselves.
- 2-2 Recognize the ways to facilitate student learning.
- 2-3 Examine how the science teacher becomes a mediator of students' ideas.
- 2-4 Examine the role of alternative conceptions in the social context of teaching science.
- 2-5 Explore concept maps as a way to help students make meaning.
- 2-6 Discuss the importance of students' own ideas.

Reflection

To Think About:

- As a child, did you ever invent your own theories for why things happened—theories that were useful at the time but did not match what the rest of the world was thinking?
- Why do you think "hands-on science" is not sufficient to help students learn science concepts?
- What do you think of when you hear the term "mediator"? How might it apply to science teaching?

2-1 Making Meaning: A Personal Story

Chapter 1 invited you to begin discovering your scientific self. As you did, you probably revisited your childhood wonderings and wanderings. One new teacher, who grew up in an urban area, remembered wondering why it was always cool in the summer in the basement of the apartment building where she and her family lived.

Children have many questions like that, but too often schools do not make room for these questions, and the children grow up, as this teacher did, with their questions unanswered. This happens because teachers, no doubt meaning well, approach science teaching and learning from their own perspective only. They ask themselves, in effect, "What do I have to *transmit* or *deliver* to my students?" As you will see in this chapter, science teaching is much more about the exchanges that occur between teachers and students as they explore science together.

When I was a little girl, growing up in an inner-city apartment building with six floors and twenty apartments on each floor, I always wondered how the mail made its way to the little mailbox that belonged to my family. It was on the second row of all the boxes—the fourth one in from the left. When I was six years old, I was allowed to use the small key to open the mailbox assigned to my family and "take out the mail." This was my daily job after school. I had my own personal theory about mail delivery. I imagined that, when the envelope was dropped in the public mailbox on the corner, a tube carried it through underground chutes to its destination in my little mailbox. Even at the age of six, however, I was troubled by not being able to explain how the letter knew how to get to my mailbox.

One day, when walking with my mother, I bent down to look under the mailbox on the corner. "What are you looking for?" she asked. "I was wondering where the tubes were," I responded. "What tubes?" she asked, and I then proceeded to share my theory. Nodding, she said that she could not explain right then how the mail got to the mailbox but she would arrange a way for me to find out.

Shortly thereafter, I was home ill from school, in the care of my grandmother. My mother called from work and asked Grandma to take me down to the mailboxes at the precise time that Artie, our mailman, would arrive. She bundled me up and I was able to witness the mailman, with his special key, open the portal to all of the mailboxes in the building. One box at a time, he inserted the mail in the various boxes.

He allowed me to help him, thrilled with my curiosity about how mail "knows" where to go. He also invited me and my family to the local post office for a view of how the postal workers sort the mail for the various neighborhood routes.

This experience demonstrates, for me, what it means to directly observe a phenomenon as I set about understanding more of my external world. It would have been easy for my mother to say, "No, Janice, mail does not travel through tubes in the ground." Instead, she honored my theory, found it quite interesting, and arranged for me to have the direct experience that would challenge my beliefs about underground tubes and mail delivery. By observing how the mailman opened all the mailboxes simultaneously with his large master key, I saw people as an intricate part of the mail delivery process. I began to expand my thinking! It no longer mattered that my idea was incorrect—because the authentic explanation made so much sense.

While you rediscover your own scientific self, you will also notice the ways in which your students express *their* scientific selves when you engage them in meaningful science activities. As we mentioned earlier, students construct meanings from science experiences on the basis of who they are, where they have been, and their own prior understandings. In this chapter, you will see how you can act as a mediator and facilitator in this process, helping your students to construct their own meanings by listening to their ideas and learning about how they think.

Much of our work will center on science stories—narrative accounts of actual experiences that teachers, including myself, have had while doing science with students. After each science story, look for ***The Teaching Ideas behind This Story*** and ***The Science Ideas behind This Story***. These sections will help you to think about the teaching strategies and the core science concepts illustrated by the story. The **disciplinary core ideas (DCIs)** and the **science and engineering practices (SEPs)** as well as the **crosscutting concepts (CCs)** from the Next Generation Science Standards will be indicated where applicable in the ***Connections to the Next Generation Science Standards*** section. Look for their inclusion in the discussion of the science stories. The ***Exploring Further*** section will help you to think about how this experience can happen in ***your*** classroom. As you will see, the science stories reflect the three main branches of school science:

disciplinary core ideas (DCIs) Science concepts addressing four domains: life science; physical science; earth and space science; and engineering, technology, and applications of science. These concepts are represented by learning progressions as students' ideas mature over time.

science and engineering practices (SEPs) The use of a particular set of practices for engaging in scientific inquiry and engineering design, providing insights into how scientific knowledge develops and gaining an understanding of the work of engineers.

crosscutting concepts (CCs) A way of linking and thinking about the disciplinary core ideas in science. These concepts help students develop a coherent and scientifically based view of the world.

- In *life science*, students and teachers explore characteristics of living things and their interactions with the nonliving environment. The current interest in "green science," which stresses the impact of human development on natural environments, falls into this category.
- In *physical science*, students and teachers look at properties of objects and materials, forms of energy, and the motion of objects.
- In *earth and space science*, students and teachers investigate properties of earth materials, objects in the sky, and changes in the earth and sky.
- Look for examples of *engineering design* and chances for students to apply their knowledge of science in the design and construction of an experiment or an object.

At times, you may engage all the students in a similar experience at the same time, or you may involve different groups in different activities that are centered on a similar theme. Sometimes you may show the students a natural event by way of a demonstration. That is what happens in the following science story.

SCIENCE STORY

The Bottle and the Balloon

I am visiting Ms. Hudson's third-grade class in a suburb of a major northeastern city. The twenty-four children come from many cultures—European American, Latino, African American, and Asian American—and a wide range of socioeconomic classes. I'm standing up front with the simple apparatus I've brought for this lesson.

The children watch as I place a deflated red balloon over an apparently empty vinegar bottle. It hangs limply to the side. I hold the bottle up to the class and ask, "What do you think is in this bottle?"

The children respond, "Air!"

I put this thick glass bottle into a pot of just-boiled water, holding the top to keep it upright. "Let's watch what happens here," I say. Slowly, the deflated balloon fills with air, until it stands erect at the top of the bottle.

The children are delighted. With only a little prodding from me, they carefully explain what they observe, and we record it: When we put the bottle in the hot water, the balloon filled up with air. "Where do you think the air has come from?" I ask. "What are some of your ideas?"

> ***My thinking:*** *At this point I am wondering if the children will grasp that making the bottle hot will heat the air inside the bottle and that the warm air expands and causes the balloon to inflate. I do not expect the children to have that level of knowledge, but I do hope they will make some connection between the heated air and the balloon's inflating. Instead, the children give me some creative but quite different explanations.*

"The steam from the boiling water went through the glass and inflated the balloon," a boy named Mike offers.

"That is an interesting idea," I answer. "Have you ever seen steam go through glass before?" After thinking for a moment, he does not remember having seen steam go through glass.

A girl named Jamila agrees with Mike's focus on steam but has a different idea about the mechanism: "The steam seeped into the balloon because the seal between the balloon and the bottle was not airtight." I respond, "That sounds as if you have really been thinking about this. Do you think that my placing the bottle in the hot water helped the steam to seep in?" Jamila says, "Yes, it helped steam get in."

It's clear to me now that several students think that steam seeped into the balloon. I continue to question them about their thinking: "Do you think that if we made the seal between the bottle and balloon tighter, we could prevent the steam from seeping in?" The students believe this is true, so I ask them how we should do it. They decide to take several bottles and balloons and securely tape each new balloon onto its bottle before placing it in the pot of hot water. We try four different setups with bottles of different sizes and shapes as well as balloons of different sizes and shapes. In each case, the balloon still inflates.

Though the results contradict their own ideas, the children enjoy watching the balloons inflate. Each time I repeat the experience, I invite the students (especially those who most firmly believe that the source of the air is *outside* the bottle) to stay close and observe. Jamila looks hard for steam seeping into the bottle. Mike holds the balloon tightly around the neck of the bottle to make sure it is airtight.

After the four additional tries, I ask the students what they are thinking now. At this point, they have mostly decided that the air inflating the balloon must be air that was already inside the bottle. We make connections between this experiment and hot air balloons as well as to the places where we find the hottest room in our houses during the summer. Some students are coming, in their own way, to the science idea that I was hoping they would grasp, namely, that warming the air changes the way the air behaves.

In these experiments, as the students have noticed, the balloon always fills gently and partially with air; it does not inflate completely. I ask them why they think the balloon did not blow up more than it did. Some students remark that it could fill up only with the air that was already in the bottle when we started. "Hooray!" I think. They really "get" it.

Finally, to help them build on their understanding, I ask myself what other demonstration I can do to show that there is air in the bottle. We proceed to take the balloon off the bottle and invert the "empty" bottle in a basin of water. The water does not rise in the bottle. Some students say that it must be the air in the bottle that keeps the water from entering.

As I am ready to leave Ms. Hudson's class, she asks the students to take laptop computers from the classroom laptop cart and visit a website about hot air balloons. With the links and pictures on this website, Ms. Hudson asks the students to do the following exercise:

> *Pretend you are going to take a hot air balloon ride. Write a letter to a friend about your upcoming adventure and be sure to include answers to the following questions: Where is the closest balloon site to our school? What is the science idea behind the way balloons operate? When did people start using hot air balloons? What is the source of heat energy for these balloons? In your opinion, how safe are they?*

The Teaching Ideas behind This Story

- When students simply repeat answers they have heard, we cannot be sure that there is any deep meaning in this knowledge. The students in Ms. Hudson's class all agreed that the bottle contained air. Nevertheless, I could tell that many were not comfortable with this idea. For some, it was just a rote answer, something they had been told was true but hadn't fully incorporated into their own thinking. *Grasping terminology is not the same as understanding the concept or being able to apply it in a real-life context* (Brooks & Brooks, 2001; Yager, 1991).
- When I asked Mike if he had seen steam go through glass, I was not making fun of his idea. Instead, I was trying to draw out his prior experiences that might have contributed to it.
- Notice how I treated the children's "wrong" ideas with respect, inviting them to test whether those ideas were true. This is a vital technique that we will discuss further in the next section.
- Although the experiment began as a demonstration, it quickly became a participatory event as the students suggested their own variations.
- Notice how Ms. Hudson used readily available networked computers to extend the lesson with a related language arts exercise based on hot air balloons. This connection to language arts is both natural and useful, and it encourages the students to express their understanding of the science idea in their own words.
- When Ms. Hudson asked students to do research on hot air balloons, she was also applying standards from the *National Educational Technology Standards for Students*, or NETS-S (International Society for Technology in Education, 2007), that state that students apply digital tools to gather, evaluate, and use information.

The Science Ideas behind This Story

- Although air is all around us and seeps into everything, it is a difficult concept for young students to understand. They can blow air onto their hands, feel the force of a breeze—but, still, it is a tricky concept. Air that is warmed expands. Its particles move faster and become farther apart. If this air has room—that is, if the walls of the container are not too rigid—the warmed air particles continue to move farther apart. Because its particles are farther apart, this warmed air is now less dense. In the experiment in Ms. Hudson's class, the colder air above—denser, with its particles closer together—dropped down, pushing the warm air upward.
- The method by which heat energy travels in liquids and gases is called *convection*. You can read more about convection in Chapter 10. Ms. Hudson or I could have introduced this term and asked the students to memorize the definition. But even after learning the term, they might have been unable to relate it to the balloon and the bottle.

Connections to the Next Generation Science Standards

- **NGSS DCI: 2-PS-1.A: Structure and Properties of Matter:** Different kinds of matter exist and many of them can be either solid or liquid, depending on temperature. Matter can be described and classified by its observable properties. Heating or cooling a substance may cause changes that can be observed.

- **NGSS SEPs:** Ms. Hudson's students were *planning and carrying out an investigation; engaging in argument from evidence;* and *obtaining, evaluating, and communicating information.*
- **NGSS CCs:** Ms. Hudson's students examined the phenomena of *cause and effect,* trying to find an explanation for the inflating of the balloon!

Exploring Further

If you were teaching this lesson, using the bottles and the balloons, you may want to understand answers to the following questions:

- How is *convection* of heat energy in the balloon experiment different from the *conduction* of heat that occurs when you touch a hot stove?
- What stories do you know that involve hot air balloons? What principle is behind the operation of these balloons?
- How might you help young students discover that air has weight and takes up space?

2-1a Helping Students to Make Meaning

Let's reflect further on what happened in Ms. Hudson's class when I helped the students experiment with bottles and balloons. As we noted in Chapter 1, the view that learning is an active process of knowledge construction is part of a family of theories called *constructivism.* Contemporary constructivism reflects what we now know about how people learn (Donovan & Bransford, 2005). In order to understand a concept, individuals *must* be engaged in the active process of making sense of their experiences. Simply "knowing" something does not constitute understanding. Instead, we gradually come to understand ideas as we turn them over in our minds and reflect on our experiences.

For students, true understanding means that they can discuss concepts freely and apply them to other areas of thinking. Students' prior knowledge is central to building this kind of understanding, and the process of reflecting on their own thinking helps them to make meaning of the "science ideas."

2-1b Prior Knowledge

The philosopher John Dewey said that concepts should be viewed as "known points of reference by which to get our bearings when we are plunged into the strange unknown" (1933, p. 153). That is, concepts don't just sit there in our minds; they help us interpret and deal with new situations. In turn, these new experiences help us refine our concepts. I like to think of our concepts as old friends—ideas we come to know as we grow and that we refine and revisit as we add new understandings to our repertoire. Our repertoire of such understandings is our **prior knowledge.** When I asked Mike in Ms. Hudson's class if he had experiences with steam before, I was trying to access his prior knowledge.

prior knowledge
What an individual has learned from all his or her previous experiences. This plays a crucial role in determining how the person integrates a new concept.

To a casual observer, it may not seem that the students in Ms. Hudson's class knew very much about the matter at hand. Nevertheless, the prior knowledge they possessed was extremely important. They knew that boiling water gives off steam, for example, and they certainly understood some of the characteristics of steam.

As I conducted my experiments, I was really interested to learn that several students thought that the balloon inflated because of the steam from the just-boiled water. If I had merely told them something different, they might have nodded at me but failed to derive any real meaning from what I said. Instead, because my interest in their thinking was genuine, the students knew that I valued their ideas and respected their prior knowledge. This leads us to our next crucial point.

2-1c Valuing the Students' Thinking

Valuing the students' ideas is a way of communicating to them that their thinking is important to the class community. When students' ideas are genuinely valued, they begin to see themselves as *knowers*. Only as knowers can they construct new meanings by building on their prior beliefs and ideas.

This is a vital principle to grasp. Creating an atmosphere in which there is a sense of trust makes it possible to help the students reflect on their new experiences and use those reflections to modify their prior knowledge. Without such trust, the students are not likely to do much serious thinking about the science experiences in which you engage them. They may memorize a "fact" or two, but their underlying ideas may remain unaffected.

When you inquire about students' thinking, you need to be ready for many types of responses. *All* of their responses have value because they provide insight into the students' thinking. If you tell the students your thinking first, they will never feel comfortable sharing their own ideas. The students will immediately think the way you think, or at least they will say they do. This is called playing the "teacher game," and even young children are good at that.

If students have difficulty reaching a "correct" scientific understanding, that is okay. Listen to their ideas and reflect on them. Ask the students questions that help you understand the nature of their prior knowledge. Encourage them to:

- Write about and draw what they have observed.
- Create stories and poems about their science activities.
- Plan other similar experiments to test their personal ideas.

Such experiences encourage them to come up with their own ideas and offer those ideas in the discourse of the classroom.

Science activities and experiments need to provide students with the freedom to say exactly what they think—even if that is the *freedom to be wrong*. In the rest of this book, you will find many examples of this teaching strategy. You will also learn the many ways in which teachers help students to correct their misconceptions and reflect on the accurate ideas behind the science experience. This was demonstrated in Ms. Hudson's class and will be reflected in Mr. Wilson's behavior later in this chapter.

2-2 Facilitating Students' Learning

> *In my entire life as a student, I remember only twice being given the opportunity to come up with my own ideas, a fact I consider typical and terrible.*
>
> —Eleanor Duckworth

mediator
A teaching role in which the teacher helps students to learn by reflecting their own ideas back to them and guiding them in sorting out the inconsistencies.

If our interest is in helping students construct meaning, then we have to teach in ways that facilitate that process. The challenge is to help students delve deeply into their thoughts and expand their own thinking about an idea. Our role therefore becomes that of a **mediator**. In everyday terms, a mediator serves as a go-between of some sort, often by helping people resolve their differences by bridging the gaps between their points of view. A teacher who is a mediator helps students to bridge the gap between their initial understanding and the deeper knowledge they can build as a result of the lesson. The teacher can do this in a variety of ways, but the process usually begins by exposing students to new experiences and helping them to probe their own thinking. (In terms of the science learning cycle described earlier, the teacher's mediation takes place during the explanation and elaboration phases.)

In the bottle-and-balloon lesson, I was helping the students probe their thinking by inviting them to try the experiment again in different ways. I facilitated that process by providing additional materials and becoming the mediator of their ideas. It wasn't easy. The students who believed that the air inflating the balloon came from outside the bottle had a hard time realizing that anything was already in the bottle when we started. Although they said "air" when asked what was in the bottle, they were merely being correct, not truly understanding the concept.

Hence, I encouraged them to test their own theories. By "theories" in this context I mean their proposed explanations for a natural event. In science, as we noted earlier in the book, the term *theory* means a belief about a science idea that has a lot of observable evidence to support it. By *students' theories* we refer to their beliefs based on their own understandings at their particular level of cognitive development. These may not be full-fledged theories in the scientific sense, but they can lead to genuine theory building as students construct further meaning. Students discuss ideas with one another as well as with you, the teacher. When groups of students become involved, the conversation often involves three or four people or more. This is what is meant by the *social construction of meaning*, a phrase that is frequently used to emphasize the importance of social context in learning. In a genuine class or group discussion, students listen to and respond to each other as well as the teacher. With this style of communication, students can flesh out their ideas and make meaning from them. In the end, this type of science teaching yields a deeper, more important, and more valid understanding of science ideas.

2-2a Alternative Conceptions

alternative conception An idea that is not scientifically accurate but represents a step toward full understanding of a concept.

As the bottle-and-balloon story demonstrates, different students construct meaning in different ways, and sometimes their ideas amount to **alternative conceptions**—ideas that are not scientifically accurate but represent a step toward full understanding of a concept. Some people refer to inaccurate ideas as misconceptions, but the term *alternative conception* helps us realize that these ideas serve a purpose. Alternative conceptions are like stops on a train route. They are places the students pass through on their journey to fuller understanding. Obviously, teachers need a thorough grasp of the science concepts behind a given topic to know when the students' own ideas represent steps in the path toward fuller understanding. As a teacher, you achieve that grasp by exploring science experiences and science concepts one topic at a time—and by locating your inner scientist. (Do not worry; it is doable and very rewarding. Chapter 10 contains some useful scientific information to jump-start your science content knowledge.)

When students reveal alternative conceptions, teachers need to evaluate those ideas and take action (Photo 2.1). This "action" is what your role as mediator is all about. Valuing the students' ideas does not mean you must let them go unchallenged. Instead, you invite your students to examine their conceptions from multiple perspectives—making connections between the experience and something else in their memory, or trying the experiment again in a different way. Thus, I asked Mike if he had ever seen steam go through a bottle before. I asked the students, too, if they thought making the seal tighter would prevent

PHOTO 2.1 This teacher and her students engage in an in-depth conversation about a project. By respecting and encouraging the students' own ideas, the teacher helps them reach a deeper understanding.

Tetra Images/Alamy Stock Photo

the steam from seeping into the balloon, and I guided them to explore that possibility. Through such means, we help them refine their ideas so their thinking matches their own enlarged experience.

2-2b Scaffolding

scaffolding
Providing temporary support or guidance to a learner who needs help to reach understanding of a concept or process. The scaffold can take such forms as key questions, important facts, a structure to frame the problem, and modeling or demonstration by the teacher.

When teachers facilitate student understanding, they help students by **scaffolding** their learning. In daily use, *scaffold* refers to a temporary platform or ledge that physically supports workers while they complete jobs above the ground—for instance, installing windows on the fifth floor of an office building. In education, the term *scaffolding* also refers to a temporary "ledge," but in this case the platform is an intellectual place—a step on the road to understanding the core concept. Just like the worker who could not complete his or her job without the scaffold, learners need scaffolding support by teachers to develop their science understanding.

The temporary scaffolding that teachers provide may include guidance during an investigation or key questions for students to think about. Sometimes the scaffolding is additional information that helps students move to the next step. In a later chapter, you will see a teacher scaffolding student learning by providing a "fact sheet" about the effects of salt water on living things. In Ms. Hudson's class, the scaffolding included the questions I asked and the experiment with the balloons taped to the necks of the bottles. Look for the scaffolding that Mr. Wilson uses in the next science story.

2-3 Teacher as Mediator

Helping students to think about natural phenomena often requires a conversation where the teacher is guiding the student to consider another direction or another way of thinking. Such is the case in the following story.

SCIENCE STORY

Icicles

It is an icy-cold winter morning in the Northeast. It snowed two days ago, and the temperature has plummeted to well below the freezing point of water. Ice and snow cover everything.

On his way to school in this urban community, Mr. Wilson notices icicles hanging from the edges of roof lines. The icicles glisten in the sun. They are of varying lengths and thicknesses. He reaches up and breaks off some extra-long ones and brings them to his third-grade classroom, where he stores them temporarily on a ledge outside the window.

After the morning business, Mr. Wilson retrieves the icicles and shows them to the children. "Where do you think I found these?" he asks. The children call out all the places where they saw icicles this morning. Some of them noticed icicles hanging from tree branches; others saw icicles on roofs and awnings. Still others didn't seem to notice any icicles at all. As a group, the children are excited that Mr. Wilson has brought some icicles to class. He describes how he reached up to a low roof and gently pulled them off, trying not to break them.

"What are all the things you notice about these icicles?" Mr. Wilson asks.

The children respond in various ways: "They're long." "They're cold." "They're cloudy." "They're hard." "They're pointy." "They will start dripping when they melt." "You can hurt someone if you stick it into them!"

"Let's explore these things before they melt," says Mr. Wilson. "What are your questions? What do you want to find out about these icicles?"

Some children are interested in knowing how long it will take for them to melt. Others suggest different questions:

"Will they weigh the same when they melt as they do now?"

"When they melt, will they be the same color?"

"Can we make them back into an icicle after we melt them?"

"Do they taste good?"

Mr. Wilson's thinking: *Notice that Mr. Wilson has asked the students to think about what they want to know about the icicles. He knows that what is really important is the students' questions—the ones they cannot answer yet, the ones that compel them to search for answers.*

Mr. Wilson engages the children in a discussion of their questions. They talk about why it may not be a good idea to taste the icicles. (Some children think they may be dirty.) Most of the children want to make the icicles melt. Some children want to place the icicles on the classroom heater. Some want to light a candle (Mr. Wilson would do that for them) and hold the icicle over it. Some children want to place the icicles on the window ledge, where the sun is streaming in.

At this point, Mr. Wilson temporarily returns the icicles to the outside ledge. He asks the children to divide up into their usual science groups. Each group will get an icicle to work with, he says, and each group should decide in advance what to do with it before it melts. As a suggestion, Mr. Wilson repeats one of the ideas the students themselves proposed: "Let's do find out," he says, "if our icicles weigh the same when they melt."

As the children are deciding on their procedures, Mr. Wilson visits each group and coaches them. He points things out to them and asks them to explain what they have come up with. He prods them, leading them with his questions, coaxing and coaching their planning. "What should we do to find out if the icicles weigh the same after they melt as they do now?" he asks various groups.

"Weigh them, before and after," the children figure out.

Mr. Wilson's thinking: *Although this is an impromptu lesson, Mr. Wilson has an objective in mind. He's hoping the students will begin to learn what melting really is. The question about an icicle's weight before and after melting was an important one, so he stimulates their attention to it. He also guides them in framing their* *investigations so they will be able to explore the changes that occur when the icicle melts. He points things out and inquires about their plans. He is somewhat like a tour guide or a coach. Unlike a tour guide, however, he does not explain the details of all the sights. Instead, he listens to the students' impressions and asks for whatever meanings they may construct.*

It turns out that one group cannot decide what to do. Mr. Wilson asks them what they have thought about so far. One student explains that "Jamie wants to make something that will keep the icicle from melting," while the rest of them (three other children) want to time how long it will take to melt.

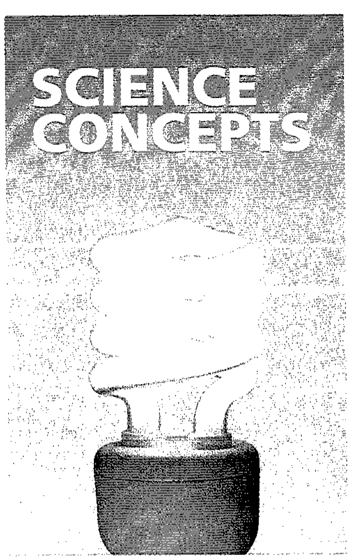
Mr. Wilson thinks about this dilemma and asks Jamie what question she has in mind. Her question is, "How long can I keep the icicle cold?" She wants to wrap the icicle up with materials from the classroom and put it in a shoebox. "Why are you interested in doing that?" asks Mr. Wilson. Jamie replies, "I want to see if I can keep it cold long enough to take it home."

"Okay," Mr. Wilson says, "why doesn't Jamie do that with one icicle? The rest of you can take another icicle and work on your plan to melt it."

Mr. Wilson's thinking: *Although his main focus in this lesson is on melting, Mr. Wilson doesn't force all the children to work on that. He knows that Jamie is becoming invested in exploring her own question, so he allows this to happen.*

When the groups have decided on their questions and procedures, Mr. Wilson takes out the scales—the double-pan balances commonly used for measuring mass in elementary grades. He distributes an icicle to each group, giving an extra one to Jamie. But before the students begin to weigh the icicles, he asks them, "How will you collect the water while your icicle is melting?" (Some of the icicles are already dripping.) The children have to consider the problem. He invites them over to the science supply table and asks for suggestions. They look at the plastic cups, aluminum foil pie pans, shoeboxes, and assorted plastic containers. Someone suggests that they allow the icicle to melt in an aluminum pie pan. Mr. Wilson encourages this idea since the pie pans are flat and can accommodate the icicles without tipping over.

Mass and Weight



In elementary and middle school science, students learn some basic ideas about matter. Matter can be defined as anything that has weight or mass and takes up space (as opposed to energy, for example, which has neither of those qualities).

Mass refers directly to how much matter is in an object. Often, the term *weight* is used interchangeably with *mass*, but in scientific usage, the two are different. *Weight* means the gravitational pull that the earth has on an object.

Since the gravitational pull of the earth is relatively constant, mass and weight are essentially the same on earth. But if you weigh an object on earth and then take it to the moon, it will weigh only about one-sixth as much because the moon's gravitational pull is about one-sixth as strong as the earth's. The object's mass, on the other hand, will be the same in both places.

Even on earth, the nearer a body is to the center of the earth, the greater the downward pull of gravity on the body and the more the body weighs. The farther a body is from the center of the earth, the less the body weighs.

> *All of us learn through our experiments. Do we give ourselves the freedom to experiment, the freedom to be wrong, the freedom to be right . . . for a little while . . . until we turn out to be wrong again?*
> —JACQUELINE GRENNON BROOKS AND MARTIN BROOKS

Now he asks the children to weigh their icicles. As their standard masses, the children use teddy bear counters: thick plastic figures, about 5 centimeters long, shaped like teddy bears. (Standard unit masses may be in gram units or in any other convenient units—for example, paper clips or pennies.)

In their small groups, the children take turns with the double-pan balance. Some children weigh the icicle and the pan together. Others weigh just the icicle. Mr. Wilson observes each group and does not give specific instructions. The children realize that the icicles have to be weighed quickly before they melt.

Mr. Wilson's thinking: *Mr. Wilson does not want to direct the students in how to weigh their icicles. Instead, he gives them the freedom to experiment—the freedom to be wrong and then to explore further until they are right. He watches, he suggests, he leads a bit, and then he lets go—until (as we will see) he needs to intervene. He is mediating their experience.*

After the weighing, the children proceed with their different plans for melting their icicles. One group, which has weighed the icicle in the pan, places the pan on the sunny windowsill and checks it every few minutes until the icicle melts. Then the group members weigh the melted icicle in the pan and compare the two measurements they have made:

icicle + pan = 20 teddy bears

melted icicle + pan = 20 teddy bears

Other groups follow different methods of melting and come up with similar results in the weight test.

Predictably, however, the groups that have weighed an icicle by itself, outside the pie pan, run into trouble. For instance, one of these groups proceeds to melt the icicle in the pan on the heater and then weighs the resulting water in the pan. This group concludes that the melted icicle weighs more than the solid icicle. Now Mr. Wilson intervenes. "What about the pie pan that you have the water in?" he asks. "Doesn't it weigh something?"

The children look at him. He explains, "You weighed your icicle on the balance scale all by itself, but you weighed the water in the pan. If you weighed the icicle all by itself, then you would have to weigh the water all by itself."

Thinking about this, the children come up with a new plan. They ask Mr. Wilson if they can try the experiment again with another icicle. "Yes," he says, and gives them a new one to work with. He has been keeping extra icicles outside the classroom window.

Mr. Wilson's thinking: *Mr. Wilson intervenes when he realizes that the children have come up with an alternative conception, an idea that has been constructed from their experience but is not scientifically accurate. He sets them on a path that will help them build a more accurate idea.*

It is interesting, though, that Mr. Wilson does not tell them to find the mass of the pie pan by itself and then subtract that from the total mass of the pie pan and water. The children have not thought of that option, and Mr. Wilson decides to allow them to redo their experiment rather than impose his procedure on them. This is an important decision: finding the right balance between guiding the procedure and allowing students to experiment for themselves. Here we see another facet of the teacher as mediator.

The group that is redoing the experiment begins by weighing the icicle *in* the pan this time. They decide to let the new icicle melt in the pan on a table in the back of the room. This icicle takes longer to melt, so they weigh the resulting water after lunch. This is their result:

icicle + pan = 15 teddy bears

melted icicle + pan = 15 teddy bears

Once all the groups are finished, Mr. Wilson again engages the entire class in discussion. The students all agree now that you have to weigh the icicle in the pan at the beginning, and then you have to weigh the melted icicle in the pan at the end. They also agree that an icicle's weight does not change when it melts, though most of them are surprised by this conclusion.

"Well, what did you think would happen?" Mr. Wilson asks. The children say that the melted icicle looked so little compared to the original icicle that they thought it would weigh less.

"What other melting experiments can we do?" Mr. Wilson wonders aloud. The children suggest using ice cubes to see if the same thing will happen. Mr. Wilson promises to bring ice cubes to class the next day. Meanwhile, Jamie has wrapped her icicle tightly in aluminum foil and paper towels before placing it in a plastic bag and putting it in a shoebox to take home.

The Next Day: From Icicles to Ice Cubes

The following morning, the children in Mr. Wilson's class come to school ready to see if a pan of ice cubes will weigh the same before and after melting. This experiment was the children's own idea, and it generates curiosity and profound interest.

Before addressing the ice cubes activity, however, Mr. Wilson gives Jamie a chance to present her experiment to the class. She explained to the class that her icicle in the shoebox did last, but it became a lot smaller. When she got home, she put it in the freezer.

Now Mr. Wilson brings out three trays of ice cubes from the school refrigerator. Weighing the tray of ice cubes before and after melting will be a repeated experience, another visit to the concept of masses remaining the same when the state of matter changes. It is an example of assessing how well the children can *apply a concept* they learned the day before. Once again, Mr. Wilson is engaging them in solving a problem, setting up an experiment, testing their own ideas, and drawing some conclusions.

But the students now are also interested in Jamie's type of experiment. They want to know if they can try different techniques to preserve the ice cubes. "Sure," replies Mr. Wilson. One ice cube tray can be used for melting, and the others can supply the cubes for the new experiments. Mr. Wilson sees that the class's further explorations can lead to ideas about the concept of insulation and the losing and gaining of heat energy. In this way, one student's question has become an entire class's experiment.

The Teaching Ideas behind This Story

- The way Mr. Wilson used the icy weather to engage the students in a science activity reflects an important connection between the environment outside the classroom and the activity within it. Making this link is a very important part of doing science with students. We will return to this idea in Chapter 4.
- Clearly, Mr. Wilson was engaging the children in a constructivist learning activity. Notice how he listened to their ideas about icicles, weighing, and melting, and then encouraged them to try out their notions. This method helps students recognize what they already know and build on it. For example, the students knew that the icicles would melt if kept indoors. They had their own ideas about places where the melting might happen quickly—the heater in the classroom and the sunny window ledge. Their prior knowledge also helped them choose an appropriate container in which to place each icicle before they melted it. Because Mr. Wilson acknowledged them as knowers, they could proceed to experiment with confidence.
- Nevertheless, Mr. Wilson did not ignore what they were doing or let them experiment entirely without help. Instead, he *mediated* their experience by giving them suggestions and guiding their activities.
- There are those who will think that Mr. Wilson should have told the children at the beginning that they needed to weigh the icicles in some kind of receptacle. Such an instruction may be time efficient, but it does not promote the development of the children's own ideas. He wanted the children to explore on their own (Photo 2.2) so they could learn the best way to measure their icicles. For that reason, he created an atmosphere in which the children had the opportunity and *intellectual freedom* to investigate their notions. He also gave them the tacit message that it is okay to be "wrong."
- When one team of students decided that the water weighed more than the original icicle, Mr. Wilson knew that this was an alternative conception that could become a stopping-off place en route to deeper

Jim West/PhotoEdit

PHOTO 2.2 Examining mud samples from a river, these students explore their own questions and discuss their ideas.

meaning. At this point he stepped in to provide some crucial information: He pointed out that if the students had weighed the icicle without the pan, they would have to weigh the water the same way. Good teachers supply enough information to show students the right path but not so much as to discourage students from thinking on their own.

- Mr. Wilson did not know in advance exactly where the icicle experience would lead. He did not impose a rigid procedure. He was intending that the students learn something about melting. But Jamie, the student who kept the icicle cold, would also learn something about insulation. He did make sure that each group explored the question of weight before and after melting—a question that the students themselves had raised in the beginning when he prompted them for ideas.
- Do you see how the approach to learning Mr. Wilson took in his class parallels the scientific process itself? In professional science, one experiment often leads to another experiment because somebody in the research team has a new but related question. In the same way, Mr. Wilson's students, stimulated in part by Jamie, follow their own questioning from one exploration to another.

The Science Ideas behind This Story

- The activity in this story addresses what happens when matter *changes state,* in this case from a solid to a liquid. The students observe that when a certain amount of matter changes state, its mass does not change. Changes in state are associated with different amounts of energy, but the amount of mass remains constant before and after the change of state. Each group of children added heat energy to its icicle so that it would melt. The icicle absorbed the heat energy. That caused its particles to move faster and spread farther apart, turning the solid into a liquid. But the additional energy did not affect the mass.
- The states of matter are a foundational property in physical science. They help students to understand the world around them, and they become prior knowledge on which to build more complex concepts, such as atomic structure.

- Icicles form when snow or ice collects on an elevated surface and the air is around the freezing point of water, 32 degrees Fahrenheit or 0 degrees Celsius. If snow or ice melts in a sunny area and drips down to a shaded area, it can refreeze in a column as an icicle.
- This activity helped students understand that when you are weighing the same object in different forms, the method you use is very important. There is a key general principle here. In a science experiment we always ask, "What are we keeping the same? What are we changing?" Scientists call these **constants** and **variables**, respectively. The students were changing the state of matter; therefore, to make this a fair test of the effect on weight, the conditions under which the two states were weighed had to be the same. A **fair test** in science requires that we keep all of the experimental conditions the same (constant) except the one that we are testing for (the variable).

Connections to the Next Generation Science Standards

- **NGSS DCI: 2-PS1-4: Chemical Reactions:** Heating or cooling a substance may cause changes that can be observed. Sometimes these changes are reversible; sometimes they are not.
- **NGSS SEPs**: Mr. Wilson's students *planned and carried out investigations; engaged in argument from evidence; constructed explanations;* and *obtained, evaluated, and communicated information.*
- **NGSS CCs:** Mr. Wilson's students examined *scale, proportion, and quantity* as a way to determine that the amount of matter they had at the beginning of their investigation was the amount of matter that remained at the end. Further the Crosscutting Concept of *energy and matter* asserts that *matter is conserved because atoms are conserved in physical and chemical processes.* Melting is a physical process.

Exploring Further

If you were teaching this lesson, having collected icicles from the outside, you may want to understand answers to the following questions:

- In what ways do you think the icicle activity stimulated the students' thinking processes?
- What prior experiences do you think the children were relying on to construct new meanings?
- What science ideas did the teacher need to know before engaging children in this activity?
- What connections could you make from this lesson to literature or social studies?
- How might you integrate technology into this activity?

2-4 The Social Context of Teaching and Learning Science: Alternative Conceptions

mass
The amount of matter that is in an object, typically measured in grams and kilograms.

constant
An experimental condition that remains the same throughout a scientific investigation.

John Dewey (1933) talked about concrete experiences as the ground and generator of the thinking process. Remarking that experience would lead to the understanding of ideas and the capacity to conceptualize, he argued for hands-on learning fifty years before it became a catchphrase. This movement from objects to ideas is what rooting science learning in concrete experience is all about. Some researchers have used the terms *situated cognition* or *situated learning* to refer to the notion that the situation or context of learning is critical and that real learning takes place only when it is situated in real-world activities (see Snowman & McCown, 2015).

> "*I think and think for months and years. Ninety-nine times, the conclusion is false. The hundredth time I am right.*"
> —Albert Einstein

variable
The property or condition of a scientific investigation that will change when experimental conditions are changed.

fair test
An investigation in which all the experimental conditions remain the same (constant) except for the one being tested (the variable).

Unfortunately, many science teachers, unlike Mr. Wilson, offer students hands-on activities that are completely predetermined and predictable. The teacher knows beforehand exactly where the students should end up. There are obvious attractions to this method; certainly you do need specific learning goals for your students. But the problem with imposing strict procedures on students when they are doing science is that the teacher does not learn what the students really think or how they construct meaning. Without learning what they think, it is extremely difficult to help them change or develop their thinking. Often students will score well on standardized tests and yet be unable to change the experience-based interpretations of nature they acquired prior to instruction (Yager, 1991).

It is important to recognize that alternative conceptions cut across age, ability, gender, and cultural boundaries. In a national study that collected data from more than 2,100 students in grades 3–5 (Barman et al., 1999, 2000), more than 13 percent of the students decided that an organism was not an animal if it didn't have fur. More than 9 percent of the students in the same age group explained that something couldn't be an animal if it wasn't a pet. An award-winning video, *A Private Universe*, shows that even Harvard graduates hold fundamental misunderstandings about the solar system. These examples point up the importance of using teaching strategies that are designed to reveal alternative conceptions and provide the repeated experiences that help change them.

Let's consider the icicles story again. Most of the children, seeing the small puddle of water left when the icicle melted, thought that it must weigh less than the original icicle. This is because, unlike other liquids, water expands when it freezes, taking up more space, and conversely it shrinks when it melts.

The idea that the water would weigh less than the icicle was contradicted by their experience. Without this experience, they might have memorized the fact that water expands when it freezes without really knowing in practice what that meant. It is only by becoming aware of students' embedded ideas about the natural world that we can begin to change their alternative conceptions. By providing opportunities for them to express their own ideas, talking about those ideas, and guiding them through tests of those ideas, we can mediate their development of more sophisticated and more accurate concepts. This role will take on deeper meaning for you once you experience it in your own classroom.

Some Strategies to Help Change Persistent Alternative Conceptions

- Listen to the students' ideas.
- Honor their thinking by reflecting on their responses.
- Ask students to explain their thinking: "That's interesting—what makes you think that?"
- Alter experiments. For example, do the same experiment again with different materials.
- Ask students to devise a plan to demonstrate that their alternative conception works: "Could we plan an experiment to see if that works?"
- Remind students that people tend to hold on to ideas that they know are not accurate. Ask them, "Why do you think we do that?"
- Find multiple ways to express and apply the accurate big ideas.

2-5 Concept Maps and Learning Science

Let's look at another illustration of how a teacher can facilitate students' learning by acting as a mediator. In this case, the students are in middle school, but the teacher again helps them to explore their own questions and develop their own ideas. In the last section of the story, you will see how the teacher deals with an alternative conception that arises.

SCIENCE STORY

The "Skin" of Water

The sixth-grade students in Ridgefield Middle School are mesmerized by the insects in the pond on the school grounds. On this warm winter day in the South, after many days of rain, the pond is quite full and the water very still. Ms. Parker has led the students outside to take some temperature readings of the pond so they can compare them with the measurements they took a week earlier. But before the students are settled around the pond, Henry shouts, "Wow, look at those two bugs!"

Skipping over the water's surface are two insects known as water striders. "Oooh, gross," says Lanie. "How do they walk on water?" Shondra asks. "Yeah," adds Shana, "how can they walk on water?" Ms. Parker opens the question to the class. "Well, what do you think, everyone?"

Ms. Parker's thinking: *Ms. Parker sees this question as a way to stimulate the students' thinking. For that reason, she doesn't leap to answer the question but instead asks the students for input.*

Some students say the insects must be very light to stay on top of the water. Another offers that the bugs seem to have pads for feet. "Their feet are far apart," says yet another student. As soon as the temperature readings are taken—the water temperature has gone down after the rain—Ms. Parker accompanies the students back to class and says they will explore Shondra's question in science period the next day.

> "*Knowledge depends on questions, and the process of coming to "really know" something entails revisiting the essential concept in new settings, under new conditions, and with new parameters often enough to challenge one's own thinking.*"
> —JACQUELINE GRENNON BROOKS

The following day, I join Ms. Parker and her sixth graders as they perform a number of experiments with water. When I enter the room, the materials table is set up with cups of metal washers, basins, foil pie pans, index cards, and stacks of empty plastic cups. In Ms. Parker's class the students work in science teams and have assigned jobs. Each group has a materials manager, a director, a speaker, and a recorder, and these jobs are routinely rotated.

Ms. Parker asks the managers to collect a cup of washers, an empty cup, a basin, and a pouring cup filled with water for each group.

My thinking: *I am impressed that in this class of twenty-eight students, only seven students come up for materials. Everyone seems to know her or his job. They have done this sort of work before.*

Ms. Parker explains that she would like each group of students to place their empty cup in a basin, fill the cup with water to the very top, and then carefully place the metal washers in the cup, one at a time. "How many washers do you predict can go into your full cup of water before the water spills over?"

As the groups make their predictions, Ms. Parker reminds the students to think about the constants and variables in this experiment. "What are you going to keep the same? What will you change?" The

TABLE 2.1 Data from the Experiment in Ms. Parker's Class

	Number of Washers	
Group Number	**Prediction**	**Actual Result**
1	4	14
2	3	15
3	5	12
4	4	13
5	2	14
6	7	15
7	4	13

students discuss how important it is for the *same* person to put the washer in the water each time. "Why is that important?" Ms. Parker asks. The students respond that if the same person puts the washer in, it will be easier to keep the procedure identical. Ms. Parker then says, "How should we place the washers in?" One student describes a way of sliding these metal circles in on the edge of the filled cup. All other group members need to look carefully at the water level as the washer goes in each time. Ms. Parker says that keeping the procedure the same each time helps the experiment to be a fair test.

Shondra asks what this experiment has to do with her water strider question. Ms. Parker says that she hopes the class will be able to help Shondra answer her question when the activities are completed.

My thinking: *I appreciate the way Ms. Parker holds out the expectation for Shondra that her classmates—not Ms. Parker—will collaborate with Shondra on the water strider question.*

After making their predictions, the students test them by sliding their metal washers into the cups. In every group, the students notice a difference between their predictions and their results. When the data are collected, the columns look like Table 2.1. One group asks Ms. Parker if they can try again. "Of course," Ms. Parker replies, and other groups follow suit. In their second try, the students adjust their predictions, but the results remain approximately the same.

Ms. Parker asks, "Why are the results slightly different from group to group and from one try to the next?" Students discuss how easy it is to start off with a little less or a little more water and so that is a variable.

My thinking: *By interrogating the data, Ms. Parker is reminding the students that there is a range of acceptable answers.*

Now Ms. Parker asks the students about the observations they made as the washers went in. "What do you think is happening to the water?" One student responds, "The water level rises." Another offers, "The water looks like a dome." Another student says, "It looked like it was never going to spill over; it just kept getting higher and higher." Lanie says, "It's like the water has a skin." Henry blurts out, "I know what happened. It is *surface tension*."

At this point Ms. Parker makes a circle on the whiteboard in the front of the room and writes the words "Surface Tension" inside. "Henry," she asks, "can you say more about surface tension? What do you mean by that?" Henry says that he is not exactly sure what it is, but "it's like when water sticks together." Ms. Parker then asks, "What were some of your observations when you placed the washers in the cup of water? What did you notice?"

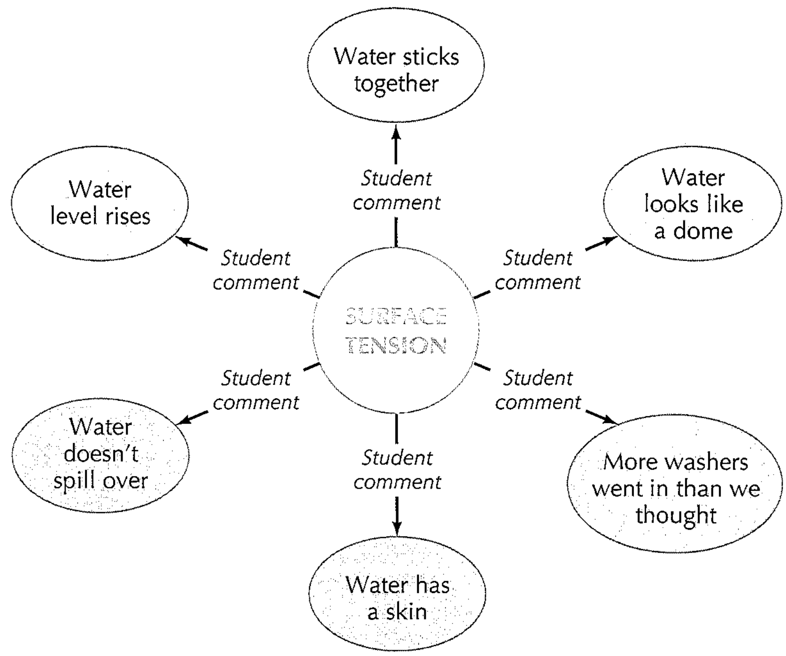


FIGURE 2.1 The concept map for "surface tension": initial stage

Ms. Parker records all the students' responses on the whiteboard. From the circle labeled "Surface Tension," she draws arrows out to other circles or ovals that contain all the comments the students have made about the water and the washers. As shown in Figure 2.1, Ms. Parker is making a **concept map** with Henry's phrase "Surface Tension" in the center. (This is just one use of a concept map; we can call this a "thinking map.")

> ***Ms. Parker's thinking:*** *Although there is a complex explanation for surface tension, Ms. Parker is confident that the students can grasp the concept with her guidance. The concept map will help represent and develop their thinking. It is a way of scaffolding the students' ideas.*

As Ms. Parker creates the graphic, she steps back and asks the students to discuss the ideas they have offered within their groups and see if they can come up with further ideas about why the water behaves in this way at the surface. Suddenly Josh calls out, "It's like Henry says. It's surface tension." Ms. Parker responds, "But what does it mean for water to have surface tension?" The class is unsure. Shondra is beginning to get the idea that surface tension is behind the explanation for the water striders. Ms. Parker now encourages the students to do some research about surface tension on one of the networked computers in the classroom.

Further Experiments and Discussion

The next day, Ms. Parker asks the students to work within their science groups again and brainstorm ideas about surface tension. She also invites them to redo the water-and-washer activity but using pennies in place of washers. One group places forty-two pennies in a cup of water before it overflows! Some groups draw pictures of water molecules; other groups retry the washer activity. Using both their research and their experience, they offer some ideas in discussion with Ms. Parker. These form a foundation for understanding what surface tension really is.

The speaker in each group then reports the group's thoughts about surface tension to the class. As the speakers do this, Ms. Parker places the ideas in another level of the concept map. Ms. Parker herself then offers a comment that reinforces the research that some groups have done: "Water," she notes, "is made of tiny particles called molecules." She places this comment on the board as well,

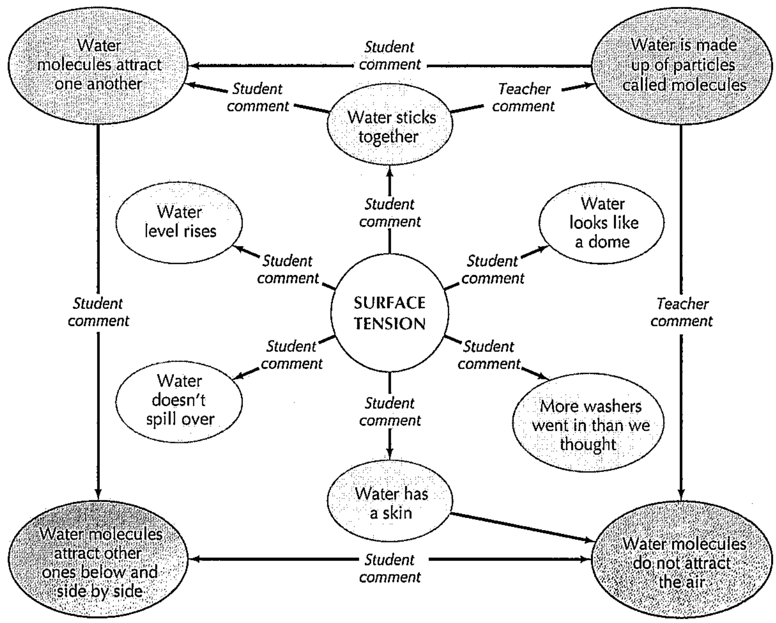


FIGURE 2.2 The concept map for "surface tension": a later stage

connecting it with an arrow to Henry's idea that water sticks together. Shondra's group then says that "Water molecules attract one another." Next, Henry's group shares the idea that "Water molecules do not attract the air." Ms. Parker asks the students to think about how this affects the water at the surface. Lanie's group has drawn circles and arrows showing the molecules of water at the surface holding on to each other and to the ones below them. Ms. Parker writes this idea, too, in a bubble on the whiteboard and links it with a line to the related comments. Now the concept map looks like Figure 2.2.

My thinking: I admire the way the concept map expands through the negotiations that occur between Ms. Parker and the students and among the students themselves. It becomes a visual record of the scaffolding of their ideas as they approach understanding.

After the groups have all reported, Ms. Parker asks Shondra if she understands why the water strider can skip on the surface of the water. Smiling, Shondra says, "It's like the water molecules hold on tighter to each other at the surface of the water and that makes the water like it has a skin." Ms. Parker adds, "This helps the water strider skip across the water without falling under."

More Challenges

The following morning, students enter Ms. Parker's classroom and are challenged with another opportunity to explore the properties of water. The materials managers are asked to get plastic cups, basins, and square pieces of cardboard (about 3 inches on each side). Ms. Parker then asks each group of students to fill a cup of water to the top and cover it with a piece of cardboard. Holding the cardboard on the top of the cup with one hand, they are to invert the cup over the basin. The children gasp, "Won't it spill?" "If it does, that's OK," remarks Ms. Parker; "you have the basin under it." She then encourages the students to try this exploration and to experiment with different amounts of water in the cup.

Squeals of delight and frustration fill the room as students explore the inverted cup of water. Most of the time, the water remains in the cup, even with just the flimsy piece of cardboard on the bottom

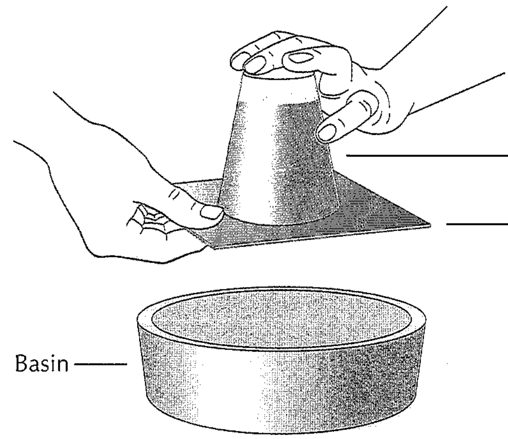


FIGURE 2.3 A surface tension experiment

(see Figure 2.3). Ms. Parker asks each group of students, with the help of the student serving as their group director, to come up with a theory about why the water does not spill out of the cup when it is turned upside down.

Students discuss this question in their groups, and each speaker reports the group's ideas. The following three explanations emerge:

1. The water sucks the card to it.
2. The air is pushing the card up and holding it there.
3. The water molecules at the surface are attracted to the water molecules that seep onto the cardboard, and the surface tension of water keeps the card and the water in place.

The students look to Ms. Parker for the right answers. Instead, she invites them to do another activity.

The students gather foil pie pans (one for each group), a pepper shaker, and a small cup of liquid soap. In each pie pan they place about 5 centimeters of water. They sprinkle the pepper on the surface of the water and observe as it clumps on top of the water. One student is instructed to dip her finger into the liquid soap and then place her finger in the pie pan. Suddenly, the pepper scatters—it appears to "run away" on the surface of the water to the edges of the pan. Then the pepper flakes begin to sink. Students are excited at this dramatic response.

Once again, Ms. Parker asks the students to discuss what happened and offer their own theories. This time the students have a plausible explanation. Each group says that the soap affects how the water acts at the surface. Two groups decide that the soap "breaks the surface tension of water."

Ms. Parker sends the students to the Internet again to find out how this happens. Students find out that soap works by reducing surface tension. Soap molecules have two very different ends. One end likes to dissolve in water and the other in oil. When you add soap to oily water, it happily mixes with the oil because the oil-loving part of the soap is on the top of the water surface, facing out. Thus, grease will dissolve in soapy water and get rinsed away.

Ms. Parker asks, "How can we test our theories for why the inverted cup of water did not spill?" Students decide to test the surface tension theory by inverting a cup of *soapy* water that has a cardboard square over it. They find that the soapy water has less surface tension, and the cardboard square holds for a much shorter time.

Ms. Parker informs the class that "Many people think the cardboard is held on by the air pushing up on the water. It is a common idea, but you have come up with a better one. You have shown how powerful the surface tension of water is and how that is responsible for holding the card."

Just before the class ends, Lanie says, "Can we do the washers in a cup of water again, with soapy water this time?" "That is a good idea; let's try that tomorrow," Ms. Parker responds.

The Teaching Ideas behind This Story

- When the class observes a new phenomenon, the water strider, and becomes fascinated by it, Ms. Parker honors the students' interests by creating a series of related science experiences. By helping students explore their own questions, she encourages them to go further in their investigations.
- Notice that Ms. Parker does not answer Shondra's original question but promises that the entire class will address it.
- To help the students' group work go smoothly, Ms. Parker has set up clearly defined tasks for each group member. In this model, the *materials manager* collects and returns materials for the group; the *recorder* keeps track of data; the *speaker* reports on results and asks the teacher and other teams' speakers for help; and the *director* makes sure that the team understands the investigation and completes the tasks. You will read more about group structure in a later chapter.
- While she honors Henry's "right answer" about surface tension, Ms. Parker knows that she has to negotiate the meaning of this term with the students.
- In this context, concept mapping is a *mind tool* that can help students understand the *why* of something. It builds on the students' experience, helping to form a structure for discovering the underlying reasons for surface tension.
- Notice that Ms. Parker gives simple, clear instructions and no handouts. She encourages students to use the Internet for research, and she also encourages them to test their own theories with direct experiments.
- The students' use of the Internet reflects guidelines from the NETS-S (International Society for Technology in Education, 2007). The way the students use technology is particularly important because students use critical thinking skills to plan and conduct research, manage projects, solve problems, and make informed decisions using appropriate digital tools and resources.

The Science Ideas behind This Story

- Water molecules have two hydrogen atoms and one oxygen atom, as indicated by the chemical notation H_2O. The extraordinary stickiness of water is caused by the two hydrogen atoms, which are arranged on one side of the molecule and are attracted to the oxygen atoms of nearby water molecules in a state known as "hydrogen bonding."
- Within the water, away from the surface, every molecule is engaged in a tug of war with its neighbors on every side. For every "up" pull there is a "down" pull, for every "left" pull there is a "right" pull, and so on. The result is that any given molecule feels no net force at all. At the surface, however, things are different. There is no up pull for every down pull because, of course, there is no liquid above the surface. Thus, the surface molecules tend to be pulled back into the liquid.
- If the surface is stretched, it becomes larger in area, and more molecules are dragged from within the liquid to become part of this increased area. This "stretchy skin" effect is called surface tension. Surface tension plays an important role in the way liquids behave. The surface tension of water is what gives the shape to raindrops.
- The water strider, also called a pond skater, is an insect that hunts its prey on the surface of still water. It has widely spaced feet rather like the pads of a Mars lander. The water strider's feet depress the skinlike surface of the water beneath them. But the insect is buoyed up by a combination of its water-repellent hairs and the surface tension of the water. Water striders and their kin are relatively common insects.

Connections to the Next Generation Science Standards

- **NGSS DCI: MS-PS1-4: Structure and Properties of Matter:** Gases and liquids are made of molecules that are moving about relative to each other. In a liquid, the molecules are constantly in contact with others.
- **NGSS SEPs:** Ms. Parker's students *planned and carried out investigations; used mathematics and computational thinking; asked questions and defined problems; analyzed and interpreted data; constructed explanations; engaged in argument from evidence;* and *obtained, evaluated, and communicated information.*
- **NGSS CCs:** The crosscutting concept of *structure and function* is seen here with the water striders as structures can be designed to serve particular functions by taking into account properties of different materials.

Exploring Further

If you were teaching this lesson about the surface tension of water, you may want to understand answers to the following questions:

- How does the structure of a water strider help it move?
- How does surface tension relate to a frozen skating pond?
- Where should Ms. Parker go next with this lesson on surface tension?
- Can you think of other ways to use concept maps? (In Chapter 13 you will find another illustration of concept maps.)

2-6 Students as Knowers

concept map
A diagram for developing an understanding of relationships between ideas. A concept map consists of circles or boxes that are called cells and that contain an idea, a selected term, or a question. The cells are linked with labeled lines that explain the relationships.

Teaching science requires *both* information *and* guidance from the teacher in order to help students learn. One of our goals is to help students become autonomous learners—to take charge of their own learning by performing tasks and making meaning of those experiences. We also know that there is a profound difference between acquiring information and gaining true understanding.

This chapter has demonstrated that building scientific knowledge requires us to engage in an active process of meaning construction in which we explore our own questions and test our own ideas. For students, this means that they become invested in seeking their own answers. The answers they seek enable them to fit their new ideas into their already existing conceptual framework—their prior knowledge.

Understanding how students learn science provokes us to find teaching strategies that honor students' ideas and create safe, open spaces in which they can create their own meanings. This is not the traditional notion of science teaching. For many people, it requires a shift in thinking. Rather than simply passing down or transmitting information through one-way communication, the teacher creates a forum for two-way or "multiway" exchanges, mediating the students' progress on the path to their own deeper understanding. To do so, the teacher must provide an appropriate context for learning and a setting in which students' own questions and ideas emerge. The teacher's role includes the following:

- Engaging students in concrete experiences
- Encouraging them to express their ideas about what they observe
- Listening seriously to those ideas and considering how they are based on the students' prior knowledge
- Asking probing questions about the students' thinking—an important technique because students usually have alternative conceptions that ought to be modified

- Encouraging the students themselves to reflect on their ideas
- Scaffolding students' learning by:
  - Offering additional possibilities, such as other possible avenues of thought for students to explore, further questions to consider, new information on the topic, and new connections to make with their daily experience
  - Suggesting new experiments and providing opportunities for students to carry them out
  - Repeating this process as the students have further experiences, so they continually build new ideas and refine their old ones

The following poem in two voices helps to express the ideas we have developed in this chapter. The voice on the left side represents some traditional notions about science teaching. The right side represents the kind of approach that I hope this book will foster:

I teach science to students.	*I do science with students.*
I provide information.	*I provide experiences.*
I seek to control the lesson.	*I watch the lesson unfold.*
I like it when my students explore my *thinking.*	*I like it when my students explore* their *thinking.*
My students ask what they should be observing.	*My students trust their own observations.*
My students memorize facts from each lesson.	*My students reflect on ideas from each lesson.*
My students know the science ideas for the next test.	*My students connect the science ideas to their lives.*
My students know that science has all the answers.	*My students know that science helps find some answers.*
I teach science to students.	*I do science with students.*