

# Module Overview

Electrical energy is a vital part of modern living. It powers a vast number of devices that we use daily, from lightbulbs, televisions, and computers to vacuum cleaners, refrigerators, and air conditioners.

Although students may come to the module with seemingly limited experience with electrical energy, they actually use it routinely—playing with battery-powered toys, watching television, listening to CDs, and using computer games. Our increasing reliance on electrical energy underscores the need for students to understand the nature of electricity. The term “electricity” is used to describe many phenomena associated with electrical energy and electrical forces. As students participate in the inquiries in this module, they begin to develop their own understanding of the meaning of electrical current, voltage, and electrical energy. They investigate how electrical energy is transferred in electrical circuits and how devices transform electrical energy into other forms of energy. Students also explore electrical components and how they function in electrical systems.

Reading selections in the module reinforce the concepts that students investigate in the inquiries. Students also learn about some of the scientists who made important discoveries about electricity and read interviews with an electrical engineer and an electrical line mechanic, professionals in fields related to electrical energy and circuits.

## **PART 1 ELECTRICAL ENERGY IN CIRCUITS**

Part 1 (Lessons 1–13) focuses on electrical energy and how electrical circuits provide a means to transfer electrical energy to devices that transform it into other forms of energy, such as heat, light, and sound.

The module begins with a pre-assessment (Lesson 1). Students examine five electrical systems and observe energy transformations in them. Teachers can assess students’ prior knowledge of electricity and discover students’ misconceptions about it. The pre-assessment allows students to use their own words to express their ideas about their observations. They will refine their vocabulary of electrical systems as they progress through the inquiries.

Lessons 2 and 3 focus on static electricity. In Lesson 2, students build an electrophorus, which they use to observe how a charged metal pie pan can provide electrical energy to light a neon bulb. They experiment with moving the pan on and off the electrophorus and observe how it affects the lighting of the neon bulb. They also investigate how well different materials can conduct electric charge and transfer electrical energy to the neon bulb. In Lesson 3, students observe static electrical forces. They observe that materials with like charges repel one another and that materials with opposite charges attract each other. They also see that different materials can acquire different electric charges. Students charge an electric plume and observe its behavior when they bring charged objects near it. A small Van de Graaff generator allows students to see the effects of large accumulations of static electric charge.

In Lesson 4, students learn how to develop and use models to explain their observations of unseen objects. To determine the contents of sealed boxes, they depend on their observations—such as estimating the weight of the boxes and judging the sounds they hear as they turn them. This investigation prepares students to work with an invisible phenomenon, charge flow (current) in a circuit, whose effect is the only thing they can see.

Lesson 5 begins the study of electrical circuits. Students are introduced to and make an inventory of the contents of their circuit systems kit. With progressing lessons, they add additional electrical components to their kits, which become their primary set of tools for performing their investigations. In Lesson 5, they use batteries, wires, switches, and lightbulbs to investigate ways to light bulbs in series and parallel configurations. Based on their experiences, students construct definitions for open and closed circuits, series circuits, and parallel circuits. Students also learn to interpret and draw schematics of electrical circuits.

In Lesson 6, students add an ammeter to their circuit systems kit and learn how to use it to measure current in series and parallel circuits. Measuring current with the ammeter placed in different locations in a simple series circuit, they obtain the same measurement at all points. They then measure current in a parallel circuit and find that the sum of the current measurements in parallel lines is equal to the current measurement in the series lines. Using a fan, students observe how switching the connections to a battery reverses the current. In this lesson, teachers introduce students to a water-circuit model. Water flow in the model represents current flow in circuits. Demonstrating the water-circuit model, teachers can explain how current can transfer energy in a circuit. The water wheel demonstrates how devices in a circuit can transform energy associated with the current into other forms of energy.

Lesson 7 introduces the concept of voltage. Students add a voltmeter to their circuit systems and learn how to connect it to electrical devices and measure the voltage drop across them. They connect single D-cell batteries in combinations to create compound batteries. They use the voltmeter to measure the voltage

across the compound batteries and look for data patterns. Students next set up a simple series circuit containing a lightbulb, a battery, and a switch. They predict how changing the number of batteries and the way the batteries are connected (series or parallel) will affect the lightbulb's brightness and the voltage across the lightbulbs. Students design experiments to test their predictions and report their results to the class. From their experiences, students begin to formulate a definition of voltage.

In Lesson 8, students further investigate current. They again set up a simple series circuit that contains a lightbulb and an ammeter. Students predict how changing the number of batteries and the way they are connected will affect the current through the lightbulb. As in Lesson 7, students design procedures to change the number of batteries (in series or parallel) and measure and record the current. They also observe and record the lightbulb's brightness, which changes as the current through the lightbulb changes.

Lesson 9 introduces another water model of a circuit, a water-battery model. Water-filled cylinders represent batteries. The cylinders have spouts out of which the water flows. By observing this water flow, students are able to draw analogies about voltage and current in battery-powered electrical circuits. Water pressure, which in this model is analogous to voltage, provides a means to push water through the "circuit." The water flow, which represents current, provides the means for transferring energy from the cylinders to a water wheel, making it turn. The concepts students learn from observing this model prepares them to investigate electrical power, which depends on both voltage and current.

In Lesson 10, students learn how to calculate the electrical power of different devices in circuits. They set up a fan circuit and measure

the voltage across the fan and the current through it and calculate the fan's power. They also determine the power supplied by the batteries in the circuit and see that it is very nearly the same as that supplied by the fan (within variances in measurements). Students then measure the power of lightbulbs in circuits and see how power is distributed among lightbulbs in a series circuit.

Lesson 11 is an assessment. Students complete tasks that assess their skills at setting up circuits, reading schematics, and making measurements using voltmeters and ammeters. They also complete written assessments in which they demonstrate their understanding of series and parallel circuits, as well as current, voltage, and power. Students are also design a circuit that functions in a prescribed way.

Lesson 12 sets the stage for the Anchor Activity (Lesson 13). Students learn how to calculate the total electrical energy that appliances use over a set period of time. They design circuits to compare the electrical energy that a fan uses in one minute to that of a lightbulb during the same time period. Students also set up a fan circuit and compare the energy the fan uses over a period of time to the energy a battery supplies to power the circuit during that same time period.

Lesson 13 concludes Part 1 of the module and introduces the Anchor Activity, a research-based activity that fuses the concepts in the module. Students conduct an inventory of the electrical energy that various household appliances use. They select appliances to monitor for two to three weeks. Students determine the power rating of the appliances and observe and record the number of hours they are used daily. They use the power rating and the average energy usage each day to determine the average amount of energy the appliances use daily and monthly. By examining electric bills, students

find out the average cost of electrical energy (per kWh) and use that to estimate the cost of using their appliances for a day and a month.

## **PART 2 ELECTRICAL COMPONENTS**

Lesson 14, which begins Part 2 of the module, focuses on various electrical components and their functions in circuits. Students examine different electrical devices. They observe a working model of each, looking inside to see its electrical components, and they identify and record them using a chart of electrical components. In Lessons 15–19, students investigate how some of these components function in circuits.

In Lesson 15, students investigate resistors. They set up a fan circuit and observe how adding resistors affects the fan's operation. By placing a thermometer on a resistor and observing its resulting temperature change, students also see evidence of energy transformations that occur in the resistor. To conclude the lesson, students use their voltmeters and ammeters for measurements that allow them to calculate the resistance of the resistors. Students also complete their first circuit component sheet; they complete one for each electrical component they investigate for the remainder of Part 2. On each sheet, students draw both the component and its electrical symbol and record how each component functions in a circuit. Students will find this information to be very useful when they complete the assessment for Part 2 (Lesson 20).

Lesson 16 focuses on the resistance of wires. Students are given nichrome wire segments to determine whether they have any resistance. When they add wires in a fan circuit, they find that they produce the same effect as when they added resistors (Lesson 15). Students read about the electrical wires and then design experiments to determine how changing either a wire's length or diameter affects its resistance.

Diodes are the topic of Lesson 17. Students investigate what happens when they put a diode in series with a device, such as a fan. They connect a diode in different ways in the circuit and find that it will only allow current through it in one direction. Students next investigate light-emitting diodes (LEDs) and observe that they too light up only when current goes through them in a preferred direction. To conclude the lesson, students design a circuit that lights different LEDs when they reverse the voltage across the circuit.

In Lesson 18, students investigate capacitors and their ability to store electrical energy. When they connect a grain-of-wheat lightbulb in a circuit with a capacitor, they observe how it initially lights, then goes out. They then obtain the same result when they remove the batteries so that the lightbulb is connected only to the capacitor. Students then observe and measure voltage changes across a capacitor as it charges and discharges. They construct a graph of voltage versus time for a discharging capacitor.

In Lesson 19, students investigate another kind of power source for circuits—solar cells. They use solar cells instead of batteries to provide power for a fan. By moving the solar cell around, students see how the light's intensity and the angle at which the light strikes the cells affects a solar cell's current output. Students determine which combination of solar cells, series or parallel, provides the most power to a fan.

Part 2 concludes with Lesson 20, which is a performance-assessment activity. As in Lesson 4, students try to determine the contents of mystery boxes, each containing one of the components they investigated in Lessons 15–19. Working with their group members, students use the tools in their circuit systems kits to perform investigations to determine the

contents of each box. Their completed circuit component sheets (Lessons 15–19) provide them with valuable information for conducting their investigations.

### **PART 3 ELECTRICAL SYSTEMS**

Part 3 focuses on the characteristics of systems, with an emphasis on electrical systems. Throughout the module, students have been working with electrical circuits that are electrical systems. In Lesson 21, they focus on properties common to many different systems (such as a supermarket, a farm, and a railroad). Students brainstorm and identify different kinds of systems. Student groups then select one system and analyze it in detail. In a class discussion, students determine the characteristics common to all systems.

In Lesson 22, students investigate open- and closed-loop systems. They build a circuit that contains a position indicator that activates a buzzer when it touches a wire. They use the buzzer's sound as feedback for determining how to move their hand along a wire assembly in such a way that the indicator does not touch the wire. To understand the importance of feedback in the decision making process, students vary the indicator's sensitivity and limit their feedback to auditory.

Lesson 23 focuses on feedback-control systems. Students build a thermostatically controlled system using a bimetallic strip as a sensor. They first investigate how the bimetallic strip responds when heated and then use the strip and a paper clip to make a heat-activated switch. They build a fan circuit in which the fan turns on when the bimetallic strip makes contact with the paper clip. The fan then cools the bimetallic strip, blowing cool air across it. The strip bends away from

the paper clip, which opens the circuit. The strip again heats up and the process repeats. This lesson challenges students to explain this system's behavior and to develop a meaning of an "automated" system.

Lesson 24 concludes the module. Students are given a set of design briefs that describe applications of electrical control systems. Student groups select one and design an electrical system to perform as described. This design challenge enables students to integrate what they have learned about electrical energy and circuit design in this module.

### Science Notebooks

Students should have a science notebook for recording their observations, data, conclusions, and answers to questions as well as their own ideas and thoughts as they progress through the inquiries in the module.

Students should use their science notebooks with the following module components:

- "Getting Started" and "Reflecting on What You've Done"—students should record written responses to the questions in both.
- Lessons Without Student Sheets—students should record data, observations, and conclusions for the inquiries in these lessons.
- Circuit Systems Kit Inventory List—students are responsible for maintaining an accurate inventory list of the materials in their circuit systems kit.
- Reading Selections—students may record their own ideas, thoughts, and reactions to what they have experienced or read in the readers.

Students should view their science notebook as a resource that they can use throughout the module. Reviewing observations, data, and

information will help them refine their understandings of key concepts and conceptual models. Teachers will find the science notebooks to be a valuable assessment tool in tracking student progress in both content knowledge and inquiry skills.

### Appendix D

Teachers will need to assemble devices used in Lessons 1, 2, 3, 6, and 20. Appendix D contains assembly instructions for these devices.

Because most are one-time assemblies that students in future classes can use repeatedly, the directions are located in an appendix rather than in the text of the Teacher's Guide.

Appendix D contains assembly instructions for the following devices:

- fan-motor assembly (Lessons 1, 6)
- motor-pulley assembly (Lesson 1)
- discharge wand (Lesson 2)
- electric plume (Lessons 2, 3)
- Styrofoam® pad (Lesson 2)
- water wheel (Lesson 6)
- electrical mystery boxes (Lesson 20)

Each device has a corresponding list of assembly materials, any assembly tools needed, and illustrations showing both an exploded view and an assembled view of the device.

It is best to assemble devices well in advance of their use so that you have time to familiarize yourself with their operation before students use them in the inquiries. You may wish to have one class of students assemble devices such as the fan-motor assembly or the electric plume. However, you should build devices such as the electrical mystery boxes yourself because students are required to determine the contents of the sealed boxes by applying what they have learned in this module.

## **Appendix E**

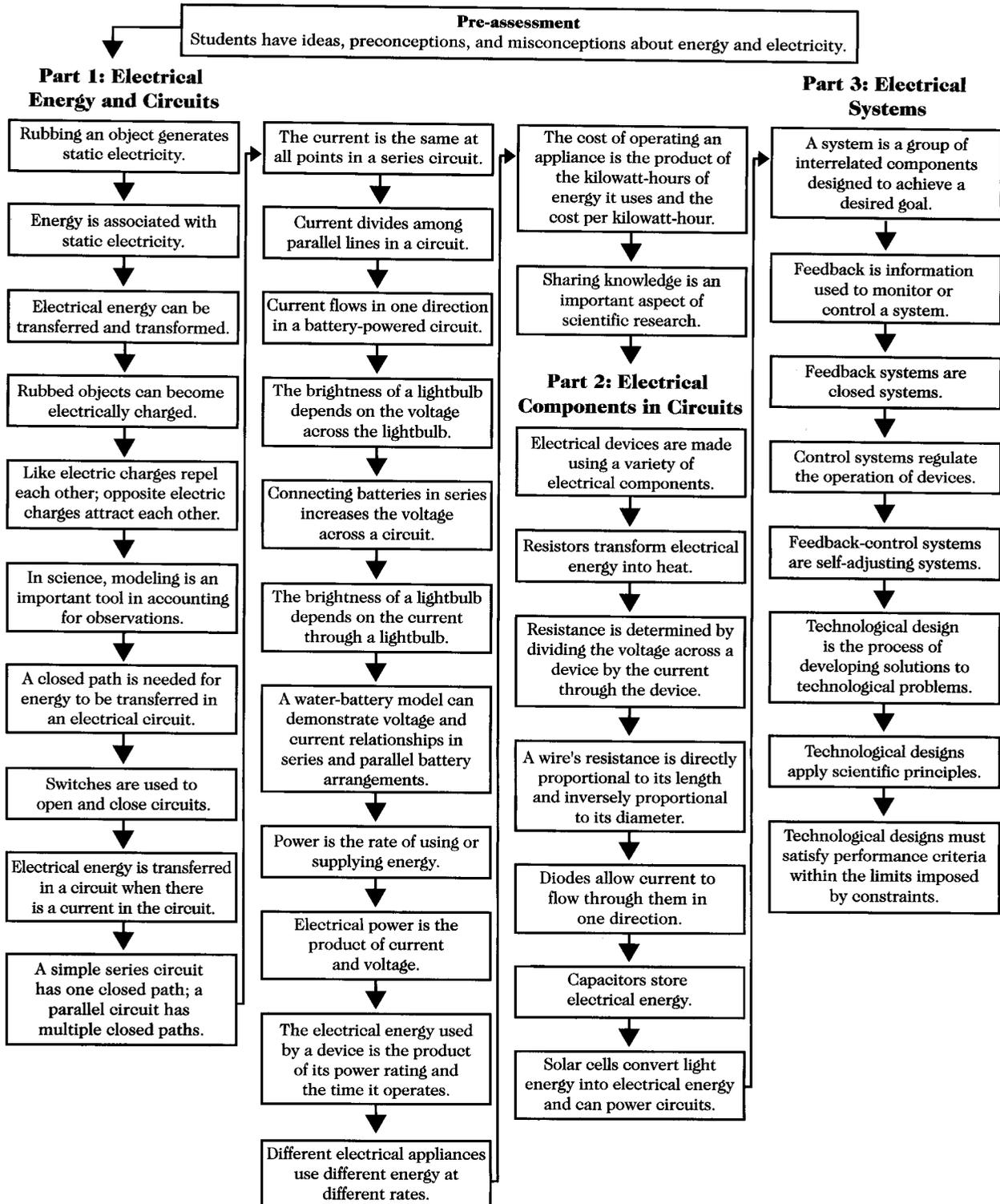
Appendix E contains the following two rubrics that you may use to assess students' experimental-design and graphing skills:

- Graphing Rubric
- Experimental Design Rubric

## **Glossary**

A glossary is included at the back of the Student Guide. It expresses scientific terms and concepts in a more formal language than students may initially use when they talk about or reflect on their observations in the inquiries. Before you introduce students to and have them use the more formal scientific terms, allow them to develop explanations and express their understanding in their own words.

## Conceptual Sequence for *Electrical Energy and Circuit Design*



## Module Structure

*Electrical Energy and Circuit Design* includes a Teacher's Guide, a Student Guide, and a master Materials List. Following are brief descriptions of the major components in the Teacher's Guide and in the Student Guide. The master list of materials for the module begins on page xli.

### TEACHER'S GUIDE

The Teacher's Guide for *Electrical Energy and Circuit Design* includes 24 lessons. Lessons may be taught in 45-minute class periods or in back-to-back periods to accommodate block scheduling. Block scheduling requires less time for materials management and allows more time for class discussion and work on the extensions. For lessons that are more than 45 minutes long, suggestions for appropriate breaking points are made.

The Teacher's Guide contains general information on teaching the module. It also includes information about the science concepts that apply to each lesson, materials and their management, assessments, homework assignments, and extension activities. It also contains information about the Anchor Activity, a major research project that students begin in Lesson 13 and continue to work on throughout the module.

The following components appear in each lesson of the Teacher's Guide:

#### Lesson Number and Title

#### Number of Inquiries and Periods in the Lesson

One period is assumed to be 45 minutes.

**Overview** A brief introduction that puts the lesson in context. It provides a link between the

current lesson and those that precede and follow it and outlines what students do in the lesson.

**Concepts** A list of the major concepts covered by the lesson. Many of the concepts are based on those in the National Science Education Standards.

**Student Objectives** A list of the things students are expected to accomplish in the lesson.

**Background** Detailed information relating to the content of the lesson. This section is intended to provide teachers who are unfamiliar with the lesson's content a foundation for answering student questions and facilitating inquiry. The Background section may also contain information about common student misconceptions that relate to the content of the lesson.

**Materials** A list of materials, presented under appropriate subheadings depending on the nature of the inquiry to be performed. The subheadings for lists of student materials include For Each Student, For Each Group, and For Each Group of 4 Students. Each materials list may also include a subsection entitled For the Teacher.

**Preparation** A list of steps explaining what the teacher must do prior to the lesson. Preparation may include photocopying student sheets, preparing transparencies or newsprint, collecting additional items of equipment not included in the kit, preparing solutions, assembling lab equipment, or setting up audiovisual equipment. It is assumed that the teacher will refill containers of chemicals and replace other consumables when necessary.

**Getting Started** A brief exercise or activity that introduces students to or provides the context for the lesson. In some cases, they first brainstorm what they already know about the topic. This encourages students to begin thinking about the topic of the lesson and allows the teacher to assess their pre-existing ideas.

**Inquiry Number and Title Lessons** may contain more than one inquiry. Each inquiry has its own number, title, and procedure.

**Procedure** A step-by-step guide for facilitating the inquiry. This section provides a carefully planned route through the lesson and complements the Procedure in the Student Guide.

**Reflections** A list of steps presenting guidance on how to provide closure for the lesson. Students may be asked to reflect on their inquiry results and discuss how the concepts encountered in the lesson can be applied to situations outside the classroom.

**Homework** Homework assignments that relate to either the current or the next lesson. Many of the assignments involve the reading selections that appear in the Student Guide. Additional homework can be assigned from the Extensions (see below).

**Extensions** Activities designed to extend students' experience of the topic into other fields of science and other content areas. These activities provide the opportunity for science teachers to collaborate with colleagues from other content areas to ensure a more integrated curriculum.

**Assessment** A section that suggests methods for assessing students for each lesson. Teachers may wish to assign point values in keeping with

their customary grading schemes. When a lesson itself is designed as an assessment, scoring rubrics are provided.

**Preparation (for a subsequent lesson)** Brief mention of preparation and/or materials needed for an upcoming inquiry when they must be prepared by the teacher in advance. It is suggested that teachers check materials requirements before each lesson is to be taught.

**Inquiry Masters** Reproducible sheets that include keys to the types of answers students may give in response to questions posed in an inquiry, transparency masters, suggested data tables and graphs, and scoring rubrics. These are generally for teacher use only. (See Appendix A for a complete list of inquiry masters.)

**Student Sheets** Reproducible worksheets that students use to record their ideas and interpret their data and to answer questions about the concepts covered in the inquiries. Student sheets may also be used for homework assignments, reviews, and assessments. Most lessons have at least one student sheet; some have several. Masters for these sheets appear at the end of each lesson in the Teacher's Guide. Teachers must photocopy sufficient quantities of them before each lesson. (See Appendix A for a complete list of student sheets.)

## STUDENT GUIDE

The Student Guide is intended to be used in conjunction with the Teacher's Guide. The components in the Student Guide complement those in the Teacher's Guide. For example, both guides contain lists of student objectives, but the wording may differ slightly between the two volumes, as appropriate for teachers and for students. The materials lists are less detailed in

the Student Guide than in the Teacher's Guide. Some sections are unique to each guide; for example, Homework and Extensions are not included in the Student Guide, while reading selections do not appear in the Teacher's Guide. The two volumes are designed to be complementary, and the teacher needs both guides to facilitate inquiry.

Each lesson in the Student Guide contains the following sections:

#### **Lesson Number and Title**

**Introduction** A brief section of text that places the concepts included in the lesson in context with those that have preceded it and with the students' own experiences. It may also provide a brief preview of the lesson. Some introductions include background information to draw students into the topic to be investigated.

**Objectives for This Lesson** A list that outlines what the students are expected to accomplish by the end of the lesson.

**Materials** A list that specifies the size of the group in which the students will be working as well as the materials they will require.

**Getting Started** A brief exercise or activity that introduces students to the topic of the lesson. It may include a brainstorming session on what students already know about the topic or a series of questions or experiences that form the basis for a brief group or class discussion.

#### **Number and Title of Inquiry**

**Procedure** Step-by-step instructions that students follow to complete an inquiry or to explore the concepts of a lesson more fully. This section often contains questions that students discuss in their groups.

**Reflecting on What You've Done** A closing section that provides students an opportunity to think about and discuss what they have learned in the lesson and to begin to apply what they have learned to new situations.

**Reading Selections** Readers—frequently accompanied by photographs and illustrations—that pertain to the content of the module or, more specifically, to that of a lesson. Most lessons in this module have one or more reading selections. A reading selection may provide background information that helps apply the concepts addressed in the lesson or it may introduce additional concepts from other areas of the National Science Education Standards. Most reading selections develop these concepts in the context of the world outside the laboratory. They are also intended to increase students' awareness of the history of science and technology.