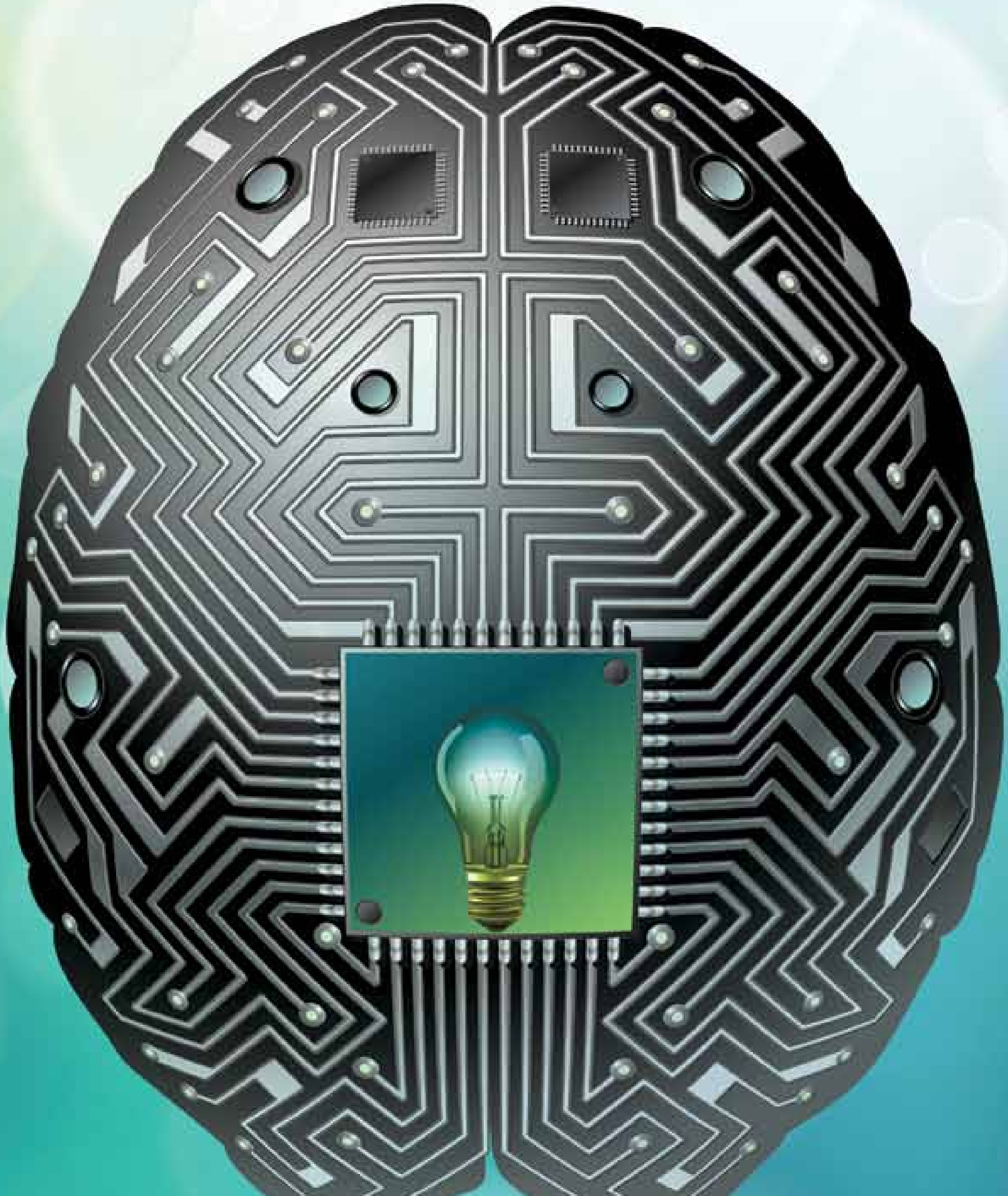
Learning & Teaching Scientific Inquiry: Research and Applications



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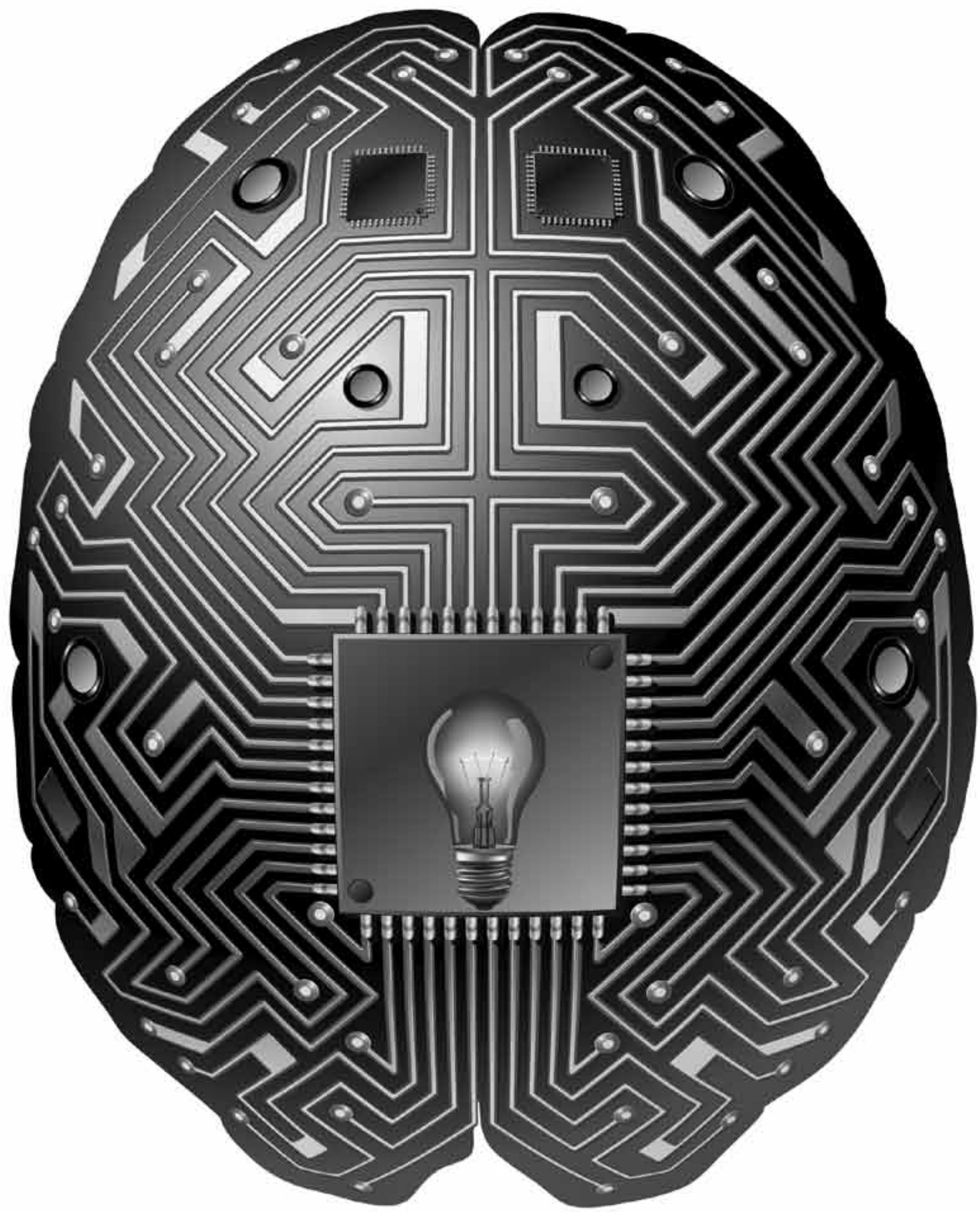

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Preface

Over the past 20 years, inquiry-based science has unequivocally become the accepted model for K–12 science in the United States. It has near-unanimous approval from teachers and is a central theme in a great many science teacher resource materials. Currently, most (if not all) science educators and teachers assert that they are doing inquiry, and they rightly advocate its merits. Why, then, publish yet another book about teaching scientific inquiry? Hasn't everything already been said?

We have several motivations for writing a book about teaching scientific inquiry. The first has to do with the traditional assumptions regarding what constitutes scientific inquiry. An increasing number of researchers in science education believe that the conventional way of defining scientific inquiry—by focusing on the *activities* of scientists—is mistaken, and this mistaken focus has resulted in classroom practices that do not do enough to authentically reflect the discipline of science. We therefore break from convention here and choose a different approach, making the argument that scientific inquiry is best understood in terms of the overall *goal* of scientists: the development of scientific models. This change in perspective—from defining inquiry based on what scientists do to what they hope to accomplish—has significant consequences for the way teachers should view and teach inquiry-based science. Consequently, the first section of this book is devoted to a description of model-making in science and how the pursuit of scientific models can be used to define inquiry in the classroom.

Second, while the science education community has been at work trying to better understand how to teach science, researchers in the field of cognitive science have been similarly occupied with studies of how children learn to reason scientifically. Unfortunately, science educators and cognitive scientists generally publish their work in separate journals and attend different professional conferences. As a result, most teachers and many science education researchers remain largely unaware of the contributions made by cognitivists toward understanding effective methods of teaching scientific inquiry. Furthermore, many concepts and ideas from cognitive science—such as cognitive overload, confirmation bias, and skill transference—that provide invaluable insight into how students learn and how we ought to teach remain largely unapplied in science classrooms. We believe these findings are compelling and warrant being shared more broadly and especially with teachers dedicated to teaching inquiry-based science. Consequently, the reader will find concepts from this field of research threaded throughout the book.

Finally, we chose to put a great emphasis on practical applications for teachers to use in their classrooms. To this end, we have included many sample and practice problems—field tested by us for more than 10 years with preservice and inservice teachers and K–8 students—that translate important research findings into teaching scenarios applicable to K–8 classrooms. Each chapter contains sample and practice problems consistent with this approach.

We hope this book assists teachers who want to increase their skills and confidence when teaching inquiry and expand their repertoire of resources from which to draw when planning instruction.

Who Should Read This Book?

Preservice and practicing science teachers, science teacher educators who teach methods coursework, science professors who teach physical or life science to K–8 preservice teachers, science consultants, and teacher leaders who are organizing professional development opportunities will all find this book useful. This book is suitable for individualized study or use in a small- or large-group setting, and for teaching in an informal or formal classroom setting.

Contents

The book is divided into three parts. Part 1 (Chapters 1 and 2) presents an introduction to scientific models and makes the case for why scientific inquiry is most naturally defined in terms of model-making. Part 2 (Chapters 3–7) examines students' abilities, motivations, and challenges when doing scientific inquiry and explores teaching strategies and methodologies known to help children grow in their scientific skills and knowledge. The reader is encouraged to work through parts 1 and 2 in sequential order. Part 3 (Chapters 8–11) provides information and teaching applications for many of the supplementary process skills used in scientific inquiry. These later chapters can be consulted in any order as need and interest dictate.

Practice problems are included at the end of many chapter sections. They are intended to foster critical thinking specific to a section of study while also serving as a resource when planning instruction. When completing the practice problems, the reader should consider two questions: (1) Do I think I understand the idea under study here? and (2) Can this problem be integrated somewhere into the K–8 science curriculum?

Acknowledgments

WE ARE DEEPLY grateful to a number of people and organizations that have assisted us in various phases of this project. The National Science Foundation has contributed invaluable financial support to us for research, development, and writing associated with this project through grants #DUE-9950460, #DUE-0639694, and #DRL-0639694. We also gratefully acknowledge the financial support of Calvin College and the Calvin College Alumni Association. We especially thank our colleague Dr. Rachel Reed for her indispensable intellectual support and vision.

A number of people helped shape this book into publishable form. We thank our editors and the helpful comments of a number of reviewers associated with NSTA Press. Their suggestions have made this book better and helped us keep issues of safety at the forefront. Former Calvin College education students—namely Jennifer (Harkema) Koning, Samuel Sportel, Allyson Green, Jeff Bucchianeri, and Nathan DeHaan—served as important "sounding boards" and research assistants and served to keep us grounded. Additionally, our colleagues, friends and family members, and especially our spouses, Robyn Jadrich and Jim Bruxvoort, were exceedingly patient and offered much encouragement, for which we are most grateful.

We are honored that so many people believed in this project and in us. It is our hope that many in the science education community will benefit from this work.

About the Authors

Jim Jadrich received his BS in physics from California State University, Fresno, and his PhD in physics from the University of California, Davis, in 1991. While still working on his PhD, he was introduced to the field of science education, which became his career of choice. He is currently a professor of science education and physics at Calvin College. He has been married to his lovely wife for 25 years and has two grown children. His professional activities include research on scientific reasoning in teachers and students, teacher professional development, and the establishment of a teachers college in Liberia, West Africa.

Crystal Bruxvoort earned a bachelor's degree in chemistry from Central College (1990), a master of arts in teaching degree from Drake University (1994), and a doctoral degree in curriculum and instruction with an emphasis in science education from Iowa State University (2005). Amidst these educational experiences, she was a chemistry instructor for 12 years. Currently, she is a science teacher educator at Calvin College, where she works with preservice and inservice teachers. Her research interests focus on teaching scientific reasoning and the nature of science. She enjoys biking and hiking near Lake Michigan with her husband and two daughters.

Safety Considerations in the Classroom

SAFETY IS OF utmost concern in a science classroom, no matter the age of the children involved or the types of activities. The person who is primarily responsible for keeping children safe during science lessons is the adult in the room—the teacher. Effective science teaching involves thinking ahead to identify possible safety hazards and properly attending to such hazards before danger escalates and causes harm.

Eyes

When working with a hazardous liquid or solid (e.g., drops of vinegar, hot water, rubbing alcohol, powder from cornstarch, bare wires), proper eye protection in the form of approved ANSI Z87.1 indirectly vented chemical-splash goggles is needed by the teacher and students. ANSI Z87.1 safety glasses should be used when working with hazardous solids such as electrical wires, metersticks, and glassware.

Fire and Heat

Substances in some activities must be warmed. The teacher must use caution when warming substances of any kind.

- If necessary, use a large, metal coffee pot as a source of hot water for a classroom. Such a source of hot water is safer than having the children warm water on a hot plate or with a Bunsen burner (if even available). Caution students not to touch a heated coffee pot, hot plates, burners, or matches, as they can burn skin.
- Children should not transport hot liquids. All hot liquids should be transported by the teacher in a heat-resistant glass container or nested set of Styrofoam cups.
- Water warmed in a coffee pot can be extremely hot to the touch. When such extreme temperatures are not needed, first fill a cup halfway with lukewarm water, then fill the cup further with hot water from the coffee pot.
- Never heat flammable liquids (e.g., rubbing alcohol).
- Never have any sources of flames or sparks (e.g., burning candles) near flammable liquids.
- Know where a fire extinguisher is located when working with burning objects (e.g., candles) and flammable liquids, and have training on how to use the device (if allowable by school or board of education policy).
- Use an electrical hot plate with caution.
- Do not overheat oil or wax, as they can ignite. If oil or wax starts smoking excessively, remove from heat immediately. Make sure there is appropriate ventilation to accommodate any smoke produced.
- If a small fire occurs, cover the fire with a larger container. Small fires can be smothered. Check with the board of education's fire-fighting policy for employees before working with fire sources.

- Allow heated materials to cool before handling.
- Never leave a hot object, such as a hot plate or coffee pot, unattended. Place a sign beside any hot object (e.g., "Caution: Very Hot!") when the object needs to cool for an extended time.
- If an unexpected fire should develop when burning such items as small pieces of paper in containers or candles, the teacher should be contacted immediately and students should back away from the fire. The teacher, not the students, is responsible for putting out a fire. A teacher is at risk for electrocution if putting out a fire near electrical outlets or wiring. Do not allow children to use matches without direct adult supervision.
- Hair should be tied back to keep it away from chemicals, flames, and other hazards. Caution students that certain hair products (e.g., hair spray) can ignite easily and should be handled with caution. Acrylic nails are also highly flammable and should be kept away from flames.

Skin

Most substances recommended for use in this book are sold in a local grocery or supermarket. As such, the substances are commonly found in home settings. The cautions one takes in a home setting are helpful reminders here as well.

- If children spill any chemical on their skin, they should flush the exposed skin with copious amounts of tepid (60–100°F or 15.6–37.8° C) water. Hazardous chemical exposure requires access to an eyewash station and, in some cases, a chemical safety shower.
- Hand washing with soap is recommended at the end of all science activities.
- Keep hands away from faces, eyes, and mouths.
- A fire burn is treated like a chemical burn. Always seek immediate medical help from the school nurse in cases of burns.
- Children should be cautioned to stay away from hot objects.
- Never smell anything directly. Smell cautiously by simply wafting with the hand over the source.
- Remind children to never taste or eat a substance. Eating and tasting should never be done in a laboratory due to potential hazards from chemical contamination.
- Closed-toe shoes (no sandals or flip-flops) are required when doing a science activity. It is also advisable to wear clothes that will protect against accidental spills. Aprons and gloves may also be necessary depending on the level of the hazard. Teachers should consult appropriate Material Safety Data Sheets (or MSDS) for directions about using all personal protective equipment.
- Information on substances (e.g., flammability, safety concerns) is available by consulting the appropriate MSDS for a particular chemical.

Electricity

- Work areas near outlets and electrical equipment should be dry and at least 3 ft. away from a water source.
- Electrical equipment should be properly grounded. The safest approach is to have ground fault circuit interrupter protection (GFCI).
- Check all electrical cords to make sure that the insulation on the wires is intact and not worn through to the bare wires.
- Do not string electrical or extension cords where children can accidentally trip or fall or knock over equipment.

Other Considerations

- Glass objects should be used sparingly. Plastic cups can be used and reused and tend to be less fragile when dropped. When sharp objects, such as broken glass, must be discarded, they should be placed in a labeled sharps container and not in typical trash cans.
- Any time a child is hurt or wounded, all persons in supervisory roles should be notified (e.g., principal, parent, guardian). Medical attention should be sought immediately if needed.
- All activities should be well rehearsed by the teacher. A teacher should never go into a science lesson without having attempted many times what the children will be doing. The teacher should give careful thought to the ways in which children might misunderstand and put themselves in harm's way. Explicit instructions—spoken and written where appropriate—should be given by the teacher to the students. The teacher must model all procedures for students prior to them doing the activity and then supervise the students' implementation.
- Teachers should review—and have students and their parents or guardians sign—a student safety acknowledgment form that notes the hazards and provides standard operating procedures to help make laboratory activities a safe learning experience.

Resources

Kwan, T., and J. Texley. 2003. *Inquiring safely: A guide for middle school teachers.* Arlington, VA: NSTA Press.

Roy, K. R. 2007. *The NSTA ready-reference guide to safer science.* Arlington, VA: NSTA Press.

CHAPTER 5
Designing Scientific Tests and Investigations

5.1 Testing a Model for the Mediterranean Sea

Water flows into the Mediterranean Sea from many sources. Rivers and streams empty into it, of course, but there are also strong currents of water that flow in from the Atlantic Ocean and the Black Sea. Surprisingly, the level of the Mediterranean Sea does not rise, even though all the water flows in and there does not seem to be any way for it to flow out. How can this be explained? What happens to the water pouring into the Mediterranean?

People tried to solve the mystery of the disappearing Mediterranean seawater for many years. One obvious explanation was that the water simply evaporates from the sea as fast as it flows into the sea. However, if that were the case, then the Mediterranean Sea would become saltier over time because salt water is flowing in from the ocean, but only water, not salt, can evaporate. The Mediterranean Sea is saltier than the ocean, but the concentration of salt is not increasing over time. Therefore, evaporation alone cannot account for all the missing water.

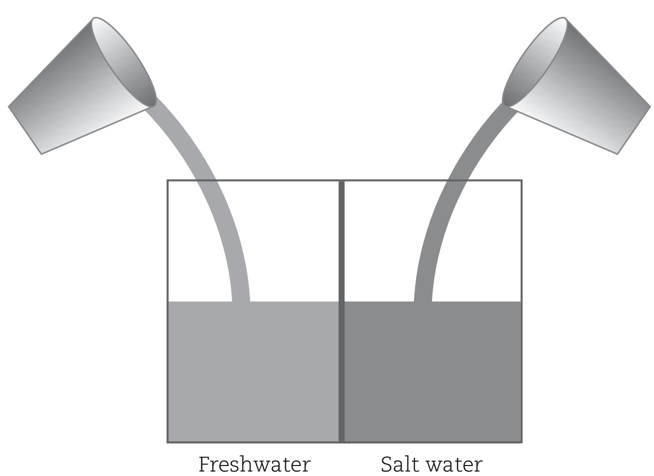
Another explanation postulated long ago was that water escaped from the Mediterranean Sea through underground channels. This is possible, but it was not a very satisfying explanation. If water was escaping through underground channels, then where was it going? At any rate, the idea could not be tested because there was no way to observe underground channels to see if they really existed.

In 1679, Count Luigi Marsili from Italy proposed a new solution. He proposed that water from the Mediterranean Sea flows back out into the Atlantic Ocean *underneath* the water flowing in from there. He based his explanation on the observation that Mediterranean Sea water is saltier than water in the Atlantic. The more salt there is in water, the denser the water is. Therefore, the denser water from the Mediterranean would naturally settle under the less-dense water from the Atlantic. Perhaps the denser water of the Mediterranean was flowing like an underwater river out into the Atlantic Ocean through the same opening that was letting water in. You would not be able to detect this current from the surface because it would be flowing along the bottom of the sea.

Marsili knew that his bold model needed to be tested, so he set out to do so. Here is a test that is similar to the one he conducted. (Safety note: This activity requires the use of indirectly vented chemical-splash goggles and aprons. Immediately wipe up any water spilled on the floor to avoid a slipping or falling hazard.)

1. Make an aluminum foil partition to separate two sides of a container that can hold water. Secure the partition to the container with masking tape. Make sure the partition is taped well on the sides and bottom so that water cannot leak through.
2. Mix a generous amount of salt into a large beaker of water. (About 50 ml of salt added to 1 L of water makes very salty water.) Add dark food coloring to the mixture. This water will represent the dense water of the Mediterranean Sea.
3. Pour the salty water into half of the container at the same time you pour freshwater into the other half. (Pouring water in both sides at the same time will keep the partition from being pushed over.) The freshwater represents the less-dense water of the Atlantic Ocean. Make sure that the water is at least an inch deep and at the same level on both sides (Figure 5.1).

Figure 5.1. Freshwater and Salt Water Are Poured Into a Container With an Aluminum Foil Partition.

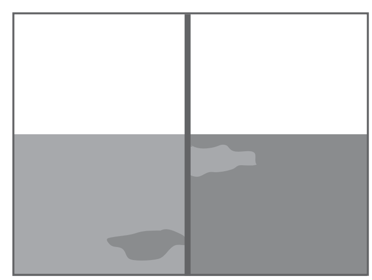


4. Make a narrow slit in the foil from top to bottom with a knife. (Or use a pencil to puncture two holes in the foil, one just below the water line and another hole directly below the first one and near the bottom.)
5. Observe the water flow for several minutes.

If you try this, you will see that the fresh (less dense) water flows into the other side of the container along the surface. The salty (denser) water flows in the opposite direction and along the bottom of the container. This is exactly what Marsili thought was happening with currents in the Mediterranean Sea and Atlantic Ocean. Water from the Atlantic flows into the Mediterranean along the surface, while at the same time currents from the Mediterranean flow into the ocean, but those currents are well below the surface of the water and cannot be seen (Figure 5.2).

Figure 5.2. Side View of the Container After Holes Are Made in the Partition

Freshwater flows to the right along the surface, and the salty, denser water flows to the left along the bottom of the container.



Marsili's demonstration showed that water far below the surface of the Mediterranean Sea really might flow into the Atlantic Ocean. While his demonstration did not prove his model, it provided strong support. Of course, we can never prove models to be true. At best, we can hope to find strong supporting evidence for them while always remaining open to the possibility that a future test will expose flaws or that another model may be proposed that explains occurrences even better than our original model.

Nevertheless, we can be more confident in some models than others. Some models seem to be so well established that scientists act as if they are absolutely correct. For example, scientists today are so convinced that Marsili was correct about the Mediterranean and Atlantic sea currents that his explanation is usually stated as a fact. (Note: Submarines traveling from the Atlantic into the Mediterranean do indeed encounter strong head currents, an observation Count Marsili could not have dreamed of making.) However, even after accumulating a great amount of evidence in support of a model, scientists must always remain open to the possibility that one day another explanation might be found that seems to work even better. What if underground channels of water were discovered one day beneath the Mediterranean? How might such a discovery affect what we think about the completeness of Marsili's model?

The remainder of this chapter is devoted to the process of designing tests and investigations to evaluate models and concludes with research-supported teaching strategies to assist students in this involved process.

5.2 Strategies for Testing Models and Explanations

Designing tests to evaluate scientific models and explanations is one of the hardest—and at the same time one of the most creative—aspects of science. To test a model, you have to come up with a way to change or manipulate a system, observe what occurs, and then determine whether or not what has happened is consistent with the model in question; or you have to carefully observe the system with fresh eyes and look for discrepancies between what you observe and what the model predicts should be the case. Success in doing this depends on your ability to conduct fair tests, evaluate evidence, and solve problems, but it also depends on how inventive and imaginative you can be. There is no logical, step-by-step process you can always follow to come up with a test for a model. There was no formula for Count Luigi Marsili to consult to work on the mystery of the Mediterranean Sea. Sometimes you simply have to rely on a flash of insight. Nevertheless, there are strategies that can help students get started when designing tests. Several of these strategies are outlined in the examples below and are intended for use with students when they have the opportunity to test the efficacy of a model or explanation.

Strategies for Helping Students Test Models and Scientific Explanations

Example: Why do coats keeps us warm when it is cold outside?

Many children mistakenly believe that coats keep you warm because they give off heat (Watson and Konicek 1990). After all, parents often tell children to put on their warm coats when it is cold outside! We will use this explanation for coats and warmth to illustrate several of the strategies that can be used to help students test models and explanations. The first two take place before the students begin designing tests.

Strategy 1: Make sure students experience or examine the phenomenon themselves.

Before even trying to test a model or an explanation, make sure students have recently experienced or observed the phenomenon. Students cannot test unfamiliar ideas, and even if they are familiar with the phenomenon (as they are likely to be from wearing coats), a fresh reminder does wonders for ensuring they understand the problem before them. In this example, the first thing to do is ask students to put on their coats indoors and note that they begin to feel warm.

Strategy 2: Extreme values should be used when observations are made.

In Chapter 4, we noted how fewer mistakes are made when testing variables if you use extreme values when making comparisons. If you change a variable by only a little bit, then even if it is an important variable, you may not clearly detect any changes in the outcome. A better approach is to change the variable a lot because then a larger change will result, which is easier to notice. In this example, students should experience extreme values both before they test and while they are testing. Before they test, they should not put on just a light sweater, but rather a heavy coat so that they cannot miss the effect a coat can have on how warm you feel. This principle of using extremes will come up again when students do their own testing.

Strategy 3: Students should generate some possible models or explanations of their own.

A thorough discussion of the usefulness of generating alternative explanations and models was presented in Chapter 3. There it was described how the very process of thinking up alternative explanations or models helps students when they have to test ideas. In the example we are considering here, the original explanation was that coats keep you warm because they give off heat. Therefore, students should be asked to brainstorm other possible explanations for why they feel hot sitting inside in their coats, or why it is that coats keep them warm outside.

Strategy 4: Insert the model or the explanation into an *If … , then …* . statement.

The use of an *If … , then …* . statement has been shown to be tremendously useful for students when they are designing tests of scientific ideas (see, for example, Lawson, et al. 2000.) The structure of an *If … , then …* . statement has the effect of reducing the cognitive load on students' working memories, thus freeing them to be more creative in their design of good tests and better able to reason logically and carefully about the results of their tests.

In the context of this example, an *If … , then …* . statement would be used in the following way. First, put the explanation or model being tested into the *If* portion of the statement:

> *If* coats keep you warm because they give off heat, *then …*

The next step is to logically decide what ought to be observed when you test this idea, assuming that the idea actually holds. Your expectation for this outcome should be inserted into the "then" part of the conditional statement. Doing so can help you think of ways to test the original statement. For example, if coats really do give off heat, then if you put a thermometer into a coat, the thermometer should register a higher temperature after a while. Inserting this expectation into the second part of the conditional statement leads to the following:

> *If* coats keep you warm because they give off heat, *then* if I put a thermometer inside a coat all by itself, the thermometer should register a higher temperature than before.

Now, the last step is to compare the prediction in the conditional statement with actual observations. In this case, when a thermometer is put inside a coat and left alone, the thermometer reading does not significantly go up. Therefore, the conditional statement is false. This can all be summarized and written in the following way:

> *If* coats keep you warm because they give off heat, *then* if I put a thermometer inside a coat all by itself, the thermometer should register a higher temperature than before. *However*, it does not. *Therefore,* this explanation is not a good one. Coats must not give off heat.

Strategy 5: Tests must be fair, and important variables must be controlled.

In their zeal to test explanations and models, students quickly forget that their tests must be made fairly. They cannot be reminded of this too many times. In the context of this example, there are many ways for students to conduct unfair tests. For example, they may try to compare a thermometer sitting out on a table to a thermometer inside a coat being worn by another student. However, there are two variables here—a coat and a human body—that might affect the second thermometer. Therefore, this would not be a fair test.

The five strategies presented here do not constitute a foolproof way to ensure that students will design good scientific tests and make reasonable conclusions. There is no way to create such a guarantee. Nevertheless, these strategies are helpful in this regard. Besides these strategies, there are many other suggestions teachers may make to students during testing that can help them along, such as suggesting they try to vary one of the variables involved or that they try to think outside the box (see Chapter 6). Still, the five strategies presented here are invariably useful for almost every situation involving testing, and we list them here again for reference:

- Make sure students experience or examine the phenomenon themselves.
- Extreme values should be used when observations are made.
- Students should generate some possible models or explanations of their own.
- Insert the model or explanation into an *If … , then … .* statement.
- Tests must be fair, and important variables must be controlled.

Practice Problems for Testing Models and Explanations

Before moving on to the process of actually designing tests of scientific assertions and models (a difficult process), it is instructive to spend some time evaluating the tests for a variety of scientific models and explanations that others have proposed. The following problems provide an opportunity to do so.

1. Many people think it is hotter in the summer than the winter because the Earth is closer to the Sun in the summer than in the winter. Read the following factual statements, and determine whether each one supports this idea, goes against this idea, or is not relevant for evaluating this model.

    a. A thermometer held close to a source of heat registers a higher temperature than one that is farther away.
    b. When it is winter in the northern hemisphere, it is summer in the southern hemisphere, and vice versa.
    c. There is more daylight in the summer than in the winter.
    d. Earth is about 91,400,000 miles away from the Sun in January and about 94,400,000 miles from the Sun in July.

2. If you place a balloon inside a 2 L bottle and stretch the opening of the balloon over the mouth of the bottle, it is impossible to blow up the balloon by blowing into the bottle. One model to explain this situation is that a bottle is already full of air, so there is no room for the balloon to expand into the bottle when you try to inflate it. A student tested this idea by puncturing a hole in the bottom of the bottle and then blowing into the balloon. He was successful in getting the balloon to inflate. What can the student conclude from this test? (Safety note: Some students may be allergic to latex balloons. Use only non-latex-type balloons.)
3. Even though it is not usually safe to drink water directly from a lake or a river, you can often drink well water without getting sick. As water seeps down through the ground and into the well, rocks and sand in the ground filter out impurities in the water, thus making it safe to drink. How could you test this explanation for water purification in wells by digging a series of wells, all with different depths?
4. A teacher states that water moves from the roots of a plant to the leaves and the flowers through long tubes in the stem called xylem.

    a. When you place a freshly cut celery stalk into a cup of colored water, the leaves of the celery turn the same color as the water after a few days. (If you do this with a flower like a chrysanthemum, the petals turn the same color as the water in the cup.) Is this a good test of the teacher's assertion about xylem? What could you conclude?
    b. Here are two other ways you might try to test the teacher's model for water transport in a plant. Are these good tests? Comment on each one.

i. Carefully make a long vertical slice in a chrysanthemum stem, and place the two halves of the stem into two cups with different colors of water. Wait to see if the individual petals of the flower turn two different colors or just one.

ii. Make several horizontal slices in a celery stalk so that every xylem tube is severed in at least one place. Place the stalk in a cup of water and see if the leaves change color.

5. A model states that eye color is correlated with hair color. Specifically, the hypothesis states that blue eyes are usually associated with people with blond hair. Which of the following would be the best way to test this hypothesis? Explain why.

   a. Observe lots of people with blond hair, and see if most of them have blue eyes.
   b. Observe lots of people with blue eyes, and see if most of them have blond hair.
   c. Observe lots of people with hair that is not blond, and see how many of them have blue eyes.
   d. Observe lots of people with blond and nonblond hair, and see which of them tend to have blue eyes.

6. A textbook states that when you drink water through a straw, the reason the water goes up the straw is because air pressure outside the straw pushes down on the surface of the water, which then pushes the water up the straw. Students are given bottles and straws and are asked to test this model concerning air pressure and drinking through straws. Which of the methods described below would be the best way to test? Explain why you picked the one you did. (Safety note: Make sure bottles or glassware have been washed and cleaned before using. This should not include any previously used lab glassware such as beakers or flasks.)

   a. Students could try drinking through straws of different lengths.
   b. Students could try drinking other liquids besides water.
   c. Students could try closing off the top of the bottle with modeling clay.
   d. Students could try puncturing a hole in the bottom of the bottle.

7. A company is selling a new product they claim can stop hair loss. Which of the following describes the best way to test their claim?

   a. Find 20 bald men, and have them try the product for several weeks.
   b. Find 20 men who are currently losing their hair, and have them try the product for several weeks.

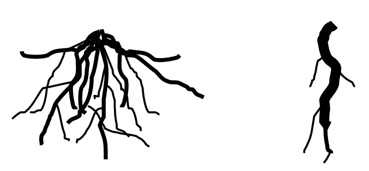
c. Find 20 men who are currently losing their hair, and have half of them try the product for several weeks.
d. Find 10 men who are currently losing their hair and 10 who are not. Have the 10 men currently losing their hair try the product for several weeks.

8. If a glass is lightly tapped on the side with a metal object, a high-pitched *ping* will be heard. If liquid is added to the glass, the pitch of the sound changes. How would you test the following ideas? (Safety note: Use caution when tapping the side of the glass. It can shatter and cut skin. This activity requires the use of eye protection—safety glasses or goggles.)

   a. The pitch produced by hitting the glass depends on the amount of liquid in the glass.
   b. The pitch produced by hitting the glass depends on the density of the liquid in the glass.
   c. The pitch produced by hitting the glass depends on the size of the object hitting the glass.

9. When a sliced piece of fruit or vegetable is left out for a long period of time, it begins to shrivel up. This may be because water from it is evaporating into the air. A student sliced an apple into two parts. One part was left on the countertop, and the other half was placed in a closed plastic bag containing a wet paper towel. If the model regarding evaporation is a good model, what should this student expect to find after a few days? (Safety note: Remember to never eat food used in a science activity, as it could be contaminated.)
10. The two most common types of plant roots encountered are fibrous and tap roots (Figure 5.3). Fibrous roots are thin, branching roots that grow from the stem of the plant. Taproots are single large roots coming from the stem, with a few smaller roots growing out from the side. It has been said that plants with taproots grow better in

Figure 5.3. Fibrous Root and Taproot



dry, sandy soil. Which of the following would be the best way to test this assertion? Explain why.

a. Dig up lots of plants in dry, sandy soil, and examine their root structures.
b. Dig up lots of plants in moist, rich soil, and examine their root structures.
c. Dig up lots of plants in both dry, sandy soil and moist, rich soil, and examine their root structures.

11. Stand with your toes against a wall. Notice that you cannot stand on the balls of your feet without falling over backward. An explanation for why you cannot do this is the following: To balance your body upright, the center of your body has to be directly over the part of your body supporting your weight.

    a. As a test of this idea, stand on the balls of your feet in the center of a room. Have a friend observe the position of the center of your body. Do your observations support this idea? Explain why or why not.
    b. Stand in the center of a room and bend over to touch your toes. Now stand with your heels against a wall, and try to bend over and touch your toes. Can this activity be used to support this idea? Explain why or why not.

12. A soap bubble was "caught" in the air with a bubble wand and the end of the wand was stuck into modeling clay to hold the wand upright. The bubble will stay on the wand for some time before it eventually pops. Here are some attempts to explain why bubbles on wands eventually pop:

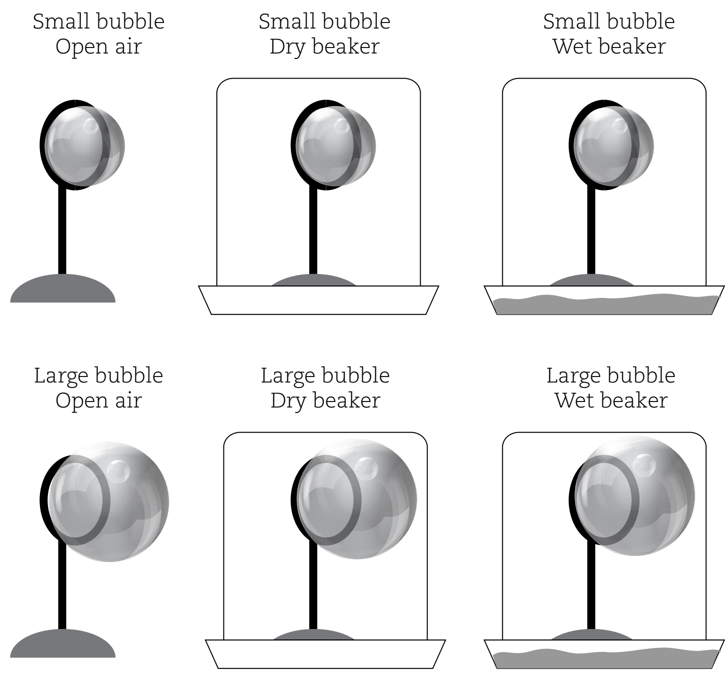
    Idea 1: Wind currents in the room cause the bubbles to pop.

    Idea 2: The bubbles pop when the water in the soap bubbles evaporates.

    Figure 5.4 shows a variety of ways that one can set up a bubble on a wand. The two farthest to the left show a small and a large bubble set up in the open air. The middle two show a small and large bubble placed under dry beakers. The two farthest to the right show a small and a large bubble under beakers placed on plates full of water. (Safety note: This activity requires the use of indirectly vented chemical-splash goggles and aprons.)

    a. Which of the six setups shown above would be the best ones to use as comparisons if you wanted to test Idea 1?
    b. Which of the six setups shown above would be the best ones to use as comparisons if you wanted to test Idea 2?

Figure 5.4. A Soap Bubble Set up on a Wand in Different Ways



5.3 Putting Testing Strategies Into Practice

In this section, we present two more simple examples of how testing strategies can be used by students. As you read these examples, look for how the strategies are put into practice by the teacher. In the section following this one, we will demonstrate how to use these strategies in more complicated situations.

Do Chemical Reactions Cause Muscle Contractions?

As part of a unit on physical and chemical changes, middle school students learned that the rate of a chemical reaction depends on temperature. Usually, the warmer it is, the faster the rate of a chemical reaction. (Students had already tested many of the variables that might affect chemical reaction rates, including temperature and amounts of reacting materials.)

As an application to the concept of temperature and reaction rates, the teacher has asked her students if they know what causes muscles to move in their bodies. After the students shared some of their ideas; which included such things as nerves, energy, and food, the teacher asked them if they could design a test to determine whether muscles contract due to chemical reactions. To help them get started, she had the entire class count how many times they could open and close their hands in 10 seconds. They found that, as a class average, they could open and close their hands 44 times in 10 seconds. Now the teacher's original question was restated in the following way: How can we test to check if muscles contract due to chemical reactions (the model)?

With the teacher facilitating, the class brainstormed ways to test this model. The teacher suggested they focus on what they knew about factors affecting chemical reaction rates, as these properties might help them think of ways to test the model. A list of those properties was written on the board. With the help of the list, and with the hand-flexing activity still fresh in their minds, several students suggested that they test if the rate at which muscles contract depends on temperature.

As was their practice in class together, the teacher helped the class formulate the first part of an *If* … , *then* … . statement involving muscle contraction and chemical reactions:

> *If* muscles contract due to a chemical reaction, *then* …

The beginning of this statement was enough to help the students design a test of the model. First, they completed the rest of the *If* … , *then* … statement:

> *If* muscles contract due to a chemical reaction, *then* we should be able to open and close our hands faster when they are warm than when they are cold.

The simplest way to make the students' hands cold was by placing them in cold water. It was agreed that the water should be as cold as possible without causing pain (a reasonable temperature range here is 60–100°F or 15.6–37.8°C) so that the difference between hot and cold would be as extreme as possible. After immersing students' hands for one minute, the class average for the number of times each student could open and close his or her hands in 10 seconds was 27 times.

Clearly, the students could open and close their hands faster when they were warmer than when they were colder. Together they completed their *If* … , *then* … . statement.

> *If* muscles contract due to a chemical reaction, *then* we should be able to open and close our hands faster when they are warm than when they are cold. *And* this is what we observed. *Therefore* the model seems to work.

This activity was concluded by the teacher making sure that students understood that they had not proven this model is absolutely correct. They had simply found evidence in support of the model. She went on to tell them that muscle movement can be quite complex, but that scientists, too, believe chemical reactions are one of the requirements needed to make a muscle contract.

Is Metal Colder Than Wood?

An elementary teacher had his students touch both the metal legs of their chairs and then the wooden tops of their tables. How did those two things feel different? The students immediately reported that the metal chair legs were colder than the wooden tables.

The teacher then asked the students why they thought it felt like the metal was colder. The students interpreted this question to be why *was* the metal colder, because they did not think it just felt colder, they thought that it was colder. "Let's test this idea," said the teacher. "If the metal really is colder than the wood, then how could you test that?"

Many students said all you had to do was feel it, but the teacher insisted that they had already done that test. He was wondering if there were more tests they could do to be more certain that the metal really was colder. He repeated his conditional statement again. "If the metal really is colder than the wood, then what could we do to test that? How do you test if something is hot or cold besides using your own hand?"

Eventually, students began to recommend that they use a thermometer to test. *If* metal is colder than the wood, *then* it should be colder when you use a thermometer. To make sure they got the best results, the students went around the room and felt many pieces of metal and wood and decided which pieces of metal seemed coldest and which pieces of wood seemed hottest. Those were the items that would be measured, because they would show the biggest differences. The class agreed that it would not be fair to measure the radiator because that was always hot, so that would not be a fair test.

After checking their measurements several times, the class did not find any temperature difference between the wood and the metal in the room. The teacher and students together tried to summarize their findings with a conditional statement:

> *If* metal is colder than the wood, *then* it should be colder when you use a thermometer, but it's not, so metal is not necessarily colder than wood.

Practice Problems on Strategies for Testing Models and Explanations

The following exercises describe either an activity or an observation, then present an explanation or a model. Design and carry out a test or a series of tests to evaluate the validity of the explanation or model given. Remember, your thoughts will be clearer and your communication more precise if you report on your tests using *If … , then …* statements whenever possible.

1. Find an empty glass bottle that has a neck that is too narrow for a dime to fit through. (A soda pop bottle works well for this.) Place the bottle in the freezer or in a bucket of ice water for 5–10 minutes. Remove the bottle, wet the very top of the bottle with a bit of water, and place the dime across the top. Wrap your hands around the sides

of the bottle for a few minutes. The dime will begin to bounce up and down. (Safety note: This activity requires proper eye protection—safety glasses or goggles.)

Explanation: Your warm hands cause the cold air in the bottle to expand, which pushes up on the dime and makes it bounce around.

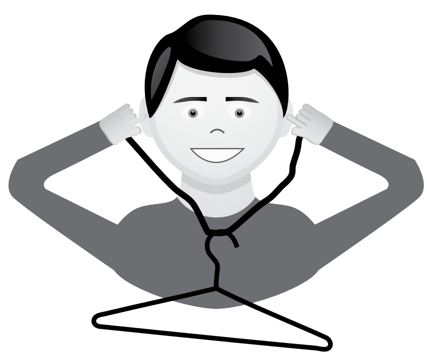
2. Fill a 2 L bottle with water. Turn it upside down and watch the water come out. The water does not pour out rapidly in one steady stream. Instead, it quickly spurts and stops over and over again as it "glugs" out. (Safety note: This activity requires proper eye protection—safety glasses or goggles.)

   Explanation: The water coming out of the spout is obstructed by air going into the spout at the same time, because water cannot come out of the bottle unless air can get in to replace it.

3. Cut a piece of string about two feet long. Tie the center of the string around the hook of a clothes hanger. Wrap the loose ends of the string a few times around each of your two forefingers, and let the hanger hang from the string as you put your two fingers into your ears. With your fingers in your ears, swing the hanger and let it bounce off a hard object, such as the side of a table (Figure 5.5). The hanger will make a wonderful gonging sound in your ears. (Safety note: This activity requires proper eye protection—safety glasses or goggles. Use caution when working with the end of a clothes hanger, as they are sharp and can cut skin.)

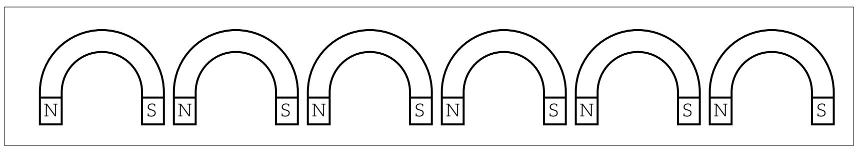
   Model: The pitch and tone of the gong depends on the shape and size of the hanger.

Figure 5.5. A Wire Clothes Hanger Dangles on a String Held by a Person With His Fingers Near His Ears.



4. Refrigerator magnets (those flat, flexible magnets used to hold up papers on the sides of refrigerators) do not have a single north and south pole (as do most magnets). Instead, the surfaces of the magnets are covered with a series of alternating north and south poles (Figure 5.6). How could you test this model to see if it is valid?

Figure 5.6. Cross-Sectional View of a Refrigerator Magnet



5. Touch your forefingers together and hold them about 6 in. from your eyes. Stare at an object behind your fingers as you slowly move your fingers apart. You should see what appears to be a small finger floating in front of your eyes.

   Explanation: This optical illusion occurs because you have two eyes. Each eye views your fingers from a slightly different direction, which confuses your brain into thinking that a floating middle finger exists.

6. Describe how you would test to see if a magnetic compass is actually made from a bar magnet.

7. When drops of water are placed on waxed paper, the drops bead up because water has a large amount of surface tension.

   Model: Soap reduces the surface tension of water.

5.4 Testing Competing Explanations and Models

There often are several different explanations that might explain a single event or set of observations. Testing multiple or competing models can be more difficult than testing a single model because your working memory can become overloaded with too much information. The key is to try to evaluate each explanation or model separately, while also keeping in mind that a test you do on one explanation may also influence your evaluation of another. In general, however, the approach you use to test several competing models is the same as when you test a single model. Below are two examples of how to test competing models.

Why Does Salt Cause Carbonated Water to Fizz?

If you pour salt into a glass of carbonated water, such as a soft drink, the water will fizz rapidly. Here are two explanations for why that happens:

1. The water fizzes because there is a chemical reaction between the salt and the water.
2. The water fizzes because the gas dissolved in the water will collect into bubbles around any small object.

The first explanation says that a chemical reaction occurs between the salt and the carbonated water, which causes the fizzing. This is a reasonable explanation because chemical reactions often involve observable changes in features such as color, volume, and temperature. The second explanation states that carbonated water always fizzes whenever a tiny amount of a substance is poured in. Since salt is just a collection of small particle grains, the salt makes the water fizz.

Remember, the first step is always to try this out yourself before you begin testing. You want to use extremes: fresh carbonated water and lots of salt, for example, so that you do not miss any subtle observations.

The next step would be to choose just one of the ideas and try to test it. Usually, you pick whichever seems easiest to test. In this case, the second model can be tested in a straightforward way. Place the model into an *If* … , *then* … . statement:

> *If* carbonated water fizzes whenever you pour in tiny objects such as grains of salt, *then* … .

A straightforward way to test this idea would be to pour in some other substance made up of tiny particles and see what happens. If you try sugar, you find that the water fizzes just as much as when you put in salt. This test provides supporting evidence for the model, but it certainly does not prove it.

> *If* carbonated water fizzes whenever you pour in tiny objects such as grains of salt, *then* no matter what substance I pour in, the water should fizz if the substance consists of tiny particles. This is what was observed. *Therefore,* there is strong evidence to support this model.

Perhaps sugar and carbonated water also undergo a chemical reaction just like salt and carbonated water do (according to the first model). If they do, then this result might actually give support to the first model. Therefore, several other granular substances should also be tried before you come to a conclusion about this model.

It turns out that no matter what substance you pour into carbonated water—such as salt, sugar, sand, or rice—the water always fizzes. These tests make the second idea seem likely, and they cast doubt on the first one because it does not seem likely that carbonated water chemically reacts with *everything* you put into it, which is the explanation associated with the first idea.

Still, it would be good if a specific test could be done on the first idea to determine if it is definitely false or also possibly the case. To do so, begin by placing it into an "*If* … , *then* … ." statement:

> *If* the water fizzes because there is a chemical reaction between the salt and the water, *then* … .

This model is not as easy to test as the second one. How can you test if there really is a chemical reaction between salt and carbonated water? One way to test this is to use rock salt instead of regular salt. Because rock salt comes in large chunks rather than small grains, rock salt should not cause as much fizzing as regular salt, if indeed the fizzing happens because of the salt's size. Alternatively, if salt does chemically react with the water, then rock salt should cause fizzing that is less rapid than with regular salt, but that continues for a lengthy period of time.

When rock salt is put in carbonated water, some, but not a lot, of fizzing occurs. Here is the resulting model in an *If* … , *then* … statement, along with a conclusion:

> *If* the water fizzes because there is a chemical reaction between the salt and the water, *then* when I put in rock salt, there should be gentle fizzing for a long time. *However,* rock salt only causes a little bit of fizzing. *Therefore,* the fizzing is probably not due to a chemical reaction between the water and the salt.

The conclusion reached is that the second explanation, not the first one, seems to better account for what occurs, but should still be regarded as a working model, not a proven model.

Why Do Ice Cubes Melt More Slowly in Salt Water Than Freshwater?

Ice cubes melt more slowly in salt water than freshwater. This can be easily demonstrated by putting one ice cube in a cup of salty water and another one in a cup of freshwater. If the salt water is very salty, then the ice cube in the salt water can take twice as long to melt as the ice cube in the freshwater. Why do you suppose that is? (Safety note: This activity requires indirectly vented chemical-splash goggles and aprons.)

Remember that you increase your chances of successfully testing a model if you can clearly observe all the relevant variables. You help yourself in this regard by making differences in the comparisons you make as large as possible. For example, ice does not melt slowly in water if it is only a little salty, but it does melt *very* slowly if the water is *very* salty. Therefore, in this example, you would want to compare ice cubes in freshwater to ice cubes in *very* salty water. Comparing extremes will help you notice important features that you might otherwise miss.

Remember as well that comparisons need to be done fairly, or else you will be misled by the results. Therefore, for all tests and comparisons, variables must be controlled. In the situation investigated here, many variables can affect how quickly the ice melts, including the temperature of the water and the size of the ice cubes. This means that the two glasses of water and the two ice cubes being melted must be identical in every way, except for the fact that one of the cups contains freshwater and the other one has salty water.

Finally, remember that people do much better at testing a single model or explanation if they take the time to think of several competing explanations of their own before they begin any testing. People have a tendency to think too narrowly about an explanation when they have not yet imagined other possibilities. Therefore, before you test your own or someone else's model, think of several additional explanations that might explain what you observe.

Before reading further, try to think of several ideas that might explain why ice melts faster in freshwater than in salty water.

Once you have made the observation that ice really does melt more slowly in salt water, and after you have generated some of your own explanations as to why this is the case, then you are ready to begin testing. In the sequence of examples given here, three different models will be presented. Each model will be treated separately because each can be tested in a different way. However, the same general approach will be used for all three. (Safety note: This entire activity requires the use of indirectly vented chemical-splash goggles and aprons.)

Idea #1: Ice melts more slowly in salt water because less of the ice touches the water.

Rationale: This explanation is based on the fact that objects float higher in salt water than in freshwater. For instance, people have an easier time floating in the ocean, which is salty, than they do in freshwater. This is because salt water is more dense than freshwater, and the more dense the water, the higher out of the water you float. Because ice cubes float much higher in salt water than freshwater, perhaps there is less salt water touching the ice, and thus the salt water cannot melt the cube as quickly.

The next step is to insert the model into the first part of an "*If … , then … .*" statement. Doing so might give you insight into a test you could do.

> *If* ice melts slower in salt water because less of the ice touches the water, *then …*

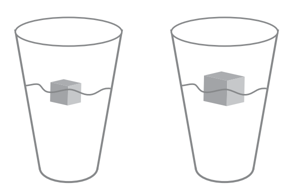
Now it is time to think of a way to test the model. Sometimes an idea forms quite easily. Other times thinking of a test proves more difficult. In this example, a simple test can be developed.

If ice melts more slowly in salt water because less of the ice touches the water, *then* when you look at the ice cubes, you should see that the ice cube in the salt water floats up much higher than the ice cube in the freshwater.

But is that what you see (Figure 5.7)? Because the ice cube in the salt water melts so much more slowly, you should be able to observe the cube floating significantly higher and out of the salt water than the other ice cube. Yet when you compare the ice cubes, they seem to float at about the same level. Therefore, this explanation does not seem to be a good one.

> *If* ice melts slower in salt water because less of the ice touches the water, *then* when you look at the ice cubes, you should see that the ice cube in the salt water floats higher in the water than the ice cube in the freshwater. *However,* the ice cubes in the two cups seem to be floating at about the same level. *Therefore,* this idea is not working.

Figure 5.7. Ice Cubes Floating in Fresh and Salt Water



Here is another slightly more difficult idea to test:

Idea #2: Ice melts more slowly in salt water because salt water gets colder than freshwater when you put ice in.

Rationale: When you pour salt on ice, the ice begins to melt and actually becomes colder. (Try this if you have never done so before.) Maybe the salt water gets a lot colder than the freshwater as the ice melts because of the salt. This effect would make the ice in the salt water melt more slowly in the long run because it would be surrounded by extra cold water.

> *If* ice melts more slowly in salt water because salt water becomes extra cold when you put ice in it, *then* …

You cannot only look at the salt water and see if it has gotten much colder than the freshwater, but you can measure and compare the temperatures of the freshwater and salt water. Measuring the temperatures of the two cups would be the test needed to evaluate the model.

> *If* ice melts slower in salt water because salt water becomes extra cold when you put ice in it, *then* when I measure the water temperatures, the salt water should be colder than the freshwater.

However, if you measure the temperatures of the liquid in the cups as the ice melts, you find that the freshwater actually gets *colder* than the salt water. This is the opposite of what was predicted based on the model.

> *If* ice melts more slowly in salt water because salt water becomes extra cold when you put ice in it, *then* when I measure the temperatures, the salt water should be colder than the freshwater. *However,* the salt water is actually warmer than the freshwater. *Therefore,* this explanation is not working.

Here is a final idea to be tested:

Idea #3: Ice melts more slowly in salt water because the cold water from the melted ice surrounds the ice cube.

Rationale: Normally, when ice melts, the very cold (and dense) melted water sinks to the bottom of the glass, leaving the ice surrounded by warm water that continues to melt the ice. However, when ice melts in salt water, the cold melted water does not sink to the bottom of the glass because the salt water is too dense. Instead, the cold, melted water remains at the top of the glass and surrounds the ice. Because the ice is surrounded by cold water, it melts very slowly.

> *If* ice melts more slowly in salt water because the cold water from the melted ice surrounds the ice cube, *then* …

We need to see if the cold, melted water from the ice cube in the salt water is surrounding the ice cube and keeping it from melting. We have to think outside the box to figure out a way to test this. We must find a way to "see" if the water melting from the ice cube in the freshwater flows to the bottom of the glass, whereas the melted water in the salt water glass surrounds the ice cube. One way to do this would be to make colored ice cubes by freezing water mixed with food coloring. Then, as the ice melts, you can see what happens to the colored water (Figure 5.8).

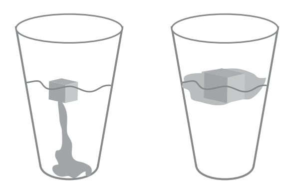
If you try this test, you will indeed observe that in freshwater the melting ice water flows to the bottom of the glass, while in the salt water the melting ice water stays at the top and surrounds the ice cube. This is exactly what you would expect to see based on the last model.

If ice melts more slowly in salt water because the cold water from the melted ice surrounds the ice cube, *then* if you use colored ice cubes, you should see the melted water in the fresh cup going to the bottom, while the melted water in the salt water cup should stay at the top. This is exactly what was observed. *Therefore,* this model seems to work.

Where did the idea of making colored ice cubes come from? There was no logical way to arrive at the idea. It simply had to come as a flash of insight. Certainly, it was helpful to use the usual strategies for testing, but in the end creativity and problem-solving skills were needed to develop this last test.

Model testing will always rely on some amount of insight and problem solving, but you will fare much better if you try to work through each situation using the five-step approach outlined in this chapter.

Figure 5.8. Colored Ice Cubes Floating in Freshwater Versus Salt Water



Practice Problems on Testing Competing Explanations and Models

The following exercises describe an activity or an observation, then two or more explanations or models. Design and carry out a test or series of tests to evaluate each of the explanations or models given.

1. Fill a dry aluminum drink can half-full with water. Make sure the outside of the can is dry. Add enough ice cubes to the water so that the water level nearly reaches the top of the can. After a short period of time, drops of water will appear on the outside of the can. (Safety note: Use caution when handling the aluminum drink can—the opening on the top can be sharp and cut skin.)

   Explanations

   a. Water vapor from the air condenses on the can.
   b. Water from inside the can leaks out onto the outside of the can.

2. Fill one cup halfway with water, and fill another cup one-quarter full with vegetable oil. Slowly pour the vegetable oil into the cup containing the water. You will find that the oil stays on top of the water. (Safety note: This activity requires use of indirectly

vented chemical-splash goggles and aprons. Immediately wipe up any water or oil spilled on the floor to avoid a slipping or falling hazard.)

Explanations

a. The water is heavier than the oil, so the water stayed on the bottom.
b. The oil stayed on top because it was poured on top of the water
c. Water is denser than oil, so it stayed on the bottom.

3. Sit with your hand hanging straight down. After a few moments, you should observe the veins on the back of your hand bulging out a bit. Now raise your hand high above your head. The veins should shrink back in size.

Explanations

a. Gravity pulls down on your blood. The lower you hold your hand, the more your blood gets pulled into your hand. This causes your veins to swell.
b. The muscles in your arm must clench to hold up your hand. As your muscles clench, blood gets squeezed out of your veins, so they shrink in size.

4. Light a small lightbulb with a battery, a bulb, and two wires. Electrical charges flow in the wires to make the bulb turn on. Which of the following ideas best describes the motion of the charges in the circuit? (Safety note: This activity requires the use of proper eye protection—safety glasses or goggles. Use caution when handling wires, as ends are sharp and can puncture skin.)

Models

a. Positive charge comes out of one end of the battery, then goes into the bulb and makes it light.
b. Positive charge comes from one side of the battery, and negative charge comes from the other. When the charges meet in the bulb, they make light.
c. Positive charge comes from one end of the battery. Some of the charge gets used up in the bulb to make light, and the rest goes back around into the battery.
d. Positive charge comes from one end of the battery. All this charge goes back around to the other end of the battery.

5. Sprinkle pepper into a cup of water. The pepper will remain on top of the water. Why doesn't the pepper sink to the bottom?

Models

a. The pepper floats because it is less dense than the water.
b. Pepper is denser than the water, but it is held up by the surface tension of the water.

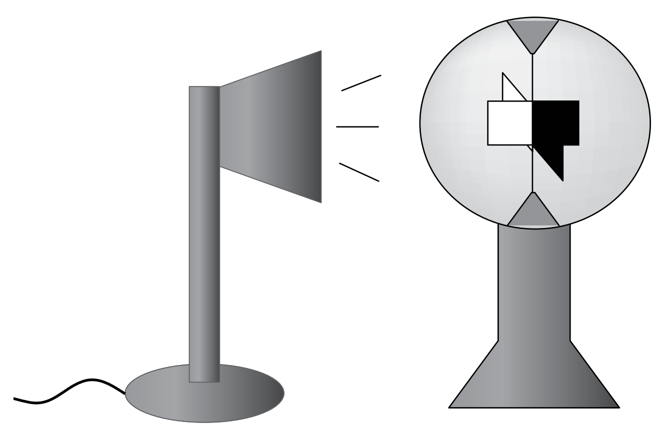
6. Obtain a cup and a piece of flat plastic that can be placed over the top of the cup. (A large plastic lid, such as might come from a margarine container, would work well.) A 3 × 5 in. paper notecard smeared with petroleum jelly can replace the plastic lid. Fill the cup halfway with water, and cover the cup with the plastic. While holding the lid in place, invert the cup so that it is upside down. Remove your hand holding the lid. The lid should remain on the cup, and the water will not spill. Why does the lid stay on the cup? (Safety note: Immediately wipe up any water spilled on the floor to avoid a slipping and falling hazard.)

   Explanations
   a. The lid is held on the cup due to the surface tension of the water.
   b. The air in the cup makes a suction, which pulls up on the water and the lid.
   c. The air pressure outside the cup is greater than inside. The outside pressure holds the lid on the cup.

7. A radiometer is a device with black and white "flags" that spin around when you shine light from a lamp on it (Figure 5.9). What makes the flags spin around? (Safety note: Use caution when handling the lamp. Do not touch the bulb, as it can burn skin.)

   Explanations
   a. Light from the lamp makes the flags spin.
   b. Heat from the lamp makes the flags spin.

Figure 5.9. A Radiometer With a Lamp Shining Light on It



8. When you blow on a lit candle, the flame goes out. Why?

Explanations

a. Exhaled breath contains so much CO_2 that the flame goes out.
b. The wind that you blow out cools off the flame and makes it go out.

9. A candle that has recently been blown out can be relit in the following way. Light two candles and hold them sideways. Blow out one of the candles, then quickly reposition the lit candle so that it is just above the smoldering candle (Figure 5.10). This repositioning will usually cause the smoldering candle to relight. What causes the candle to relight? (Safety note: This activity requires proper eye protection—safety glasses or goggles. Remember to keep all flammable items away from the flame, such as clothing and artificial fingernails.)

Explanations

a. Heat radiating downward from a candle is enough to light another candle on fire.
b. Wax from the bottom candle is still vaporizing and moving upward. When the vapor hits the flame above, it catches on fire, and the flame moves down the vapor trail to the bottom candle.
c. The upper candle is heating the air. Warm air rises, so the bottom candle can feel air moving by it. Air blowing by the candle causes it to relight.

10. Put about 300 ml of water into a tall beaker. Use a metal spoon to tap lightly on the side of the beaker, and listen to the pitch of the sound that is produced. Next, pour 75 ml of salt into the water, and stir the water with the spoon until the salt dissolves. Notice that the pitch of the sound made by tapping the beaker with the spoon is now lower than it was before. Why is the pitch lower? (Safety note: This activity requires indirectly vented chemical-splash goggles and aprons. Use caution when tapping against the glass, as it can shatter and cut skin.)

Explanations

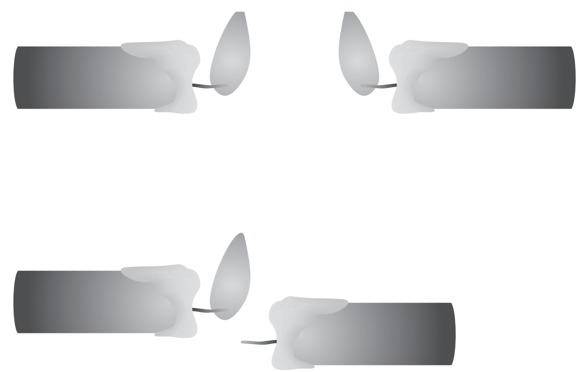
a. The water level in the beaker is higher than before. The higher the water level, the lower the pitch.
b. The water is now denser because of the dissolved salt. The denser the water, the lower the pitch.

11. What determines whether a soft drink can (when full) will float or sink if it is placed in water?

Explanations

a. Dark-colored soft drinks sink. Clear soft drinks float.
b. Beverages containing sugar sink. Beverages without sugar float.

Figure 5.10. Two Candles Are Lit; One Candle Is Blown Out, Then Quickly Repositioned Just Below the Lit Candle.



c. Beverages containing caffeine sink. Beverages without caffeine float.

12. When a seed germinates (sprouts), what determines the direction in which the roots will grow?

Models

a. Roots always grow downward, as dictated by gravity.
b. It depends on the way (orientation) in which you plant the seed.

13. What determines the direction in which a plant stem will grow?

Models

a. Plants grow upward, in the opposite direction of gravity.
b. Plants grow in the direction in which they receive the most light.

14. Why are the connections between the batteries and the lightbulbs in an electrical circuit made with flexible metal wires?

Explanations

a. Metal is a good conductor of electrical energy.
b. These connections need to be made with a flexible material.

15. Measure the temperature of a glass or beaker of water at room temperature. Next, stir a large amount of salt into the water and measure the temperature again. The water will

now be cooler than before. Why? (Safety note: This activity requires use of indirectly vented chemical-splash goggles.)

Explanations

a. Stirring water decreases the temperature of the water.
b. Dissolving salt in water decreases the temperature of the water.

16. Place a candle upright in a tray by anchoring it to the bottom with modeling clay. Add water until it is about 2 cm deep in the tray. Light the candle. Then, in one quick motion, place a beaker over the top of the candle, and rest it upside down on the bottom of the tray. After a few moments the candle will go out and some water will move into the beaker. Why does the water go into the beaker? (Safety note: This activity requires use of proper eye protection—safety glasses or goggles.)

Explanations

a. Smoke from the candle pulls the water into the beaker.
b. Water goes into the beaker to replace the oxygen that was used by the burning candle.
c. Water goes into the beaker because the gas inside cools and contracts when the candle goes out.

5.5 An Example of Model Testing With Students

Andrea teaches fourth grade and was ending her school year with a unit on light. Her district content standards state that students should understand the idea that "dark objects absorb more light and heat up faster than light-colored objects." The days were getting warmer with the onset of summer, so Andrea decided to begin her unit by exploring this concept outside.

The day was warm and sunny. Andrea had carefully surveyed areas of the school grounds the day before for broken glass and other sharp objects. She also marked off sections of ground where students would be standing and walking to ensure they would be safe. (Safety note: Use caution—on extremely hot days, black asphalt can burn the bottom of feet.) When Andrea took her students outside, she instructed them to remove their socks and shoes and walk across designated sections of sidewalk and asphalt in the parking lot. Under the warm spring Sun, students found the black asphalt seemed much hotter than the cool, white sidewalk. After spending some time reflecting on the differences between the sidewalk and the asphalt, the class retrieved their belongings and went back inside.

At the front of the classroom, Andrea wrote this question in large letters across the top of the board:

Why is the parking lot hotter than the sidewalk?

The rest of the board was left blank. Possible ideas would soon be listed, but first students exchanged ideas in small groups. Andrea knew that the quality of students' ideas would improve if they first had time to discuss their ideas with their peers, but she also knew that students needed time to examine their beliefs and generate a variety of possible explanations if they were going to design tests for evaluating scientific ideas.

Andrea took time to circulate among student groups and listen to their discussions. She hoped that at least one group would suggest that the difference in temperature between the dark asphalt and the light sidewalk had something to do with the Sun shining on them. If students did not come up with this idea on their own, then she would have to introduce it herself, which of course would bias the students into thinking it was the best explanation to consider. To guard against this assumption, Andrea planned, if necessary, to offer a few other explanations as well, so that the students would not be clued into which model she preferred. Fortunately, several groups were already discussing the possibility that sunlight had caused the temperature difference.

After allowing a few more minutes of group discussion, Andrea asked for volunteers to share their ideas. When stating their ideas, students were required to give an explanation to support their idea, or at least they had to provide their thought journey as to how they came up with their idea. Without this explanation, students can often propose ideas that make little sense to the rest of the class, and therefore they are next to impossible to test. At the same time, Andrea would not expect her students to state their ideas using precise language. Most statements need to be worked on by the teacher and the class before they can be written on the board.

Here are the ideas proposed by Andrea's class:

Why is the parking lot hotter than the sidewalk?

Ideas

1. The parking lot is hotter than the sidewalk because cars drive on it.
2. The parking lot is hotter than the sidewalk because the sidewalk is cooler.
3. The parking lot is hotter than the sidewalk because it is hard.
4. The parking lot is hotter than the sidewalk because black things get hotter in the Sun.
5. The parking lot is hotter than the sidewalk because the material (asphalt) was hot when they made it. (Several students proposed this idea because in the past they had seen steam coming from hot asphalt when workers were building a road.)

Before jumping into model testing, it is always a good idea to make sure that all of the models are good, scientific explanations. With this in mind, Andrea asked the class to examine each idea and evaluate it according to the scientific criteria displayed nearby on a poster.

A scientific explanation should …

- explain what, why, or how;
- be consistent with the evidence; and
- be consistent with existing models.

As they went through the list, several students immediately recognized that the second idea was really not a valid scientific explanation. It did not give a reason for why the parking lot was hotter. It just said that it was hotter, a fairly common mistake made by students when they generate models. The class agreed to eliminate that one, and now they were left with only four ideas.

1. The parking lot is hotter than the sidewalk because cars drive on it.
2. The parking lot is hotter than the sidewalk because it is hard.
3. The parking lot is hotter than the sidewalk because black things get hotter in the Sun.
4. The parking lot is hotter than the sidewalk because the material (asphalt) was hot when they made it.

Now it was time to begin testing. However, Andrea knew that her students could not deal with all four of these ideas at the same time. So much information and so many choices all at once would overwhelm their working memories and they would become confused. Consequently, her plan was to begin working through the models as a class one at a time, starting with whichever model seemed easiest. This turned out to be the second one: The parking lot is hotter than the sidewalk because it is hard.

To begin, Andrea wrote the first part of an "*If … , then … .*" statement on the board. Andrea left the statement hanging on the board and waited for student ideas.

> *If* the parking lot is hotter than the sidewalk because it is hard, *then …*

Several students offered up ideas. A few of them were similar to the following:

> *If* the parking lot is hotter than the sidewalk because it is hard, *then* the parking lot should feel hard when you touch it. We observed that the parking lot is hard, so this idea seems valid.

Although these students were using sound reasoning, they were clearly missing an important point. Andrea had to break down their line of reasoning with the entire class. She asked questions such as, "Did you feel the parking lot?" and "Was it hard?" There was general agreement about those answers. She then asked more complicated questions. "Did you feel the sidewalk?" "Was it hot?" "If hard things are hot, like the parking lot, then shouldn't the sidewalk also be hot?"

Andrea's last question sparked a response from several other students: "The sidewalk is hard, but it didn't feel hot. Shouldn't the sidewalk feel just as hot as the parking lot? That can't be right."

The task now was to put these new thoughts into an "*If … , then … .*" statement to more clearly see the logic. Here is what the class came up with after much effort and careful assistance from Andrea.

> *If* the parking lot is hotter than the sidewalk because it is hard, *then* the parking lot must be harder than the sidewalk. *However*, the sidewalk is just as hard as the parking lot. *Therefore*, this model must not work.

Many students easily saw from this statement and argument that the model was unsupported by evidence. However, during the class discussion Andrea was able to assess that several students were still confused. For their benefit, she broke down the argument line by line into a simpler form that was easier to follow. When it appeared that the confusion was finally cleared up, this model was crossed out, and Andrea suggested they test another one. She wanted to do one more together as a class before allowing the individual groups to work independently. Andrea wrote the next model statement on the board.

> *If* the parking lot is hotter than the sidewalk because cars drive on it, *then …*

Once again, students discussed ideas for tests within their groups first. When sharing ideas later as a large group, several students argued in favor of the model based on their experience near warm car exhaust. "Since car exhaust is very hot," they said, "the parking lot would get hot when people drive their cars on it. So, this model must be right."

Andrea recognized that these students had made an argument based on "personal theory," and not on an actual test they had done. Consequently, she insisted that they design a way to test their idea to see for sure. After all, in science, models must be tested. You cannot just claim that they must be true.

After much discussion and brainstorming, students were able to come up with two ways to test this model. The first method had to do with finding a section of the parking lot that cars don't drive on. If cars don't drive on a certain section of the parking lot, then that section should not be hot. They wrote this down in the following way:

> *If* the parking lot is hotter than the sidewalk because cars drive on it, *then* in areas where no cars drive, the parking lot should not be hot.

Fortunately, a section of the parking lot was inaccessible to cars because of fencing, so this test could be done easily and safely.

The second test required a bit more creativity. The students asked, and Andrea agreed, to have someone drive a car several times over a section of the sidewalk that was adjacent to the parking lot. This way they could test whether the sidewalk would get as hot as the parking lot if a car drove on it. They wrote their test like this:

> *If* the parking lot is hotter than the sidewalk because cars drive on it, *then* if a car drives over the sidewalk, the sidewalk should get just as hot as the parking lot.

It did not take any persuading on Andrea's part to get the students to go back outside to conduct these two tests. Andrea brought an aide with her to ensure that students would be a safe distance away while a car was driven near the students. Much to the dismay of some students, the portion of the black asphalt inaccessible to cars was not significantly cooler than any other section of black asphalt. In addition, even after the car was driven over the sidewalk several times, the sidewalk was still much cooler than the parking lot. These observations did not seem to provide supporting evidence for the model.

Back inside, the class was now left with two ideas to consider.

Ideas

1. The parking lot is hotter than the sidewalk because black objects get hotter in the Sun.
2. The parking lot is hotter than the sidewalk because the material (asphalt) was hot when they made it.

It was now up to the individual groups to design ways to test these models. Before testing, however, each group had to report on their plans to the rest of the class. This gave Andrea and the other students a chance to make helpful suggestions to the groups, allowed her the opportunity to judge whether a proposed test was feasible and safe, and provided each group with the opportunity to consider using some of the testing ideas presented by other groups.

Here are a few of the good ideas for testing whether the parking lot is hotter because it was black:

1. Feel portions of the parking lot directly in the Sun and the shade. The parts in the Sun should be much hotter than the portions in the shade.
2. Shine a bright light on pieces of black and white construction paper. The black construction paper should get hotter.
3. Feel the parking lot on cloudy days. It should be much cooler on those days.

Ideas for testing if the parking lot is hotter because asphalt is hot when it is spread into a parking lot included the following:

1. Feel portions of the black asphalt directly in the Sun and the shade. The whole parking lot should be hot in warm weather because that was the way the asphalt was made.
2. Feel the parking lot early in the morning before the Sun gets a chance to heat it up. The parking lot should already be hot before the Sun hits it.

By the time these tests were completed and conclusions had been reached, Andrea was quite satisfied with the results. On one hand, she could have saved one or two periods of class time by simply telling her students that dark-colored objects heat up more than light-colored objects when you shine a light on them. But if she had done so, what would have been accomplished? Instead, by letting her students generate and test models, they had

- engaged in real-life science;
- learned more about the process of science and the need for testing;
- developed their testing skills;
- stretched their critical-thinking skills;
- exercised their creativity;
- generated concrete experiences related to the concepts of heating and light that foster student learning; and
- confronted and discarded a variety of misconceptions about heat and temperature that would have gotten in the way when students were learning a new concept.

As a result, Andrea's students were on the way to becoming scientifically literate, and Andrea could be confident that she was teaching in an inquiry-based manner.

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