Science & Technology Concepts

STC/MS™

for Middle Schools™

Energy, Machines, and Motion
Changes to the Teacher's Guide
and
Energy, Machines, and Motion
Changes to the Student Guide and Source Book

Since publication of the *Energy, Machines, and Motion* Teacher's Guide and the *Energy, Machines, and Motion* Student Guide and Source Book, data and instructions for batteries, washers, and motors in both books have been revised. In the Teacher's Guide, changes in data and instructions affect Lessons 7, 8, 9, and 16. In the Student Guide, data changes affect Lessons 8, 9, and 16. Please replace the pages in your texts with the revised pages provided.

This errata set includes the following:

- For the *Energy, Machines, and Motion* **Teacher's Guide** – revised pages 80, 83-84, 88, 90-93, 97, 100, 102-104, 106, and 187.
- For the *Energy, Machines, and Motion* **Student Guide** – revised pages 73, 77, 83, 85-86, and 151.

Photocopy and distribute these new instruction pages as needed.

If you have questions about these changes or about the module in general, call Carolina's product information staff at 800-227-1150 (8 am–5 pm ET, M–F), or email stcms@carolina.com.

CAROLINA

Carolina Biological Supply Company

800.334.5551 www.carolina.com

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4. Check the batteries with the voltmeter, as shown in Figure 7.4, to see that they are fully charged. The voltage of a NiMH battery should be 1.2 V.
5. Make sure all the washers at each station are identical.

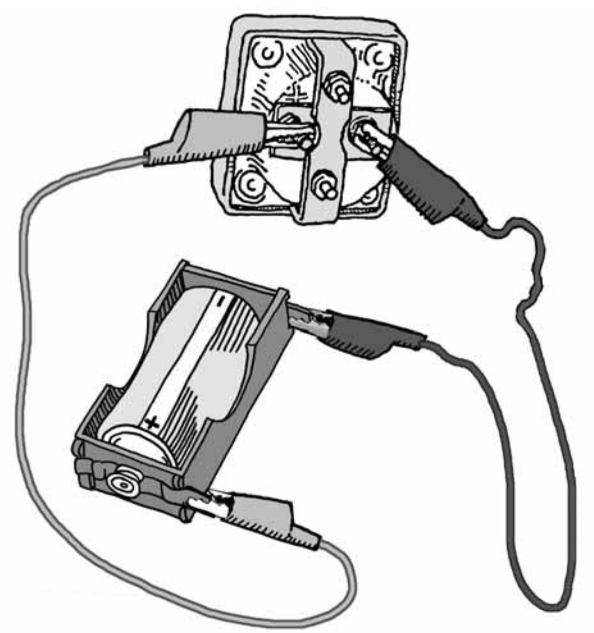

Figure 7.4 *A battery connected to a voltmeter*

Getting Started

1. Emphasize that the goal of this inquiry is to create a good experimental design and execute it.
2. Review the elements of good experimental design with the class.
3. Review the meaning of independent and dependent variables. Because students will have three independent variables to control in this activity, review with them how to keep one variable constant while changing the others.
4. Focus attention on the sample setup. Discuss each part of the apparatus and what it does.
5. Have students discuss with their lab partners the following questions:

   A. How many washers can the motor lift?

   B. Can you think of anything that would affect the motor's ability to lift the load of washers? If so, what is it?

6. Initiate a class discussion in which students share their answers to the questions in Step 5. Then have students summarize the ideas in their science notebooks.

Inquiry 7.1
Measuring the Force Exerted by a Motor

PROCEDURE FOR PERIOD 1

1. Ask students to predict what combination of motor, batteries, and string will enable the motor to lift the largest number of washers. Students will use the materials at their inquiry stations to answer this question. They need to present experimental evidence that justifies and demonstrates their answers.

2. Tell students that the goals for this part of the inquiry are to check the equipment to see how it works and to plan an investigation of the proposed question. In the next period, they will execute their plans.

3. Have students set up the pegboard assembly, which is depicted in Figure 7.1 in the Student Guide. You may also want to show them how to do the following:

A. Use the motor clamp to attach the motor to the pegboard.

B. Connect the knife switch in series with the battery and motor.

C. Use the knife switch to open and close the circuit.

2. Have students answer the following question in their science notebook:

What is the maximum force exerted by the motor? (The average maximum force exerted by the motor is around 3.0 N. There will be some variation in this value depending on the condition of the motors and batteries.)

HOMEWORK

Period 1
Have students write out procedures for their inquiry.

Period 2
Have students analyze their data and describe the arrangement that exerts the greatest force.

Period 3
Have students read "Motors—Getting Smaller Every Day," on SG pages 68–71, and write a paragraph in which they describe their thoughts and reactions about what they read.

EXTENSIONS

Science

1. If you have motors available besides those provided for this lesson, have students take the maximum load their motor lifted and try to lift the same load on a different motor. They can use their original battery-and-string setup with the second motor. If it cannot lift the entire load, have them find out how many washers it can lift by removing one washer at a time. If the motor does lift the load, have them add one washer until the motor can no longer lift the load. Ask students what they can conclude from this investigation.

Science

2. Have students use the spring scale to weigh the load lifted by the motor in this lesson. How does this measurement compare with the measurement they made of the motor's maximum force?

Science

3. Have students use a voltmeter to measure the voltage across the batteries when they are connected to the motor in series, and again when they are connected in parallel. What do they find?

Social Studies

4. Have students answer the following questions: Who made the first electric motor? When was it made? Where was it made? What was its function?

Technology

5. Have students investigate how a motor is made, how many different kinds of motors there are, and what the advantages of different motors are.

Art

6. Have students draw and label the parts of a motor and describe the purpose of each part.

Language Arts

7. Ask students to identify two or more motors at home or somewhere other than in the classroom. Have them write a paragraph describing these motors and what they do and why they are helpful. Students should describe the similarities and differences between the two motors and the similarities and differences between those and the motor used in class.

ASSESSMENT

The focus of this inquiry is experimental design. Use the list that follows as a guide. Check to see that students did the following things:

- identified variables
- controlled variables
- constructed an appropriate data table
- had data that fell within reasonable expectations
- appropriately displayed data
- logically interpreted data

Anticipated Outcomes

1. Students will find the following:
   A. Connecting additional batteries in parallel does not change the maximum number of washers the motor can lift.
   B. Adding batteries in series increases the number of washers the motor can lift.
   C. Connecting the string in different ways affects the motor's ability to lift a load. When the motor is connected to the nail, it can lift more washers than it can when it is connected to the pulley.
2. The arrangement that raises the most washers is three batteries in series with the string attached to the nail. This arrangement will lift about eight 30-g washers.
3. The force exerted by the motor for this arrangement is around 3.0 N. Values will vary with battery condition and motor variances. The exact value recorded by students is not critical, but values probably will be between 2.0 N and 4.0 N.

NOTE In an ideal experiment, all motors would yield the same results. However, because of variations in production, some small electric motors may be slightly stronger than others. For this reason, your actual values may differ from the anticipated outcomes.

4. Students should have produced a well-written report that shows the elements of good experimental design, including an appropriate conclusion.

PREPARATION FOR LESSON 8

Leave the pegboards, motors, and knife switches set up for use in Lesson 8.

conceptualize this abstraction, the student sheets lead them through the mathematical manipulations step by step. Students should focus on making correct measurements, using appropriate units, and relating the work calculation to the motor's operation.

Reading Selections

Three reading selections accompany this lesson in the Student Guide. "The Meaning of Work" introduces work and its calculation; you will want to discuss the concepts it presents with the class thoroughly. "Measuring Up" describes why standard units are important and explains that some metric units are named for famous scientists. Because "Measuring Up" is quite short, you may want students to read it in class. "Klamath Falls—A Real Hot Spot" describes how thermal energy within the earth is put to use. You may want to include this reader as part of the homework assignment.

NOTE If you have access to probeware, you may wish to have your class perform this lesson as described in *The Guide to Probeware and Computer Applications for STC/MS™*, available online at www.nsrconline.org.

MATERIALS FOR LESSON 8

For the teacher

K'NEX® parts for sled (refer to Inquiry Master 1.1: Directory of K'NEX® Parts):
- 1 orange connector (C3)
- 14 red connectors (C4)
- 8 yellow connectors (C10)
- 8 green rods, 1.5 cm (R1)
- 4 white rods, 3.25 cm (R2)
- 3 blue rods, 5.5 cm (R3)
- 4 red rods, 13.0 cm (R6)

1 voltmeter
1 pair of scissors*

*Needed, but not supplied

For each student

Completed copy of Student Sheet 6.1: What a Drag!
1 copy of Student Sheet 8.1a: How Much Work Was Done?
1 copy of Student Sheet 8.1b: Thinking About Work and Force (optional)
1 copy of Student Sheet 8.2: Lifting a Load

For each group of 4 students

1 electric motor with wire leads and alligator clips
1 motor pulley with nail
1 motor clamp
1 knife switch
1 pegboard assembly
3 machine screws with wing nuts
3 batteries, dry cell rechargeable, D-cell
3 battery holders, D-cell
5 insulated connector wires with alligator clips
1 paper clip (large)
1 piece of string, 1 m
1 piece of masking tape, 5 cm
14 washers (large), 30 g
1 spring scale, 0 to 10 N
1 meterstick

K'NEX® parts for sled:
- 1 orange connector (C3)
- 14 red connectors (C4)
- 8 yellow connectors (C10)
- 8 green rods, 1.5 cm (R1)
- 4 white rods, 3.25 cm (R2)
- 3 blue rods, 5.5 cm (R3)
- 4 red rods, 13.0 cm (R6)

PREPARATION

1. For each student, make a copy of Student Sheet 8.1a: How Much Work Was Done? and Student Sheet 8.2: Lifting a Load. If you wish, make copies of Student Sheet 8.1b: Thinking About Work and Force, which is optional.
2. Make sure the batteries are fully charged. NiMH batteries should each have a voltage of 1.2 V.

Inquiry 8.2
Measuring the Work To Lift a Load

PROCEDURE

1. Have students work in groups of four. Have them connect the motor to three batteries in series, as shown in TG Figure 8.2 (SG Figure 8.1). A sample setup will help them remember how to put the board together.

2. Make sure the string and paper clip are attached so the load rises 10.0 cm, as marked by the tape on the pegboard (see Figure 8.2).

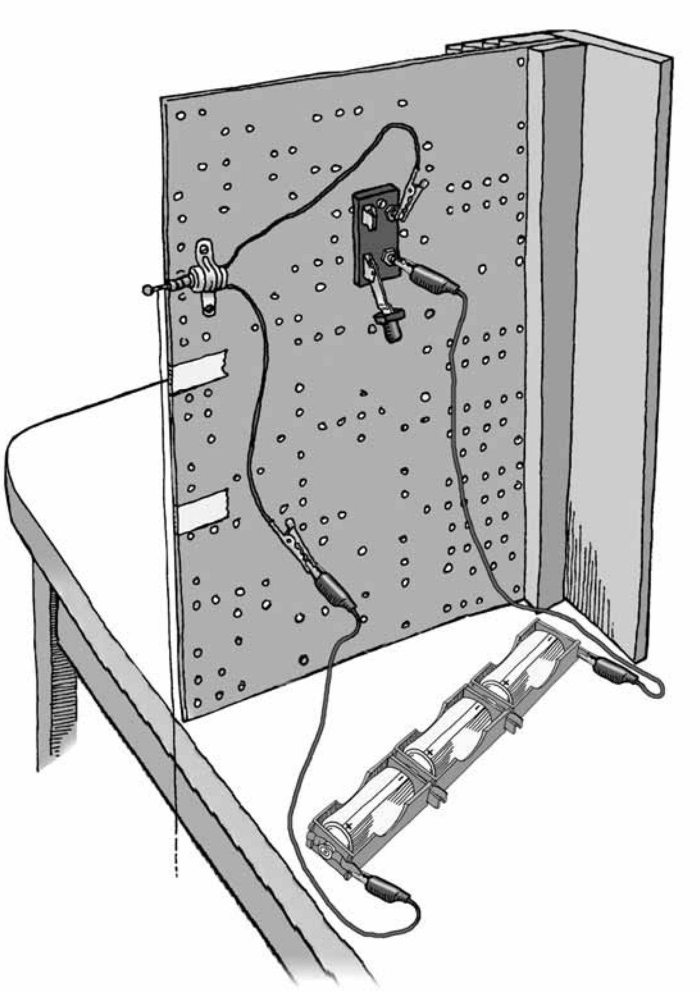

Figure 8.2 *Setup for Lesson 8*

3. When students use their spring scales to measure the weight (in newtons) of the six washers, remind them to make sure the scale is calibrated to read zero and to read the scale carefully. The weight is the force the motor must exert to lift the six washers. Students should record this force on Student Sheet 8.2.

4. Have students use the measurements of the washers' weight and the distance they were lifted to calculate how much work it took to lift them. Remind students that Student Sheet 8.2 guides them through the calculations. Make sure they include units of measure and that they remember to change 10.0 cm to 0.10 m.

5. Students should compare the work the motor can do with the work needed to raise the six washers. They will see that the motor can lift the load. Because the force of the motor is greater than the weight of the washers, the motor can lift the load and do the work to lift the washers.

6. Have students build a sled using K'NEX® parts and 14 washers, as shown in SG Figures 8.2 through 8.5. The assembled sled is shown in TG Figure 8.3. Have students label or tag their sled; they will use it again when they investigate simple machines in Lessons 11 through 16.

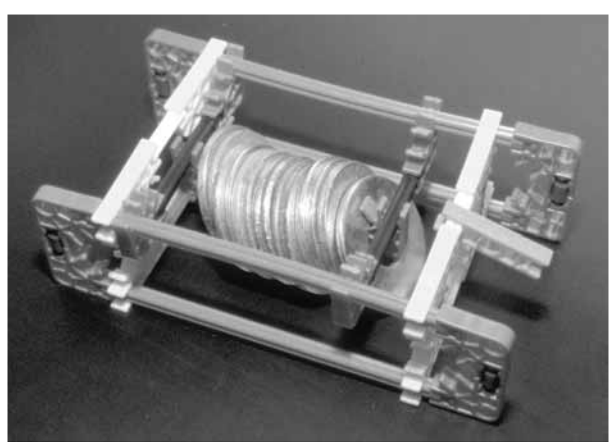

Figure 8.3 *Assembled K'NEX® sled*

7. After building the sled, students should estimate its weight. Students get a hint in the Student Guide to help them estimate the sled's weight. Many students are not comfortable making estimates or predictions. Stress that the estimate does not have to be exact; a reasonable estimate is acceptable. Some students will need help making the estimate. Help guide them through the thought process. The sled with washers weighs about 5.0 N.

8. Have students try to lift the sled using the motor. They should record their observations about their attempt in their science notebooks. They will not be able to lift the sled with this arrangement of motor, batteries, and string. This sets the stage for investigating simple machines—devices that enable the motor to lift the load.

NOTE If your students find they can lift the sled using the motor, then have them add washers to the sled one at a time until they determine the number of washers the motor cannot lift.

9. When all students have finished this inquiry, have them complete "Reflecting on What You've Done." Invite them to share their results and observations during a class discussion. Make sure the discussion focuses on these ideas:

A. How much force is required to lift the sled?

B. How much force can the motor exert?

REFLECTIONS

Have students discuss the following questions with their lab partner, and invite them to share their results and observations during a class discussion.

A. Look at your table on Student Sheet 8.1a. Why do you think different amounts of work were done as you pulled the block across different surfaces? (Students find that the work it takes to move a block across different surfaces differs because they applied different effort forces to pull the block. For each surface, the block was pulled the same distance, but because the effort force varied with each surface, the product (Fd) varied. Make sure students do not equate work with force. The effort force, not the work done by the effort force, counterbalanced the frictional force. Both effort force and friction did work on the block. Friction did the same amount of work as the effort force, but it worked against the motion and prevented the block from speeding up as it was pulled.)

B. In Inquiry 8.2, when you tried to lift the sled with the motor, what happened? (When the sled was attached to the motor, the motor did not lift the sled.)

C. How much work did the motor do on the sled? (Although the motor exerted a force, no work was done because the load did not move. If the motor had been left running, the energy that went into the motor to do the work of lifting would have become heat and could have burned out the motor. That is what happens when a motor is overloaded.)

D. Compare the maximum force of the motor with the weight of the sled. Explain why the motor could not do the work it takes to lift the sled. (The maximum force of the motor is about 3.0 N, and the weight of the sled is about 5.0 N. The gravitational force is greater than the force of the motor, so the motor could not lift the sled.)

E. Since the motor cannot exert a greater force, think of ways to get the motor to do the work to lift the sled. List your ideas. (Students will have a variety of ideas. Accept all ideas. In Lessons 11 through 13, students will investigate simple machines. They will later use these machines with the motor to lift the sled.)

HOMEWORK

Period 1

If you plan to use optional Student Sheet 8.1b: Thinking About Work and Force, have students complete it. This student sheet reviews and reinforces how to calculate work and prepares students for Inquiry 8.2.

Period 2

Have students read "Klamath Falls—A Real Hot Spot," on SG pages 80–81.

EXTENSIONS

Language Arts

1. Have students write a paragraph describing the hardest work they have ever done. What did they do? How long did it take? What kinds of forces were involved? Is there anything they could have done to make it easier to do the work? Was this work as defined by science? You may want students to share their paragraphs with the class.

Mathematics

2. Use the graph in Inquiry 5.2 (force of gravity versus mass) to have students estimate the weight of the sled. Explain that to do this, they must extrapolate the graph to just beyond 14 washers because the sled has mass, too. Then they should compare the estimate with the weight measured on the spring scale.

Science

3. Have students investigate the work done by friction. In Inquiry 8.1, students calculated the work done in Inquiry 6.1 when they pulled a block across the different surfaces. The effort they exerted was not the only force acting on the block. Friction also acts on the block as it is pulled, and friction does work, too. Have students examine the data on Student Sheet 8.1a and ask them how those data would differ if, instead of the effort force, the force of friction were used for the calculations. Because the effort force is equal to and opposite the force of friction, the friction force is the same size as the effort force. That means it does the same amount of work. But the work done by friction is negative, because it opposes the motion; friction works against the motion.

Technological Design

4. Have students write a paragraph on the design of exercise equipment. They should include a discussion of how designers use the principle of force and distance to maximize the work someone does when he or she exercises. How is the equipment designed to control the effort force? How is the equipment designed to control the effort distance? What is the effect of the work done when someone exercises?

Table 8.1 Sample Data for Inquiry 8.1

Surface	Effort Force (N)	Effort Distance (m)	Work Done (N-m)
Tabletop	0.52	0.27	0.14
Waxed paper	0.60	0.27	0.16
Paper towel	0.80	0.27	0.22
Fine sandpaper	1.90	0.27	0.51
Coarse sandpaper	1.80	0.27	0.49

ASSESSMENT

This assessment should focus on the following points:

- Students identified the conditions necessary to do work on an object.
- Students used correct units of measure in recording force and distance.
- Students recorded work units in newton-meters.
- Students' mathematical calculations were correct.
- Students built the sled correctly.
- Students worked effectively as team members.
- Students' homework assignment was complete and correct.

Anticipated Outcomes

1. The introductory exercises and the homework give students a chance to master identifying and manipulating force and distance information to calculate work.
2. Sample data and rubrics for Student Sheet 8.1a and Student Sheet 8.2 follow. Do not worry about small differences in values between groups in the data for Table 8.1 and for the Student Sheet 8.2 rubric. Variations in motors and batteries may affect results. Assess for correct processing of information and for logical conclusions.

NOTE In an ideal experiment, all motors would yield the same results. However, because of variations in production, some small electric motors may be slightly stronger than others. For this reason, your actual values may differ from the anticipated outcomes.

Sample Data for Student Sheet 8.2: Lifting a Load

1. Motor force with three batteries in series: 3.0 N

2. Work done by motor when it lifts a load 10.0 cm (0.10 m):

Work = 3.0 N × 0.10 m = 0.30 N-m

3. Weight of six washers: 1.8 N

4. Work to raise six washers 10.0 cm (0.10 m):

Work = 1.8 N × 0.10 m = 0.18 N-m

5. Your estimate of the sled's weight: Student responses vary

6. Sled's actual weight: about 5.0 N

7. Work to lift sled 10.0 cm (0.10 m):

Work = 5.0 N × 0.10 m = 0.50 N-m

Name: ______________________________

Class: ____________ Date: ______________

Student Sheet 8.2
Lifting a Load

Directions Answer the questions as directed in the Procedure for Inquiry 8.2.

1. Motor force with three batteries in series: ______________________

2. Work done by a motor when it lifts a load 10.0 cm (0.10 m)

   Work = ________________ × ____________ = ___________

3. Weight of six washers: ______________

4. Work to raise six washers 10.0 cm (0.10 m):

   Work = ________________ × ____________ = ___________

5. Your estimate of the sled's weight:

6. Sled's actual weight:

7. Work to lift sled 10.0 cm (0.10 m):

   Work = ________________ × ____________ = ___________

of the motor, graph the data, and complete "Reflecting on What You've Done." This should allow time for a comprehensive discussion of the energy changes and power relationships demonstrated in the lab. There are no student sheets provided in this lesson. By this time, students should be able to record data and construct graphs on their own.

Work, Energy, and Power

Whenever work is performed, energy is converted from one form to another. For example, during the investigations in Lesson 3, electrical forces transformed chemical energy in the battery to heat and light in the lightbulb. In Lesson 6, the force of friction worked to transform kinetic energy (energy of motion) to heat energy in the surfaces over which students pulled wooden blocks. An energetic object has the ability to transform its energy to other forms, which means it has the ability to do work. **Energy,** then, is defined as the ability to do work. **Power** is a measure of the rate at which work is done or at which energy transformations take place. The Student Guide defines power in terms of work done: Power is the rate of doing work.

To calculate power, the work done is divided by the time it takes to do the work.

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

The unit of power is the watt (W); 1 W is defined as 1 joule (J) of work per second.

$$1 \text{ watt (W)} = \frac{1 \text{ joule (J)}}{1 \text{ second (s)}} = \frac{1 \text{ newton-meter (N-m)}}{1 \text{ second (s)}}$$

Use the newton-meter as the work unit; this will reinforce the approach used in Lesson 8. But if you feel that students have mastered the work concept, you may prefer that they use the joule as the work unit for power calculations.

The kilowatt (kW) is another unit of power (1 kW = 1000 W). Scientists and engineers use the kW for very powerful devices. Electric companies use this unit to calculate kilowatt-hours, a unit that measures electric energy. Horsepower (hp), another power unit, is used primarily to describe the power of automobiles, motors, and heavy equipment; 1 hp = 750 W.

Measuring Power

In Inquiry 9.1, students calculate the work required to lift a load of three washers a given distance. In the first trial, they connect one battery to the motor and measure the time it takes to lift the load. In each subsequent trial, students add a battery to the motor in series with the first battery. Because a standard distance and load are used for each trial, the work done to lift the load is the same for all trials. This difference in the power provided by each battery arrangement is represented as a progressive decrease in the time it takes the motor to lift the load. Decreased time indicates increased power. Students measure the time and then calculate the power output for each trial. They then graph the results.

When the motor lifts a load to a certain height, the work it performs transforms chemical energy in the battery into other forms of energy. One form is gravitational potential energy, which is the energy the load gains when lifted. The gain in gravitational potential energy is the work done to raise the load a given distance. The other forms of energy are the electrical energy in the circuit, the heat energy in the motor, and the kinetic energy in the moving load.

It is difficult to measure all these forms of energy. Therefore, to determine the relationship of the power of the motor to the number of batteries, students measure only the gain in gravitational potential energy. The average power of the motor as calculated by students is less than the actual power of the motor, because students are measuring only one form of energy. Nonetheless, this method of determining the average power of the motor produces data that reveal the relationship of the power of the motor to the number of batteries in series.

the time it takes the motor to lift the maximum loads for the battery combinations they used in Lesson 7. Then have them use their calculations of the work done for each lift and the time to lift the load to calculate the power of the motor.

NOTE If you have access to probeware, you may wish to have your class perform this lesson as described in *The Guide to Probeware and Computer Applications for STC/MS™*, available online at www.nsrconline.org.

MATERIALS FOR LESSON 9

For the teacher

Voltmeter
Graph paper*
1 pair of scissors*

For each pair of students

1 pegboard assembly
3 washers (large), 30 g
1 electric motor with wire leads and alligator clips
1 motor pulley with nail
1 motor clamp
3 machine screws with wing nuts
3 batteries, dry cell rechargeable, D-cell
3 battery holders, D-cell
1 knife switch
5 insulated connector wires with alligator clips
1 paper clip (large)
1 piece of string, 1.5 m
1 meterstick
1 spring scale, 0 to 2.5 N
1 piece of masking tape, 2 cm
1 student timer

*Needed, but not supplied

PREPARATION

1. Check the batteries with a voltmeter to make sure they have a voltage of about 1.2 V.
2. Check the wire leads on the motors.
3. Set up a sample pegboard.

Getting Started

1. Have students read “Work, Energy, and Power” (SG page 84) and answer the questions A, B, and C in Step 1 of “Getting Started” in the Student Guide.
2. Discuss students’ answers to the questions. Then perform a few practice calculations at the board to review the math. Following are two practice calculations. Have students write these examples in their science notebooks to use as references.

   A. A girl pushes at a steady pace with a force of 8.0 N on a box. She moves the box 3.0 m in 5.0 s. What is her power output?

   Work = 8.0 N × 3.0 m = 24.0 N-m
   Power = Work/time = 24.0 N-m/5.0 s = 4.8 W

   B. A motor steadily lifts a load that weighs 5.0 N a distance of 1.5 m in 2.0 s. What is the power output of the motor?

   Work = 5.0 N × 1.5 m = 7.5 N-m
   Power = 7.5 N-m/2.0 s = 3.75 W

NOTE In these calculations, students compute work before computing power. This reinforces the logical two-step process that they will follow during Inquiry 9.1. During that activity, students will calculate the work needed to lift the load and then use their time measurements to calculate the power of the lift.

3. With the class, discuss factors that could affect the time it takes a motor to lift a load.

Inquiry 9.1
Measuring Power

PROCEDURE

1. Have students work with their partners to assemble the motor and knife switch on the pegboard.

2. Inform students that they will first measure the time it takes the motor, with one battery, to raise the washers to the tabletop three separate times and determine the average lift time. Later they will use the average time to calculate power. Make sure students design a data table with columns for three time measurements and an average time for each of the three battery arrangements.

3. Students may need to conduct a few practice trials with the student timer to become comfortable with its operation. Explain the start-stop and reset sequence. Remind students to press firmly on the start-stop button to control the timer and to aim for consistency in timing (although no timing will be exact). Erroneous timings usually come from start-stop errors; students should repeat, not record, such timings.

4. Check first-trial timings to make sure students know how to use the student timers, and check average times to make sure students calculate them correctly.

5. Have students and their partners predict the effect of adding a second battery to the motor. They should write this prediction and a reason for it in their notebooks. For example, a student might write, "I think the time to lift the load will be half as much with two batteries, because with two batteries the motors can do twice as much work in the same time or the same work in half the time." Have students add a second battery and measure how long it takes the motor to lift the washers. Have students record results and their comments in their data tables.

6. Students should repeat the timing process with three batteries in series and record the results in their data tables.

7. Students should use graph paper to graph the average time versus the number of batteries in series. Remind them to draw a smooth curve through the data points. Review good graphing techniques with students, if necessary.

8. Remind students to make sure the spring scales register zero when held vertically with nothing attached. If necessary, adjust the scales. Have students measure the weight of the three washers and the distance the washers are lifted.

NOTE Students should measure the distance from the washers on the bottom of the string to the tabletop.

9. Have students write the work calculation in their notebooks. Make sure they understand that the same work is done each time the motor lifts the washers through this distance.

10. Have students use the following equation to calculate the power provided by the motor with one, two, and three batteries connected in series:

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

11. Students will need to make a data table with columns for power and number of batteries and record these values and their power calculations. Let students decide how to graph these data. Tell them you will check for good techniques and proper plotting.

12. Students should complete the questions in "Reflecting on What You've Done" and discuss their answers with the class.

REFLECTIONS

Have students complete the following questions and discuss their answers with the class.

A. Did the amount of work done each time by the motor to lift the load depend on the number of batteries used in the circuit? Why or why not? (The amount of work done in the lift alone is the same each time; it is independent of the number of batteries connected to the motor. The motor lifts the same weight the same distance each time. The work [force × distance] to lift the washers is the same each time.)

B. Suppose you made a graph of the work it takes to lift the washers versus the number of batteries. Describe what that graph would look like or draw a picture of such a graph. (The graph of work versus number of batteries is a horizontal line, indicating the same amount of work for all battery connections.)

C. What changed as you added more batteries? (As students add more batteries, the force exerted by the motor changes, the time to lift the washers changes, and the speed of the rising washers changes.)

D. Look at your graph of "Average time to lift" versus "Number of batteries." Is the time needed to lift the washers related to the number of batteries added in series? How? (The time to lift the washers depends on the number of batteries in series. As students add more batteries in series, the time it takes the motor to lift the load decreases. Sample data are included in the Assessment section.)

E. Look at your graph of "Power" versus "Number of batteries." Does the power to lift the washers depend on the number of batteries in series? How? (The power of the lift does depend on the number of batteries in series. As students add more batteries, the motor has more power because the work is the same and the time it takes to lift the load decreases. Sample data are included in the Assessment section.)

F. Suppose you need to lift a larger load. What can you do to make the motor produce more power? (Adding more batteries will make the motor more powerful. Adding too many batteries may cause heating effects that can burn out the motor.)

G. The batteries supplied energy for the motor circuit. Did the motor use all the energy supplied by the battery to lift the load? If not, what other forms does the battery's energy become? (Some of the energy supplied by the battery is converted to heat due to internal friction in the motor. The work calculated by students is the work it takes to lift the load. More energy is supplied than is needed for the job, so the rest of the energy supplied by the battery becomes kinetic energy in the motion of the washers. A detailed discussion of the energy transformations is presented in the Background section of this lesson.)

- Power calculation is correct.
- Graphs demonstrate good graphing techniques (that is, the graph is titled, axes are labeled, and points are connected by a smooth curve).
- Points are plotted correctly on the graph.
- Information is interpreted correctly.
- Students demonstrate effective teamwork skills.

Sample data for this inquiry are presented in Tables 9.1 and 9.2; for graphs of these data, see Figures 9.1 and 9.2, respectively.

Timing values that students record and work values they calculate in lifting the load will depend on the height through which they lift the washers. However, the graphs students plot should show a similar pattern to these graphs.

Table 9.1 Number of Batteries and Time To Lift the Load

Number of Batteries	Time 1 (s)	Time 2 (s)	Time 3 (s)	Average Time (s)
1	7.00	7.44	7.38	7.27
2	2.34	2.53	2.72	2.53
3	0.69	0.59	0.75	0.68

Time To Lift Versus Number of Batteries

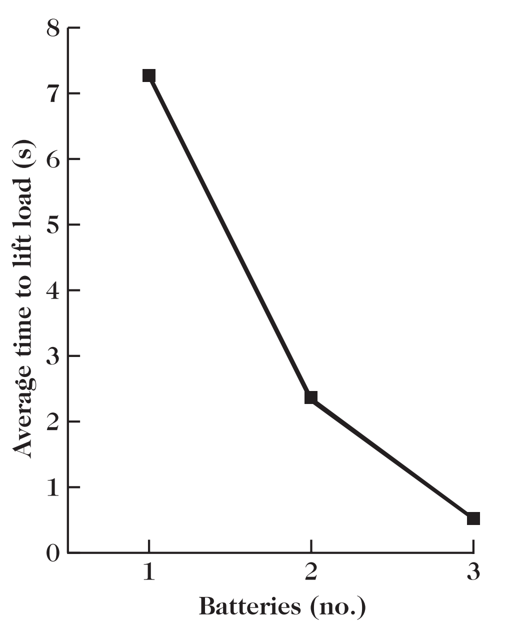

Figure 9.1 *Time to lift versus number of batteries*

NOTE The data shown here were obtained by lifting 3 washers (weight = 0.90 N) a height of 0.41 m.

Sample calculation:

Work = weight x distance = 0.9 N x 0.41 m = 0.37 N-m

Power = work/time = 0.37 N-m / 2.53 s = 0.14 W

Table 9.2 Number of Batteries and Power of the Motor

Number of Batteries	Power (W)
1	0.05
2	0.14
3	0.54

Power Versus Number of Batteries

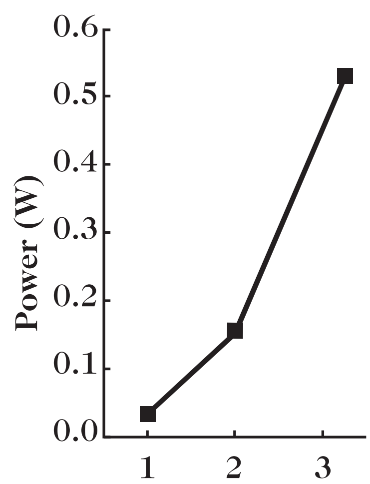

Figure 9.2 *Power versus number of batteries*

PREPARATION FOR LESSON 10

Leave the pegboard and motors set up so students can use them during the assessment in Lesson 10, but remove the batteries from the setup. Check to confirm that you have enough working lightbulbs.

In designing their machine-and-motor solution, students should think about the mechanical advantage needed to lift the load. They should refer to data from Lessons 7 and 8 to determine the actual mechanical advantage needed to lift the sled. The actual mechanical advantage is the load force divided by the effort force. The load force is the weight of the K'NEX® sled, which is about 5.0 N. (Some students may remember this weight from previous experiments; others may choose to weigh the sled again with a spring scale.) The effort force is the maximum force that the motor can exert, which is about 3.0 N.

NOTE The maximum force of the motor depends on the condition of the motor and batteries.

The actual mechanical advantage needed to lift the sled then is 5.0/3.0 N, or an actual mechanical advantage of 1.7. Since the actual mechanical advantage is always less than or equal to the ideal, this puts a lower limit on the value for the ideal mechanical advantage (the ratio of effort distance to load distance.) Using these values, one concludes that the ideal mechanical advantage should be a number greater than 1.7. Students should refer to data from Lessons 11, 12, 13, and 14 to design motor/machine system with the ideal mechanical advantage of 2, which should be sufficient to lift the load.

Reading Selections

This lesson has four reading selections. The short reader "Science and Technology" describes the differences between scientific research and technological design. Students are asked to return to this topic after they have completed their own technological design and to discuss their experiences with the class. "Technology—It's Not Just Computers" explains the technological design process. "Linking a Country to a Continent" describes a major technological design challenge: the construction of the tunnel under the English Channel to link England to France and the rest of Europe. "Report to the Pharaoh" is an imaginative description, in memorandum form, of the challenges associated with building a pyramid in ancient Egypt.

MATERIALS FOR LESSON 16

For the teacher

1 copy of Inquiry Master 16.1: Scoring Rubric for Technological Design Challenge
1 voltmeter
1 pair of scissors*

For each student

Completed copy of Student Sheet 11.1: Forces on a Cart on the Inclined Plane
Completed copy of Student Sheet 12.1: How Is a Pulley System Used To Do Work?
Completed copy of Student Sheet 13.2: Lifting Loads With a Lever (optional)
Completed copy of Student Sheet 14.1: The Mechanical Advantage of Machines
1 copy of Inquiry Master 16.1: Scoring Rubric for the Technological Design Challenge
1 copy of Student Sheet 16.1a: Planning Our Solution to the Technological Design Challenge
1 copy of Student Sheet 16.1b: Evaluating Our Solution to the Technological Design Challenge

For each group of 4 students

1 assembled K'NEX® sled (from Lesson 13)
1 pegboard assembly
1 knife switch
1 motor clamp
1 electric motor with wire leads and alligator clips
1 motor pulley with nail
3 paper clips (large)
3 batteries, dry cell rechargeable, D-cell
3 battery holders, D-cell
3 insulated connector wires with alligator clips, black
3 insulated connector wires with alligator clips, red
1 spring scale, 0 to 2.5 N
1 spring scale, 0 to 10 N
3 machine screws with wing nuts
1 piece of masking tape, 20 cm

*Needed, but not supplied

In Lessons 5, 6, and 7, you studied four different forces and learned something about how each force behaves. Those forces have different properties, but they also have something in common—they can all do work. In this lesson, you will learn how forces do work and how to calculate the amount of work being done. You will calculate the work done by three of the forces you studied—gravity, motors, and friction.

Getting Started

1. In your group, discuss the meaning of the word "work." List examples of work being done. Share examples with the class.

2. Read "The Meaning of Work" in this lesson. When you finish, review the examples of work you listed earlier. Do your examples match the scientific meaning of work? Discuss this with the class.

3. With the class, review how to calculate a value for work and explain the units of measure for work.

4. Work out this problem: Alice pulls a sled with a force of 12 N. She pulls the sled through a distance of 5 m. How much work does Alice do on the sled? In your notebook, write down your calculation and check your answer. Keep this sample as a reference for when it is time to calculate work.

MATERIALS FOR LESSON 8

For you

- Your completed copy of Student Sheet 6.1: What a Drag!
- 1 copy of Student Sheet 8.1a: How Much Work Was Done?
- 1 copy of Student Sheet 8.2: Lifting a Load

For your group

- 1 electric motor with wire leads and alligator clips
- 1 motor pulley with nail
- 1 motor clamp
- 1 knife switch
- 1 pegboard assembly
- 3 machine screws with wing nuts
- 3 D-cell batteries
- 3 D-cell battery holders
- 5 insulated connector wires with alligator clips
- 1 large paper clip
- 1 piece of string
- 1 piece of masking tape
- 14 large washers, 30 g
- 1 0- to 10-N spring scale
- 1 meterstick
- K'NEX® parts for sled (see Appendix A: Directory of K'NEX® Parts):
  - 1 orange connector (C3)
  - 14 red connectors (C4)
  - 8 yellow connectors (C10)
  - 8 green rods (R1)
  - 4 white rods (R2)
  - 3 blue rods (R3)
  - 4 red rods (R6)

3. Use what you learned in Lesson 7 to attach the string to the motor so the motor exerts the greatest force on the washers. Attach a paper clip to the string so the bottom of the string is below the 10-cm piece of tape, as shown in Figure 8.1.

4. In Lesson 7, you measured how much force the motor exerts when it is connected to three batteries arranged in series. Record that force on Student Sheet 8.2 at Step 1.

5. Use the force the motor exerts to calculate how much work the motor does when it raises a load 10 cm (0.10 m). Record your calculation on Student Sheet 8.2 at Step 2.

6. Put six washers on the paper clip.

7. Close the switch and run the motor. Does the motor lift the washers? If not, remove a washer and try again. Keep removing washers one at a time until the motor can lift the remaining washers.

8. How much work did the motor have to do to lift the washers 10 cm? To answer that question, use a spring scale to weigh the washers. Record the weight on Student Sheet 8.2 at Step 3. Then multiply the weight by the distance (0.10 m) to get the work done in lifting the washers. Show your work on Student Sheet 8.2 at Step 4.

9. You have calculated work in two ways. One way was using the force of the motor. The other way was using the weight of the washers. How do the two values for work compare? Record your answer in your science notebook.

10. Now build your sled using K'NEX® parts and 14 washers. Follow Figures 8.3 through 8.5 to assemble the sled. The finished sled will look like the one shown in Figure 8.2.

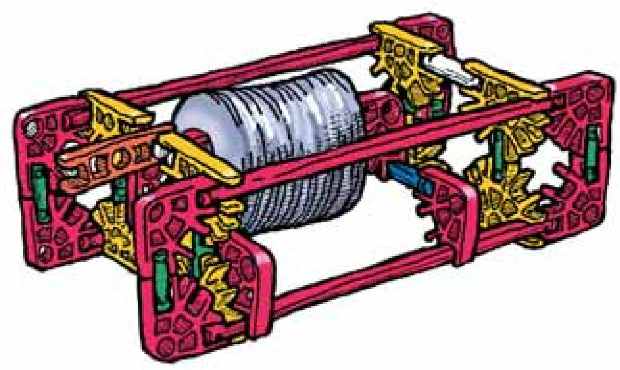

Figure 8.2 *The assembled sled*

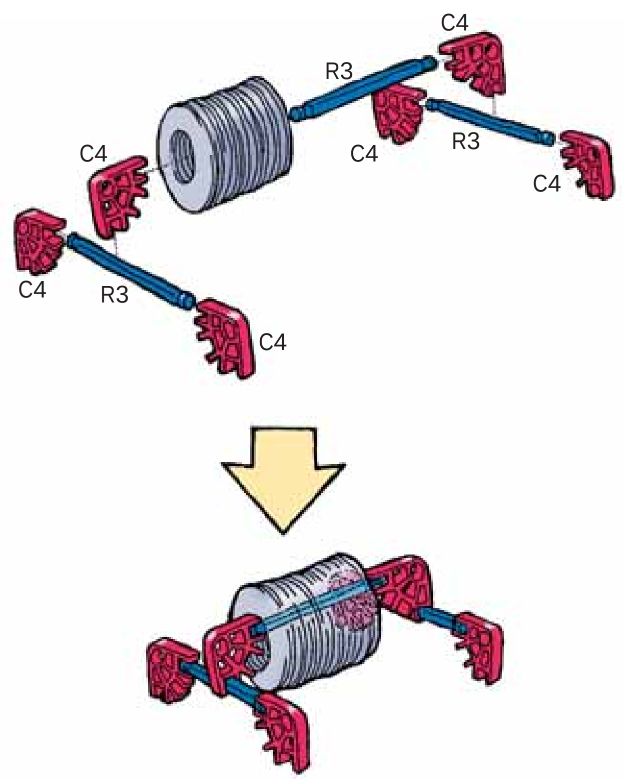

Figure 8.3 *How to assemble the washer seat for K'NEX® sled*

Getting Started

1. If you have not already done so, read "Work, Energy, and Power" on page 84. Then answer the following questions in your science notebook:

A. How are work and energy related?

B. How do you calculate power?

C. What are the most commonly used units of measure for power?

2. Before you start this inquiry, you need to practice calculating power. Two situations are described here. For each, calculate the power output. Practice these calculations on your own, writing them in your science notebook. You may want to use them later to help with calculations for this lab.

A. A girl pushes at a steady pace with a force of 8.0 N on a box. She moves the box 3.0 m in 5.0 s. What is her power output?

B. A motor steadily lifts a load that weighs 5.0 N a distance of 1.5 m in 2.0 s. What is the power output of the motor?

3. What factors might affect the time it takes a motor to lift a load? Discuss your ideas with the class.

MATERIALS FOR LESSON 9

For you and your lab partner

- 1 pegboard assembly
- 3 large washers
- 1 electric motor with wire leads and alligator clips
- 1 motor pulley with nail
- 1 motor clamp
- 3 machine screws and wing nuts
- 3 D-cell batteries
- 3 D-cell battery holders
- 1 knife switch
- 5 insulated connector wires with alligator clips
- 1 large paper clip
- 1 piece of string
- 1 meterstick
- 1 0- to 2.5-N spring scale
- 1 piece of masking tape
- 1 student timer

Inquiry 9.1
Measuring Power

PROCEDURE

1. Set up the pegboard assembly as shown in Figure 9.1. Include each of the following steps:

A. Make sure the string is long enough to reach from the motor to the floor.

B. Tie one end of the string to the nail on the motor shaft. Put a small piece of tape over the string where it is tied to the nail to keep the string from slipping when lifting the load.

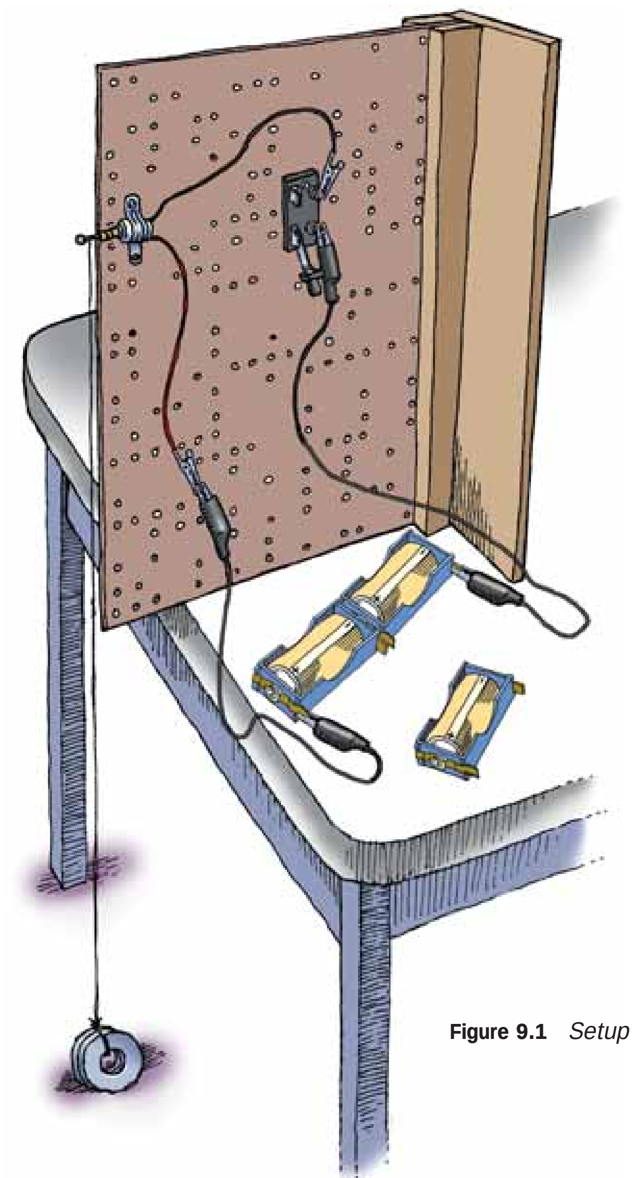

Figure 9.1 *Setup for Inquiry 9.1*

C. Attach three washers to a paper clip at the free end of the string, so that the hanging washers just touch the floor.

2. You will measure and record the time it takes the motor to lift three washers when one battery is connected, and then when two batteries and three batteries are connected in series. Before you begin, design a data table in your science notebook with columns for three time measurements and an average time for each of the three battery arrangements.

3. Connect one battery to the motor. Close the switch. Record how many seconds it takes the motor to lift three washers to the tabletop. Lower the washers until they just touch the floor. Raise the washers again and record the time. Repeat this for a total of three measurements.

4. Record the three time measurements in your data table. Calculate and record the average time of the three trials.

5. Discuss the following questions with your partner and record the answers in your notebook:

A. What effect would adding a second battery in series have on the time it takes the motor to lift the washers?

B. Why do you think this will happen?

6. Now try it. Measure and record the time it takes to lift the washers to the tabletop. As before, record the time measurements in your data table and then calculate and record the average time. How well did you predict what would happen? Record your comments in your notebook.

7. Add a third battery in series to the motor. Determine the average time it takes to lift the washers in the same way.

8. Using the information recorded in your data table, graph the average time it takes to lift the washers versus the number of batteries in series.

9. Use the spring scale to measure the weight (in newtons) of the three washers. Record this information in your science notebook.

10. Measure the vertical distance (in meters) that the motor lifted the washers each time.

11. Using the weight and distance measurements, calculate and record in your science notebook how much work the motor did to lift the washers.

12. Calculate and record how much power the motor provided using one battery. Remember:

$$\text{Power (W)} = \frac{\text{Work (N-m)}}{\text{Time (s)}}$$

13. How much power did the motor provide using two batteries? Three batteries? In your science notebook, make a table with columns for “Power” and “Number of batteries.” Record the power data in the table.

14. Use your table to plot a graph that represents “Power” versus “Number of batteries.”

REFLECTING ON WHAT YOU’VE DONE

Answer the following questions. Support your answers with evidence from your data. Be prepared to discuss your answers with the class.

A. Did the amount of work done each time by the motor to lift the load depend on the number of batteries used in the circuit? Why or why not?

B. Suppose you made a graph of the work it takes to lift the washers versus the number of batteries. Describe what that graph would look like or draw a picture of such a graph.

C. What changed as you added more batteries?

D. Look at your graph of “Average time to lift” versus “Number of batteries.” Is the time needed to lift the washers related to the number of batteries added in series? How?

E. Look at your graph of “Power” versus “Number of batteries.” Does the power to lift the washers depend on the number of batteries in series? How?

F. Suppose you need to lift a larger load. What can you do to make the motor produce more power?

G. The batteries supplied energy for the motor circuit. Did the motor use all the energy supplied by the battery to lift the load? If not, what other forms does the battery’s energy become?

Inquiry 16.1
Choosing the Machine for the Job

PROCEDURE

1. With your group, review Student Sheet 16.1a: Planning Our Solution to the Technological Design Challenge. The task and specifications for this challenge are described in the Project Brief on the student sheet. You and your fellow engineers will fill out this sheet as you complete your design. The K'NEX® sled with 14 washers is the piano for your model solutions.

2. Read the Project Brief on Student Sheet 16.1a. In your science notebook, answer the questions that follow. Then discuss your answers with the class.

   A. What is the human need described in the brief?

   B. What will indicate that your design solution is successful?

   C. What are the constraints that you must work within when you design your solution?

3. Study the recommended time frame in Table 1: Production Schedule on the student sheet. Discuss this schedule with your team members. Note how much time is suggested for each part of the process. As you move through each step of the design challenge, be sure to record how much time you actually spend on each part.

4. Your teacher will give you a copy of Inquiry Master 16.1: Scoring Rubric for the Technological Design Challenge. Review it with the class.

5. You have worked with three simple machines—the inclined plane, the pulley, and the lever—in previous lessons. Now decide with your teammates which of these machines you will use to build your machine-and-motor apparatus.

6. Work with your team to plan your solution to the design challenge. Be sure to complete the Design Brief on Student Sheet 16.1a: Planning Our Solution to the Technological Design Challenge.

7. Implement your plan by setting up the machine you have selected and connecting it to the motor and batteries.

8. Test your setup. Record the result of the test in your science notebook. Keep in mind the criteria set by the challenge.

9. If the motor did not lift the load, analyze your design, modify it, and try again. Technological designs are often tested and modified to produce the best working model.

10. Evaluate your solution and complete Student Sheet 16.1b: Evaluating Our Solution to the Technological Design Challenge. Answer these questions on the student sheet: How successful were our plan and design ideas? How well were we able to follow our plan? What changes did we make to our original design? How close were we to meeting our proposed time frame as shown in the Production Schedule? In what ways is our final machine-and-motor design different from the design specifications provided? How successful is our final design? If we were to redesign our apparatus, what changes would we make?