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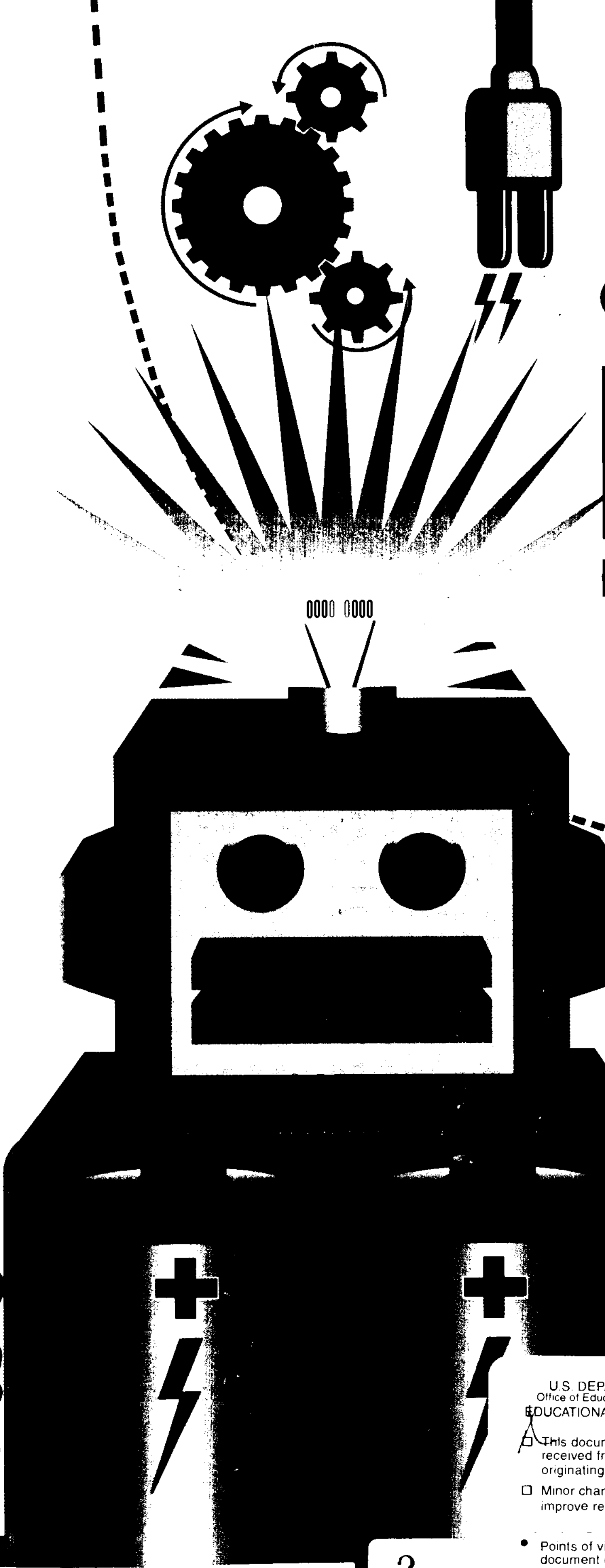
ABSTRACT

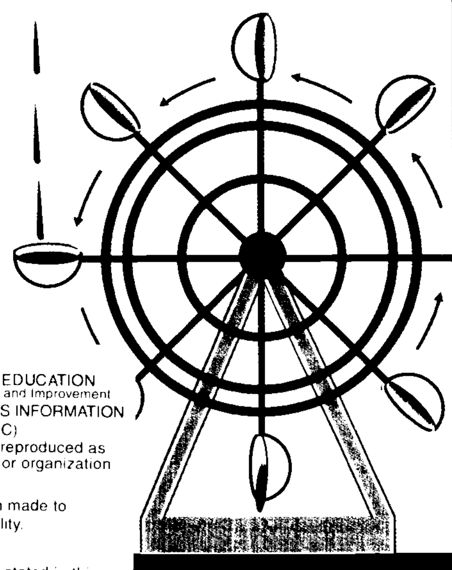
The goal of this guide is to provide resources for teachers and trainers to use in helping students improve their scientific thinking and problem solving skills in real-life situations. Each activity is characterized by inquiry-based learning, process skill development, and gender equity considerations. Topics for activities include problem solving through design, simple machines, electricity, heat, and liquids. Appendices contain references, resources, basic scientific principles, selected science proficiency outcomes, and a matrix of learning activities and process skills. (DDR)

Based on National Science Standards



FUN *with* PHYSICS

Real-Life Problem Solving for Grades 4—8



Note to Non-Science Teachers and Other Professionals

Science is a topic that is sometimes under-emphasized especially in elementary-level classroom. In addition, some educators who teach science may feel unprepared to lead lessons in a content-rich subject like science. However, the information in this book is designed to empower *anyone*—even non-science teachers—to teach science.

In *Fun with Physics: Real-Life Problem Solving for Grades 4-8*, scientific background is presented succinctly and in an easy-to-read format. Even the learning theory behind the practical exercises is explained and modeled for the reader. In addition, the book's activities are hands-on and "minds-on," drawing students into their own learning. And the exercises have been tested successfully in both science and non-science classrooms, demonstrating that you, the teacher, do not have to be a physics expert. You can learn along with the students and relieve yourself of the pressure to know all the answers. If mistakes are made in completing the activities, so much the better! Learning has still taken place because trial-and-error is a very effective teaching method, not to mention problem-solving process. Thus, anyone—from veteran science teacher to inexperienced professional—can feel comfortable using any section of this resource.

So relax and let the learning begin! Ask questions, predict, and observe with your students. We believe that both you and your students will have fun and become scientific thinkers and problem solvers in the process!

Scientifically yours,

Authors and pilot teachers, *Fun with Physics*

P.S. If, after reading through the activities, you have questions, we encourage you to seek help from someone in your school or your district. Many people would be delighted to support your efforts, but a science teacher may be the most helpful. If you cannot find assistance within your district, feel free to contact one of the book's contributors.

FUN with PHYSICS

Real-Life Problem Solving for Grades 4–8

Notice to the Reader

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Preface

Project Overview

Fun with Physics: Real-Life Problem Solving for Grades 4–8 was developed with funding from an Ohio School-to-Work Systems Building Grant. The goal was to develop resources for teachers and trainers to use in helping students improve their scientific thinking and problem-solving skills in real-life situations.

This book, and its companion volume, *Fun with Physics: Real-Life Problem Solving for Grades K–3*, were co-written and piloted with a diverse group of teachers and teacher trainers. In addition, fifty K–8 teachers provided practical input for the books through a week-long Applied Technology Institute. During the Institute, they learned to teach problem solving with physics and made worksite visits to learn how academics are used at work.

Both books are distributed by The Ohio State University's Vocational Instructional Materials Laboratory (VIML), a division of the College of Education's Center on Education and Training for Employment. Similar books for grades 9–12 and adults, which support the ACT Work Keys System, also have been developed and are distributed by the VIML. The sales office can be reached by telephone at 800/848–4815 or fax at 614/292–1260.

In-Service Training

The VIML provides coaching and training that will prepare teachers and trainers to effectively use the *Fun with Physics* books and other VIML publications. Workshops in problem solving with physics and math for grades 9–12 and adults working in industry are also available. For further information about these services, contact the VIML directly at 800/848–4815 or 614/292–8300.

Acknowledgments

The project staff extend sincere thanks to the many people who committed their time and talents to create this useful resource for teachers and other professionals who want to provide opportunities for students to solve real-life physics problems.

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CONTENTS

About This Book

Purpose

Many teachers want to prepare students to be effective problem solvers, but they don't have the time or the expertise to design the necessary learning strategies. *Fun with Physics: Real-Life Problem Solving* was developed as a practical guide and resource for these teachers. Its easy-to-read format and classroom-tested learning activities can also be adopted by professionals outside academic settings including school-age child care programs and youth groups.

The following parameters guided the authors as they created *Fun with Physics*:

- *Fun with Physics* was written for **non-science teachers**. You can make full use of this book without any formal training in physics or other science areas. Still, even formally trained physics teachers will find value in this book's practical focus on applications to real-life situations.

- *Fun with Physics* gives teachers a **brief background** about the key scientific principles involved in the learning activities. It does not provide in-depth information about those principles or a comprehensive list of the scientific principles involved in solving real-life problems. Such a list does not exist. However, a *brief* list of basic scientific principles was compiled by *Fun with Physics* pilot teachers. See Appendix C, pp. 318–326. Also, resources that provide more detailed information are provided in Appendix B, pp. 299–317.

- The skills addressed in *Fun with Physics* are intended for **all students**—not just those who plan to study in technical areas, because almost everyone encounters physics-related problems that demand to be solved. A few such challenges are fixing toys and bicycles; operating copy machines, computers, and VCRs; and repairing toilets.

- *Fun with Physics* **supports what teachers are already doing** by offering ideas and materials for achieving their current goals and objectives. It is not a new program or a new curriculum. Rather, it is a resource that complements existing instructional efforts.

- Because *Fun with Physics* is not meant to be a complete curriculum, it **supplements the established curriculum** by giving teachers a wide variety of learning activities from which to choose.

- *Fun with Physics* was designed to help students become more effective problem solvers, which involves skills that have been identified in **national standards** and are measured by state proficiency tests. Therefore, the National Science Education Standards and the Benchmarks for Science Literacy were considered in the book's development.

- Each learning activity in *Fun with Physics* notes the specific **Ohio Science Proficiency Outcomes** that it addresses. Proficiency Outcomes are listed in Appendix D, pp. 327–329.

- *Fun with Physics'* activities allow students to solve real-life problems that involve physics principles associated with **simple machines, electricity, heat, and liquids**.

Structure

Fun with Physics includes a wide variety of information that will help you, the teacher, provide students with highly effective instructional experiences in scientific thinking and problem solving.

The information provided in the **Where Do I Begin?** section will help you figure out how to start using the ideas found in *Fun with Physics*.

In the **Learning Concepts and Strategies** section, you will find information and insights about relevant learning theories and their practical applications, such as **inquiry-based learning, process skill development, gender equity, various instructional strategies,** and **assessing student learning.**

The **Learning Activities** section is divided into five categories: **exploring design, exploring simple machines, exploring electricity, exploring heat,** and **exploring liquids**. An index of learning activities is included in each section.

The **appendices** contains a variety of **support materials** to help you use and extend the concepts and activities provided in this book. These appendices include:

- References (Appendix A)
- Resources for Teachers and Students (Appendix B)
- Basic Scientific Principles (Appendix C)
- Selected Proficiency Outcomes (Appendix D)
- Matrix of Learning Activities, Proficiency Outcomes, and Process Skills (Appendix E)

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Where Do I Begin?

Congratulations on deciding to use *Fun with Physics* as a resource for helping students with science-related learning! The only question is: Where to begin? That was a difficult question for the authors to answer, because everyone using this book has a unique blend of experience, ideas, resources, and needs. In the end, authors and pilot teachers developed the following two lists as guidelines. The first organizes the book's information into six broad, sequential steps for implementing science instruction. The second, titled Helpful Hints, contains the most essential ingredients for success, as derived from the writers' and pilot teachers' collective experience.

Implementation Framework

You may want to think of these steps as the process for building a car. The steps, when taken sequentially, will provide a solid "chassis" for giving students science-related learning experiences. Once you've built the chassis, get creative and have fun installing the "accessories" and applying the decorations!

Step 1 **Help students grasp *why* becoming an effective problem solver is so important**. Discussions—better yet, demonstrations—of practical, everyday uses of physics in *students'* lives (at school, home, and work) will help them recognize and accept the relevance of physics-related principles.

Step 2 Help students gain an understanding of the basic principles of physics and problem solving by **structuring inquiry-based learning opportunities** that follow the *Five Es of Instruction* format. The Five Es (which are described in detail on pp. 10–14) are:

- Introduce a new concept to students with an **engagement** activity (optional).
- Provide **exploration** activities for students.
- Then, help students **explain** what they learned during exploration.
- **Evaluate** students to make sure they understand the concepts being taught.

- Provide students with opportunities to **extend** their learning to other applications of the concepts and skills that have been learned.

Step 3 **Supplement *Fun with Physics* materials** with other science resources. *Fun with Physics* was created as a practical guidebook instead of a comprehensive science curriculum. Supplemental materials are especially helpful during the explanation and extension phases of the Five Es.

Materials that offer additional hands-on science activities are suggested in the Resources section, Appendix B, pp. 299–317.

Step 4 **Check the results of your physics learning activities**. Strategies for assessing your instructional efforts, as well as the importance of checking the learning, are explained on pp. 43–49.

This step corresponds with the evaluation phase of the Five Es.

Step 5 **Plan additional instructional strategies for students to extend their learning** to other applications of the concepts and skills that have been learned.

This step corresponds with the extension phase of the Five Es.

Step 6 Plan **additional instructional strategies for students whose skills did not improve** as much as needed. You may want to seek help from colleagues concerning students who continue to struggle.

The problem-solving skills developed through science-related learning are a "must" for success in the real world, so no student can afford to be left behind.

Step 7 Provide frequent opportunities for *all* students to practice problem solving.

Helpful Hints

Teachers who authored and piloted *Fun with Physics* made the following suggestions:

- **Model** problem-solving strategies. For example, explain your rationale for making decisions while solving problems.
- Provide **frequent and varied hands-on practice**, in an atmosphere that fosters curiosity and risk taking.
- **Value** the different and unique ways that students explore.
- Base learning activities on **students' interests**.
- **Instill confidence** in students' abilities to solve problems.

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- Provide students with **sufficient materials, information, and space** for learning.

- Provide opportunities for students to **solve problems cooperatively** (e.g., to work individually but share ideas with classmates, to work in assigned pairs, and to work in assigned small groups).

- **Vary practice circumstances** to mirror those found in the workplace. Have students work on some tasks individually, some in pairs, and others in small groups of 3-5 students.

Notes

FUN WITH PHYSICS

Real-Life Problem Solving for Grades 4–8

Learning Concepts & Strategies

This section describes the learning concepts that undergird the real-life learning activities developed for this book. It also outlines teaching strategies for building a learning environment that develops scientific thinking and problem solving.

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Notes

Inquiry-Based Learning

What Do We Mean By "Inquiry-Based Learning?"

Many teachers spend a considerable amount of time and energy trying to figure out how to get students interested in, motivated about, and able to remember what they are taught. A strategy that has worked for a wide variety of teachers (and their students) is inquiry-based learning. This instructional strategy puts the student at the center of the learning process. The student gains an understanding of the material through active participation rather than from passive activities like listening and taking notes. When using an inquiry-based learning format, **teachers provide students with opportunities to ask scientific questions, then to answer those questions for themselves through investigation.**[1] Teaching through inquiry also helps teachers wishing to integrate their curriculum.

The following example gives a brief comparison of how a lesson can be taught using traditional instruction and inquiry-based instruction:

Traditional instruction
The teacher's objective is to teach students about potential and kinetic energy. She does a short lecture, during which she defines the two terms and gives examples. She then provides a demonstration of the scientific principles using a wind-up toy. Students' understanding of the principles is tested on a written unit test.

Inquiry-based instruction
The teacher's objective is to help students understand potential and kinetic energy. First, she structures and assigns a hands-on learning activity during which students build a roller coaster (with pipe insulation) and explore how a marble travels through it. After students explore, the teacher facilitates a class discussion during which the scientific principles involved in the roller coaster course, including potential and kinetic energy, are discussed. The class also brainstorms where examples of the principles can be found in their everyday lives. This integrated activity lent itself to additional activities, including measuring angles, calculating rate of travel, and creating a commercial that advertises the roller coaster. Students' understanding of the principles is tested through teacher observations (and grading with a rubric), journal entries, and a performance assessment. (Note: A roller coaster learning activity is included on pp. 169–178 of this book.)

[1] *Science With Reason* (1995) p. 7.

Studies show that passive learning is much less effective than active learning. Even more important than such studies is wisdom derived from personal experience. Most of us have experienced firsthand both passive and active learning. Wasn't it much easier to both comprehend and retain information that you ***experienced*** *in a lab setting than information you* ***heard*** *during a lecture?*

When structuring learning activities of this type, teachers should consider these inquiry-based instructional characteristics.[2] Inquiry-based instruction:

- Starts with questions
- Engages students actively
- Concentrates on collection and use of evidence
- Requires clear expression (e.g., written and verbal communication)
- Uses a team approach
- Does not separate knowing from finding out
- Welcomes curiosity and rewards creativity
- De-emphasizes memorizing technical vocabulary

Why is Inquiry-Based Learning Important to Scientific Problem Solving?

Solving science-related problems requires inquiry—sometimes called the scientific process, which includes predicting, testing, observing, and concluding. So, it makes sense to help students explore concepts through inquiry as part of teaching problem solving. Since inquiry-based learning helps students to gain an understanding of the material **through active participation**, they are more likely to remember what they learn.

An Inquiry-Based Learning Model

Many teachers have used the **Five Es of Instruction**, an inquiry-based learning model, with great success. The Five Es, which is an expansion of the learning cycle, can be used as a *format for structuring lessons* that allows people to learn through an inquiry-based process. The components of the Five Es are listed and described below.

Engagement

How will you introduce the topic and get students interested? What "hook" will you use to motivate students to learn more about the

[2] *Benchmarks for Science Literacy* (1993) professional development CD-ROM

topic? How will you promote excitement? Engagement usually involves students in a thought-provoking or discrepant event. Demonstrations followed by an entire-class or small-group discussion are often used. In science education, the engagement step usually helps students gain insight into their preconceived ideas about a given concept.

Note: This step is optional. Sometimes, the exploration activities outlined in the next paragraph are sufficient "hooks" to engage students.

Exploration

What hands-on activities (e.g., investigations, discussions, individual and/or cooperative group activities) will guide students to make observations, identify patterns, and collect data? Please note that during exploration, students are **not** given explanations about what to expect, why things happened as they did, or new vocabulary.

Explanation

In this stage, the teacher's job is to help students draw conclusions and form new ideas from their observations and the patterns that surfaced during exploration. Traditional instructional strategies (e.g., demonstrations, short lectures, lecture-discussions, textbook assignments, team reports, video tapes, and library research) may be included at this time.

Evaluation

How will you confirm that students understand the concepts and processes delivered during their inquiry-based learning experience? Both traditional testing methods (e.g., quizzes, unit tests, essays) and practical assessments (e.g., spontaneous oral reports, teacher observation, and reflective journal entries) can be used.

Extension

What possibilities exist for building upon what was learned in this activity? In this segment of the model, teachers help students use what they learned to solve new problems.

Example of the Five Es in Action

Here's how one teacher used the Five Es format to structure a physics-related learning activity. Feel free to use it to create your own scientific exploration!

Engagement

A teacher wanted to introduce the principles of electricity to her sixth-grade students. Beginning with a **discrepant event**, she asked students to **predict** what would happen when she touched a pickle with 2 wires that were attached to a battery. After the students offered a wide range of predictions, she poked a wire into each end of the pickle and it lit up! She then explained to the students that they would have the opportunity to explore why that happened.

Exploration

Immediately following the introduction, the teacher provided each student with a zip-type sandwich bag containing a battery, 2 coated copper wires, a flashlight bulb, a bulb holder, and masking tape. She did not give any specific instructions. She simply challenged them to make the battery light up. As students worked, the teacher walked around the room to observe what they were doing, to give hints to students who were "stuck," and to provide input and direction by asking open-ended questions. She did not give any answers, but she encouraged students to share ideas with each other. After the students tried several methods for lighting the bulb, the teacher distributed a worksheet titled "How many ways can you make a bulb light?" Students were asked to draw diagrams in two columns: "Ways the Bulb Lit" and "Ways the Bulb Did Not Light."[3]

The next day, the class reviewed the worksheet. Then the teacher gave each student a zip-type sandwich bag containing 3 batteries, 8 coated copper wires, 4 flashlight bulbs, 4 bulb holders, and masking tape. She challenged them to learn everything they could by connecting the materials. Again, no further instructions were given. As she circulated among the students, most of them highly motivated, she asked questions such as, "What would happen if you connected two or more bulbs?" and encouraged students to learn from each other with comments like, "Maybe Andrea can explain to you how she connected her bulbs." For homework, students completed a worksheet[4] that required them to predict which battery-wire-bulb configurations would make a bulb light and which would not.

Explanation

Once the students had been given plenty of time for exploration, the teacher facilitated a class discussion during which they shared what they learned from the experiences. The teacher asked questions like:

- "To light the bulb, what specific places on the battery must be touched?"
- "How could you get your bulb to shine most brightly?"

[3]Learning activity from the *Electricity* book developed by TOPS Learning Systems. See description in Appendix B, Guides for Educators Section

[4]Ibid.

"How could you attach your bulbs so that they all light up?" and "Were they all equally bright?"
"What other observations did you make?"
"When two or more bulbs were attached, how could you get them to shine the brightest?"
"What conclusions can you draw from your observations?"
"Suppose you had a string of Christmas tree lights and a bulb burned out. What would happen? Why? What would happen if appliances in your home were arranged like Christmas tree lights?"

Next, the teacher guided class discussion to help students make generalizations about electricity, including the following:

- Metal ends of batteries, wires, and bulbs need to be joined together in order for the bulb to light. Students labeled this a *circuit*.
- Bulbs attached beside each other (students labeled these *series circuits*) were brighter than those attached in a row (students labeled these *parallel circuits*).
- The more batteries in a circuit, the *brighter* the bulbs glow.
- The more bulbs in a circuit, the *dimmer* the bulbs glow.

Finally, the class brainstormed how principles of electrical circuitry are used in their homes, school, and community.

Evaluation

Since the teacher's objective was that students gain a general understanding of batteries and bulbs, she checked individual students' understanding of the principles of electricity by giving a quiz. Students were asked to reconstruct six electrical circuits from diagrams and explain how each circuit worked. *(Note: This could have been done as a performance assessment.)* In addition, the teacher reviewed students' journal entries to check for their understanding of the basic principles related to electricity.

Extension

Once the students demonstrated a basic understanding of primary electrical principles, they were assigned new problems that required them to apply what they had learned to real-life situations. Activities included:

- Building an electrical game board
- Designing a flashlight
- Constructing buildings that light from empty food boxes and the electrical supplies that were used during the unit and putting each team's building together to create a "city of lights."

This type of inquiry-based "teaching," conducted **after** students explored the concepts for themselves, helped students absorb the concepts and apply them to practical situations.

What is the Teacher's Role in Inquiry-Based Learning?

Since inquiry-based learning is student centered, the teacher becomes a **facilitator** rather than a "bestower of knowledge." Facilitator is a new role for many teachers. The information presented in this section is designed to help teachers transition more smoothly into this role. Facilitating inquiry-based learning requires:

- Determining the content that will be studied
- Organizing exploratory experiences for students
- Facilitating student questioning
- Assessing what learning has taken place

In short, an inquiry-based teacher provides a framework for **collecting information** and **making generalizations**.

Specifically, the teacher uses the Five Es of Instruction to structure a learning activity. First, she provides a motivating activity, then explains what is expected in the exploration activity—including safety precautions. Next, she steps back and allows students to discover answers for themselves. (This is sometimes the hardest thing for teachers to do!) Once discovery has occurred, the teacher helps students synthesize what they have learned, label it, and apply that understanding to other situations. In this way, **teachers *facilitate* the learning process rather than control or direct it**.

In inquiry-based learning, the facilitator also functions as a **resource person** for students. For example, a resource person assists students by encouraging *them* to locate answers to their questions rather than *giving* the answers. A resource person gives only information that is absolutely necessary and lets students discover the rest for themselves.

To be successful in the facilitator and resource person roles, you may need to develop skills in some different instructional methods, including those outlined in the following pages.

Instructional Method	Explanation/Examples
• *Put students in the center of the learning process.*	Learn facilitation skills and become proficient in them, so that you become an expert at drawing students into the center of their own learning.
• *Include process skills in learning activities so that students can learn and practice them.*	See pp. 24–28 for a complete description of process skills and sample learning activities.
• *Lead discussions.*	Guide students into discussions by **making observations and asking questions**. For example, all students used the same materials in an experiment, but some bulbs are dimmer than others. Ask the class, "What could some students do differently to make their bulbs brighter?" Discussions are excellent tools for evaluating student learning, discovering extension opportunities, helping students clarify ideas, and more.
• *Use discussions to stimulate logic, reasoning, and communication skills.*	For example, present an exercise to the class. After allowing students time to process the information, ask a few to share their hypotheses and make predictions (or guesses). Ask probing questions that help students share the logic and reasoning behind their ideas. Then encourage all students to test these and their own hypotheses and predictions while completing the exercise. After exploration, guide the students to discuss their test results with the class. In this way, the facilitator is **encouraging students to synthesize their understanding** and **share that knowledge with peers**. Some questions teachers ask include:[5] Draw out the student's **reasoning** by asking, "Are you saying that...?" Help students **provide validity to their statements** by asking, "Why do you think...?" Help students **identify alternatives** by asking, "Couldn't it be right that...?" Help students **provide supportive evidence** by asking, "How do you know that ...?" Lead students to **find supportive evidence** by asking, "How might we find out whether...?"

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[5]Questions were adapted from Matthew Lipman's work, which is cited in *Science With Reason*, pp. 36–37.

Instructional Method	Explanation/Examples
• *Embrace the concept of not knowing the answers to student questions.*	**Get comfortable** with sentences like, "I don't know." and "That's a new one on me!" Equally important, follow up sentences like those by asking questions that **lead students to finding their own answers**, e.g., "What could you do to find out?" In this way, you are **modeling** the behavior you are instructing students to adopt. Additional information concerning questioning can be found in the rest of this table and on pp. 18–21.
• *Create an instructional environment that promotes inquiry-based learning.*	For inquiry-based learning to achieve the desired results, you should **build a "safe" environment for participation**. For example, when questioning, your *tone of voice* must convey a sincere desire to know the answer. In addition, your *behavior* (i.e., verbal and nonverbal) must consistently show students that a wrong answer is okay. For example, avoid right or wrong labels; redirect the student instead, e.g., "Is there another method/alternative?" Furthermore, you should use *positive feedback*, e.g., "Sally, you've really been persistent when doing this exercise. Good job!" Positive feedback also encourages enthusiasm.
• *Replace "bestowing knowledge" with asking questions.*	Effective questioning is one of the most difficult facilitation skills to develop. Mastering it requires significant planning and commitment. Many teachers find the following strategies helpful in becoming a proficient questioner: **Prepare start-up questions** in advance, making sure they cover the key points of the discussion. **Ask open-ended questions**—anything that *cannot* be answered with "yes" or "no." **Prepare questions that require students to think critically** in order to explain their observations and draw conclusions. Let's use the light bulb exercise as an example of critical thinking questions. You could ask students to: • **Explain** what they observed by asking, "Why is there a limit to the number of bulbs that will light up with one battery?" • **Synthesize** what they learned by asking, "What can you generalize about all circuits?"

Instructional Method	Explanation/Examples
• *Replace "bestowing knowledge" with asking questions.* (continued)	• **Develop predictions** based on what they understand to be true by asking, "What would you predict will happen when more batteries are used?") • **Apply** what they learned to other situations by asking, "When planning electrical circuitry for a new building, what do engineers need to consider?" When appropriate, **answer students' questions with other questions**, and/or **direct them to other students** for answers. After asking individual or teams of students a question, **allow 5–10 seconds of silence** (which is sometimes called wait time) before giving a prompt or calling on someone else. Wait time encourages participation from students who lack confidence and/or who prefer to mentally check their answers. **Ask questions without bias.** Demonstrate equity by: • Posing the *same number of questions* to males and females and to students of all races and physical abilities • Asking *challenging questions* of males and females and to students of all races and physical abilities • Following **every** student's answer to one question with a *second, more difficult question.* Refer to the "Gender Equity: What Can Teachers Do?" section on pp. 33–37 for additional ideas. In addition, see the following page for lists of questions that teachers might ask students during science-related learning experiences.

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Inquiry-Based Learning: Questions Teachers Might Ask

Questions that teachers can ask students to encourage them to explore and synthesize the concepts they're studying are virtually unlimited. The following sample of open-ended questions can be particularly useful in **exploring scientific principles.**

"What would happen if ......?" For example, "What would happen if you added more batteries?"

"What makes you think that?"

"What else could you try, in order to find out?"

"What would you predict?"

"How do you know?"

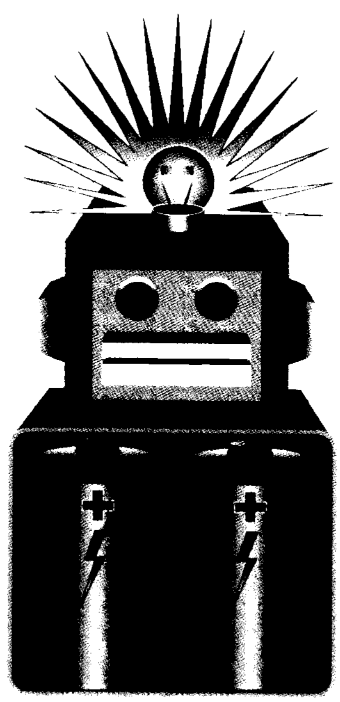
"What isn't being considered?"

"What are the facts and limitations?"

"What is (or can be) reasonably inferred?"

"What potential outcomes and/or precautions should be considered?"

"What do you need to consider in order to determine ________?"



Teachers can also ask specific, open-ended questions that guide students in **investigating systems** and solving problems related to those systems. The questions listed below[6] can be especially helpful to you in guiding instruction on practically any system.

1. "When this system is working, what does it do?"
2. "Must this system receive input in order to function?"
3. "What, if any, output does this system produce?"
4. "Identify at least four parts of this system. Describe what each part does, and tell how each part contributes to the system as a whole."

[6] *Benchmarks for Science Literacy* (1993) professional development CD-ROM

5. "Choose an interesting part of the system and list at least four words or phrases that describe that part. Which, if any, of those words or phrases also describe the whole system?"

6. "Could any of the parts of this system be made of different material without affecting how the system works? Explain."

7. "Can any one part of the system do what the whole system does? Explain."

8. "Can you take a part from another system of the same kind and use it to replace a part in this system? If you do so, will this system work the way it does now?"

9. "Identify at least two parts of this system that must interact if the system is to function. Describe how these parts interact. Could the parts of this system be arranged differently and the system still function?"

10. "What is the boundary of this system?"

11. "Can you identify any subsystems within the whole system? If so, describe one."

12. "Does this system require symmetry between any of its parts? If so, describe the symmetry."

13. "Describe how the functioning of this system would change if one of the parts wears out."

14. "If this system stops working, how would you go about fixing it?"

15. "Give an example of how this system might respond to a stimulus from outside itself." or "Give an example of how this system might respond to a stimulus from the environment outside the system."

16. "In what way is it useful to think of this item as a system?"

17. "Could someone develop a computer simulation of this system? Justify your answer."

Example: Students can study systems by analyzing a specific **toy as a system**. Sample questions that could be used to facilitate inquiry-based learning in this situation are listed below.

- "How does this part help the toy work?"
- "How did you figure out what this part does?"
- "If the part does not help the toy work, is there some other reason that it is important to the toy?"
- "Does this part affect other parts of the toy in any way?"
- "If you put the parts of this toy together in a different way, would it still work like it does now? Explain your answer. Use drawings, if you wish."
- "Could you take away any part of this toy without changing the way the toy works? If so, which part(s)?"
- "Let's take the information you learned about systems from this toy and see how it applies to things around the school. Can you identify three parts of our school's system?"
- "How does each part affect the other two?"
- "If you took one of the three parts away, would it affect our school's system?" Please explain."

Example: Here are some questions that could be asked of students who are studying the **bicycle as a system**.

- "Identify at least six parts of the bicycle. If you don't know the name of a part, make up a name. Explain the function of each part."
- "The seat is one part of the bicycle. Use three words or phrases to describe the seat. Do any of these words or phrases also describe the whole bicycle?"
- "Could any part of this bicycle be made of a different material and still help the bicycle carry out its function?"

- "Can any one part of the bicycle carry out the job of the whole bicycle? Explain your answer."
- "What parts of the bicycle must work together if you want to ride around a corner?"
- "Can you take a part from another bicycle and use it to replace a part in this bicycle and still have the bicycle carry out its function?"
- "Could some parts of the bicycle be arranged differently and the system still carry out its function? Explain your answer."
- "Can you identify any subsystems within the whole bicycle system? If so, describe one subsystem."
- "Does the bicycle require symmetry between any of its parts? If so, describe the symmetry."
- "What will happen to the bicycle if one part, such as a spoke, breaks? What if all the spokes break?"
- "Is it useful to think of a bicycle as a system? Justify your answer."
- "Now think about our cafeteria system for a minute. In what ways does it function like the bike system?"

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Inquiry-Based Learning in the Real World: A Teacher's Reflections

Dear *Fun with Physics* User,

Students arrive in our classrooms with a variety of perspectives on science—depending on their past experience. Our job is to create an environment in which each student can learn the objectives and skills set by us and the curriculum. Inquiry-based learning is one of the best ways I've found to create such an environment. However, success in this endeavor requires experience, knowledge, personal commitment, and organization. Most important, successful teaching through inquiry requires a student-centered mind-set that is obvious at all times. This book can help you gain knowledge and experience; commitment is an individual task. So, I'll share some key points I've learned about organization and the student-centered mind-set.

Organization and Focus. I design textbook reading and note taking into most learning activities. My 6th-graders read background information as preparation for the lab portion of the exercise. They must take notes—one note per paragraph. The reading familiarizes students with the general topic; note taking helps with retention and keeps them focused.

Organization and focus can be achieved in the lab experience, too. I start by clearly defining the objectives and skills to be targeted, then wrap them into the scientific process to create a learning activity that provides a feeling of discovery for my students. My lab exercises usually begin with a question developed by either the students or me. Research follows; it can be as simple as the verbal description of a ping pong ball or a written report. Next, students write a hypothesis—a guessed answer to the lab question. Then they complete the experiment part of the lab, focusing on answering the question. Students are given supplies and/or data with which they can work out an answer. To keep them focused on the question, I write it on the board or have students write it in the notes section of their folders. My labs end with clean-up and sharing what we learned through verbal, dramatic or similar presentation. Consistent with the scientific process, students answer the lab question while sharing lab results. Often results lead to more questions, which can be investigated in future lab experiences—either in the classroom or at home. My most successful labs have been those that prompted students to involve their families in an extension of the learning at home.

Student-Centered Retention. I frequently tell my students,"Knowing the meaning of a word is power." For this reason, the students and I create vocabulary words from both the textbook reading and the lab experiences described above, and a student lists them on the board. The class defines the words based on these learning experiences. Then they verify the definitions with a dictionary. Finally, the words and definitions are stored in the vocabulary section of students' folders. These can be used later in an assignment; however, most frequently the words are seen again in future reading or in a test question only.

Potential Problem with Student-Centered Methods. Inquiry-based classroom experiences allow students to take significant responsibility for their learning. Teachers must be cautious, however, about assuming that because the student completes the experience, learning has occurred. Ways I have found to avoid this potential problem are to: (1) keep students focused on the learning procedure, and (2) stay organized. The methods I described in this note really help! I hope that sharing some of my experiences with inquiry-based learning encourages you to try it yourself. The time and energy required to gain knowledge and experience in this method, as well as to maintain focus and organization, pays huge dividends in successful learning outcomes.

Wishing you much success,

Patricia Bosh
Mifflin International Middle School Teacher and *Fun with Physics* Author

Process Skill Development

What Do We Mean By "Process Skill Development?"

Learning subject matter **content** (e.g., facts, theory) has always been a primary function of instruction. Such learning is especially important in science, because students must understand basic scientific principles in order to become proficient in competencies identified by science educators. Similarly, to be successful on the job, workers must understand the scientific principles that underlie systems they work with.

However, learning such content is not enough. People also must be able to *apply* their content knowledge in problem solving situations. Developing **process skills** meets this need. When paired with scientific knowledge, process skills allow students to **participate in the scientific process**.

The Process Skills Checklist on the next page defines the process skills generally used in science education. You may wish to use it to identify the process skills you are currently helping students develop and practice, and other skills you want to work on. (In addition, see the information concerning assessment, on pp. 43–51, where you will find a sample tool for assessing students' process skills.)

Why Are Process Skills Important to Instruction?

Process skills, when coupled with subject knowledge, lay the foundation for people to successfully solve problems in real-world situations. Traditional teaching curricula and methods already successfully impart the necessary **facts**, **data**, and **theory**. However, most do not include learning activities aimed at developing **process skills**. Consequently, teachers of all levels need to add process skill development to their science instruction plans.

The benefits of process skill development go beyond creating better-skilled problem solvers, however. When learning activities are geared toward helping students practice process skills, the learning becomes more **active**. And active students learn more than those who listen to lectures or observe demonstrations.

Process Skills Self-Check

Instructions: In the first column, check the process skills that you currently use in instruction. In the second column, check those skills you'd like to add or expand upon. Use the resulting information as you choose learning activities from *Fun with Physics*.

I Provide	I Want to Do More	
☐	☐	**Categorizing or classifying:** Arranging objects or systems into categories based on shared characteristics. Can also refer to labeling objects or systems based on unique characteristics or some other specified criteria.
☐	☐	**Communicating:** Conveying information (e.g., insights, explanations, results of observations or inferences, measurement) to others. Communication methods might include verbal, pictorial, graphic, or symbolic presentations.
☐	☐	**Comparing:** Relating one thing to another in order to identify similarities and differences.
☐	☐	**Controlling variables:** Holding all variables constant that impact an experiment or situation, except one variable whose influence is being investigated in order to evaluate changes in the others.
☐	☐	**Experimenting:** Testing a hypothesis through information gathering.
☐	☐	**Hypothesizing:** Forming precise questions to be tested scientifically. Formal hypotheses are stated so that each explanation may be tested and, based upon the results of those tests, accepted or denied.
☐	☐	**Inferring:** Suggesting explanations, reasons, or causes for observed events.
☐	☐	**Interpreting data:** Studying data, then summarizing its implications in the context of a scientific investigation. Familiar language should be used to describe the significance or meaning of data and observations.
☐	☐	**Making models:** Constructing a representation of a system that is based on observations and inferences.
☐	☐	**Measuring:** Using instruments to define objects or systems quantitatively, either as compared with others or as compared with a standard. Measuring includes the monitoring of changes in size, shape, position, and other properties.
☐	☐	**Observing:** Using the senses and extensions of the senses to closely examine or monitor a system, noting and recording aspects that are not usually apparent under casual scrutiny.

I Provide	I Want to Do More	
☐	☐	**Ordering:** Using observed characteristics to organize objects or systems in a sequence.
☐	☐	**Predicting:** Forecasting a future observation or the next occurrence in a system or series of events based on prior observations and inferences.
☐	☐	**Recognizing relationships:** Interpreting interactions between different components of a system.
☐	☐	**Recording:** Creating a written record of observations made during experimentation.

Notes

How Can Teachers Help Students Develop and Practice Process Skills?

Students learn process skills most effectively through practice. Frequently, these skills can be integrated with instruction about scientific principles. The learning activities provided in this book allow students to practice a wide variety of process skills while learning basic scientific principles. (The first page of each learning activity outlines the process skills that are targeted. And a chart that identifies the process skills included in each learning activity is located in Appendix E, pp. 330–334.)

In addition, there are probably situations that are more suited to **direct instruction** of process skills. **Teaching process skills in isolation provides students with the foundation skills needed for future scientific problem solving**. Let's use the process skill of classification for a practical example of direct instruction of such skills:

> Scientists put the objects they study into categories in order to understand similarities and differences—the classification process. Similarly, the ability to organize (e.g., information, inventory, budget data—even people) is important for success at work. Students can develop these important organization/classification skills from activities that help them to sort objects with the same or different characteristics. Some sample classification activities follow.

Classification Activity: Observable Characteristics

Procedure

1. Provide teams of 2–4 students with items they can use to practice classification (e.g., toys, buttons, toy cars/trucks, fruits, vegetables, flowers, leaves, shells, counting manipulatives, stones, keys, kitchen utensils, tools, cutouts of geometric shapes, natural vs. manufactured items, items of clothing).

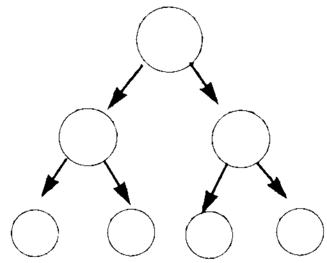
2. Instruct individual students to examine each object, looking for their **observable characteristics**. In other words, have them describe the objects by characteristics such as color, shape, texture, and size.

3. Have each student in the team describe the characteristics of one object to the other team members.

4. Tell each team to put all items into two piles—depending on the similarities and differences of their observable characteristics (e.g., all large objects in one pile and all small ones in another; all red objects in one pile and all non-red objects in another; all objects with wheels in one pile and all objects without wheels in another).

5. Help students discuss the criteria that they used to separate the items.

6. Direct students to construct a dichotomous key (or chart) similar to the sample provided here. They should classify objects until all items have been separated *singularly*. (Note: When this process skill is being introduced to students for the first time, the key can be developed by the whole class, with coaching from the teacher. Once students gain experience with the classification process, the chart should be completed in small groups and/or individually for more effective practice of the skill.)



Extension activities

After students and/or teams complete their charts:

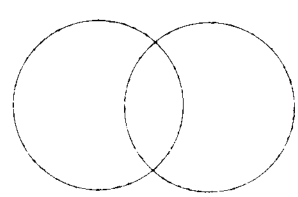
* Introduce 2–3 new, related objects. Have students "test" their charts by adding the new items to it.

* Instruct a representative from one team to read a description (i.e., the characteristics) of an object on their chart to the entire class. Then have classmates determine which object is being described.

* Place sets of different kinds of objects at different stations. Have teams of students rotate from station to station, developing a chart for each set. Later, have them compare and contrast all the charts from each station.

* Have each student choose from the team's objects 5 items that share a common observable characteristic. Then have team members deduce which characteristic all 5 items share.

* Have students identify the relationships between machines. Have them complete a Venn diagram to show the relationship. For example, clocks and can openers both have gears.



Notes

Problem-Solving Skill Development

What Do We Mean By "Problem-Solving Skill Development?"

In the last section, we discussed how learning the **content** isn't enough for students to employ the scientific process. We described how teaching **process skills** is appropriate and often necessary for students to have a strong enough foundation to solve scientific problems. Likewise, it is often appropriate to teach students about **solving problems**. In addition, by teaching students a process for solving problems, we are teaching them how to solve problems in non-science areas as well. Therefore, instruction about problem solving provides an easy and effective method for **integrating subject matter**. For example, when designing and reporting about their invention, a team of students can use communication (English), science, math, computers, social studies, and other subjects. By conducting integrated learning activities, such as solving problems, we are helping to prepare students for the workplace—where integration is an everyday occurrence. And as our world becomes increasingly technology-rich, skills like those listed in the next paragraph will become critical to students' ability to perform *any* job. Obviously, the development of problem-solving skills is imperative for *every* student.

For these reasons, the authors have included some basic problem-solving information. The general concepts are outlined below. Practice activities for solving problems can be found on pp. 55–86.

Identifying Problem-Solving Skills

Teachers can help students develop the skills needed for becoming both scientific thinkers and effective worksite problem solvers by providing opportunities to **practice solving problems**. Success in such areas requires people to develop the ability to:

- **Understand cause-effect relationships**, e.g., What parts of systems affect and are affected by other parts?
- **Make comparisons**, e.g., What commonalities and differences do systems have?
- **Recognize probable outcomes**, e.g., How will the system react to a specific action?

- **Predict what should happen next**, e.g., Based on what has been observed, what is known about a specific system, and what is known about related scientific principles, make a prediction about what will happen next.

- **Judge spatial relationships**, e.g., Visualize how a system operates and mentally rotate system parts to solve problems within a given system.

- **Notice what appears out of place**, e.g., Observe a malfunctioning system in operation and identify the source of the malfunction.

Strategies for Helping Students Practice Problem Solving

To become expert problem solvers, students must be given opportunities to develop and refine such skills. Options for providing and promoting problem-solving practice are limited only by our creativity. The following guidelines may be helpful in stimulating your ideas:

- **Minimize instructions** so that students are encouraged to invent innovative ways to accomplish their tasks.

- **Provide students with a variety of materials** from which to choose.

- When students have questions, **repeat the initial instructions without giving further information**. This strategy encourages students to search for and/or create their own solutions.

- **Allow plenty of exploration time**. As long as students are actively engaged, learning is taking place. In addition, when ample time is given, students can pursue deeper levels of investigation.

- **Encourage students to share ideas with each other**. This strategy reflects how people solve problems in the workplace—with input from others. Most problem solving activities lend themselves to having students work individually or in pairs. Occasionally, it is appropriate for students to work in teams of 3–5. When students work individually, they should be encouraged to seek others' input.

Note: Remember to organize students into both same-gender and mixed-gender teams. *See "Gender Equity: What Can Teachers Do?" on pp. 33–37 for more information.*

Give students opportunities to solve problems. Many commercial games require players to use problem-solving skills, including hypothesizing, categorizing, and drawing conclusions. Some games are listed below to help you get started.

Abalone®	Connect Four®	Sequence®
Backgammon	Mastermind®	Shape by Shape®
Battleship®	Mancala	Tangoes®
Checkers	Othello®	Tangrams
Chess	Quarto®	TriOminoes®
Chinese Checkers		

In addition, students can practice problem solving when teachers assign a weekly "brain teaser." Refer to books such as *Games for the Superintelligent*, *More Games for the Superintelligent*, *Favorite Problems*, and *Super Problems* or game card packs such as Mind Trap®[7] and Visual Brain Storms®[8] for ready-to-use activities. Information about the books is provided in Appendix B.

Several games on the list may not be available from local retailers. However, suppliers of instructional materials, such as William Sheridan & Associates, which is listed in Appendix B, pp. 314–315, should carry them.

A Problem-Solving Model

The IDEAL[9] model, which is described below, is one well-known aid for teaching and improving problem-solving skills. It guides students through the problem-solving process. The IDEAL process includes the following steps:

I = **Identify the problem** (e.g., determine what needs to be done)

D = **Define and represent the problem** (e.g., sharpen and clarify the boundaries)

E = **Explore alternative approaches** (e.g., analyze and evaluate alternatives)

A = **Act on a plan** (e.g., determine the logical steps to be used and how to progress through the steps)

L = **Look at the result** (e.g., determine whether or not the plan worked)

[7]Developed for teams, this game includes 500 classic puzzles, conundrums, murder mysteries, and trick questions.

[8]Visual Brain Storms: The Smart Thinking Game® and Visual Brain Storms 2® are distributed by Binary Arts Corporation.

[9]*The IDEAL Problem Solver: A Guide for Improving Thinking, Learning, and Creativity* (1984)

Problem-Solving Practice

A variety of problem-solving practices, which use design, invention, and black-box activities as their foundation, are located on pp. 55–86. Also refer to the resource lists in Appendix B, pp. 299–317, for books, kits, computer software, and Internet sites that describe additional strategies for helping students practice solving problems.

Notes

Gender Equity: What Can Teachers Do?

An entire section has been devoted to this topic because educational equity is specifically relevant for teachers of girls who are entering middle or junior high schools. Research[10] has clearly shown that this is the age when girls' self confidence (and resulting interest in science, math, and technology) tends to take a plunge. There are long-term consequences to these early-age decisions to take minimal science, math, and technology-related courses—the most significant of which is the restriction from entering high-paying careers. Not only does this affect the individuals, but it also affects our country's ability to be productive and remain competitive in a highly technical, global economy.

In addition to providing teachers with information about gender equity and suggestions for addressing these subconscious biases, this section includes a career-related game called *Women Scientists* on pp. 38–41. The game can help **all** students increase their awareness of options for choosing science-related careers.

The focus of this section is on gender equity, although generalizations about educational inequities can be made about many groups, including those who belong to racial minority groups and those who are disabled.

*It is important to note that instructional strategies that provide a good education for girls, in turn, provide a good education for all students. Equity is about supporting **all** students to achieve instructional goals by providing equitable opportunities for everyone in the classroom.*

Why is Gender Equity Important?

Teachers face an important challenge: to provide learning opportunities that will help **all** students succeed. **Gender equity** is an aspect of instruction that teachers need to consider in order to meet this challenge, **especially** when planning to help students develop science and related skills. Unfortunately, gender equity is often overlooked when developing math, science, and technology instruction.

Many girls do not have the same types of experiences, either inside or outside of school, as boys. As a result, boys and girls have traditionally received differing qualities of education even when they study in the same classroom. You may be skeptical about this conclusion, especially if you are male. Please don't stop reading; review this simple list of biases to check it out for yourself.

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[10] *Girls in the Middle* by the American Association of University Women (AAUW), 1997.

Biases in Classrooms

Researchers[11] have found the following (subconscious) inequities in the ways that boys and girls are treated in school:

- At all grade levels, **female students receive less teacher attention** and **less useful teacher feedback**.
    - Teachers **call on** girls less often than they call on boys.
    - Teachers ask fewer **probing and higher-order thinking questions** of girls than they do of boys.
    - Teachers often **give** boys **instructions** for performing tasks, but tend to **do** the same tasks for girls.
    - Teachers tend to **give** girls less **feedback** (e.g., praise, criticism) than they give boys.
- In class, **girls talk significantly less** than boys do.
    - In elementary and secondary school, girls are eight times less likely to **call out** comments. When they do, they are often reminded to raise their hands, while similar behavior by boys is accepted.
    - Girls are less likely to **raise their hands**. Reasons for this are that they are aware that boys get called on more, they may take longer than boys to think about their responses before raising their hands, and they may not have confidence in their ability to answer correctly.
- When working in **mixed gender pairs**, boys tend to dominate in math, science, and technology-related activities. Such dominance results in girls having fewer opportunities to do hands-on learning in these subject areas.

[11] The most comprehensive research on the topic of gender equity has been done by Myra and David Sadker. Their findings are published in *Failing at Fairness: How America's Schools Cheat Girls* (1994).

- **Females' contributions** are rarely mentioned in the curriculum. Most textbooks continue to report male contributions and include pictures of boys actively doing things while girls passively watch and support them.

- Girls experience **pressure** from their friends to *not* do well in science, math, and technology-related classes; they may be teased for being "nerdy" or not feminine if they try to do well.

Furthermore, outside the classroom, most girls have not been given opportunities to work with tools or mechanical systems. And they aren't given as many toys that encourage them to build, explore, or tinker. For example, girls do not generally build with LEGOs® or fix their own bicycles. And similar to classroom situations, adults tend to *give instructions* to boys on how to perform tasks, but tend to *do* tasks *for* girls. As a result, **many female students have not developed the foundational skills necessary to succeed in science, math and technology classes**. (This inequitable experience is something that teachers can identify and counteract by providing equitable learning opportunities in the classroom. Refer to the following section for strategies.)

This **subconscious** inequity has far-reaching **consequences**. Because girls have had fewer opportunities to develop "mechanical" skills, they are often less prepared for and less likely to take courses in math, science, and technology. In addition, it is clear from the research that those girls who do take upper-level math and science courses are also treated very differently than their male classmates; therefore, many stop taking such courses. Taking fewer of these courses has resulted in fewer high-paying occupational options for female workers.

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Strategies for Combating Gender Inequity in the Classroom

Hint: These suggestions might seem overwhelming. Please don't get discouraged. A strategy that some teachers have successfully used is to focus on one suggestion at a time.

What can a teacher do to help girls and boys have equal chances to succeed with math, science and technology? The following list provides some ideas:

- **Be aware of your subconscious bias**. The most important thing you can do is to accept that *virtually everyone* (both male and female) has been socialized to have that bias. If you don't believe that you treat male and female students differently, ask a colleague to observe you in the classroom or make a videotape of your teaching or training to determine whether you provide female students with less attention and different expectations than you do male students. You may be quite surprised! (Many professional educators are.)

- Make a conscious effort to **provide boys and girls with equal amounts of attention**. Some teachers alternate calling on boys and girls. Others monitor which students they call on with a written record.

- **Create an atmosphere that fosters girls' participation**. Because girls are generally shyer than boys about speaking in public, you must encourage them to express themselves by making small changes in *your own* behavior. For example, when asking questions in mixed gender settings, make a conscious effort to wait 5–10 seconds before calling on anyone. You'll be surprised at the number of timid hands that go up in those few seconds. Or, if only ⅓ of the students have their hands up after you ask a question, you might want to say, "Think about it and talk with the person sitting next to you. I'll ask again in a few minutes."

- **Pay attention to group dynamics**—who speaks, how often, for how long, in what order, and who interrupts whom. Since girls tend to speak less often and for shorter periods of time, be sure to acknowledge their contributions.

- **Don't "teach down" to any students.** Expect equally high performances from boys and girls and of people of all races and national origins (e.g., don't assume that a female student can't use tools or analyze complicated systems).

- **Arrange seating for gender balance** when setting up the classroom.

- **Involve female students in construction and manipulation of equipment and use of tools**. They may not have experience in these areas. For example, many girls have not used pliers, pipe wrenches, handsaws, electric drills, ratchet sets, ohmmeters, micrometers, gauges, or bench vises. They simply have not been given opportunities to gain this experience. Therefore, teachers should make a special effort to provide opportunities for them to learn these skills.

- **Provide female students with additional instruction or practice in science-related skills** when needed.

- **Use a collaborative, cooperative approach to activities** rather than a competitive one.

- **Use interactive methods**. Have students do some of their work in small groups. Girls tend to be more effective when they can share their ideas with others.

- **Pair girls with girls and boys with boys** some of the time to prevent boys from dominating activities in which they have higher skills because they have more experience.

- **Foster girls' independence**. Hold them accountable when they engage in *learned helpless behavior*. When they claim, "I can't do it!" before exerting effort, find ways to re-engage them in the activity. Demonstrate your confidence in their abilities to do things for themselves by pointing out parts of the task that they *are* doing well and giving them encouragement to persist.

- Ask both girls and boys to **help with heavy equipment and books**. Encourage students (both male and female) of smaller stature to simply carry fewer books or seek assistance. Help them learn to take responsibility for accommodating their own physical size needs rather than avoid physical activities.

- Use **more than one method of assessing students' achievement**. For instance, evaluate through multiple-choice tests and model building (at which boys tend to perform better), as well as essay tests, projects, and reports (at which girls tend to perform better). A variety of assessment strategies are suggested for each *Fun with Physics* learning activity. Refer to the Assessment section, pp. 43–51, for additional options.

Women Scientists[12]

Time
1 class period

Materials
6 playing cards for *Women Scientists*

Preparation
Duplicate and cut one set of 36 cards for each group of 3–5 students. Form student groups for a typical card game.

Instructions
Have students work in groups of 3–5.

For centuries, women scientists have remained unknown to most people—their names and histories are unfamiliar. In this activity, students acquire knowledge of women of historical importance in the scientific professions.

Women Scientists is a go fish type of card game made up of three information cards on each of 12 women in history who made contributions to scientific and technical fields. The object of the game is to collect the most *books*; each book consists of three cards that are about the same woman scientist.

In each group, a student shuffles the cards and stacks them, face down, on the table. In turn, each player draws a card, reads it aloud, and keeps it in his or her hand. When a player has a card that s/he remembers is similar to one held by another player, s/he may ask for the similar card during his/her turn—before drawing. If the request is correct, the similar card (or cards) must be given to the requesting player and s/he may continue to ask for cards. If the request is incorrect, the player asked replies, "Go take another science course." The requesting player then draws from the pile. If the card just asked for is drawn, the player gets another draw.

Each card that is drawn from the stack must be read aloud before the player places the card in his or her hand. Any player who notices that another player forgot to read the card may claim it, read it, and keep it as part of his or her hand. Players may lay down any complete books they have at the end of their turn. The play continues until all cards are used. The player with the most books wins.

Have fun!

[12]Adapted and reprinted with permission from the book *SPACES* (1982). EQUALS, Lawrence Hall of Science, University of California at Berkeley.

Ellen Swallow did outstanding work in chemical analysis.	Contributions to physics, especially in the area of sound and elasticity, were made by Sophie Germain.	To discourage Sophie Germain from studying later at night, her parents took away her sources of heat and light.
A famous mathematician tried to get Emmy Noether a place on the faculty of a German university saying, "After all, we are a university, not a bathing establishment."	Emmy Noether altered the course of algebra by her work.	In 1900 Emmy Noether, mathematician, was one of two women among the 1,000 students enrolled in her university.
The first woman ever invited to join the American Academy of Sciences was Maria Mitchell, astronomer.	In 1847, Maria Mitchell sighted the first comet ever discovered by telescope.	Maria Mitchell, astronomer, started the association for the advancement of women in 1873.
Since women were not admitted, Marie Curie could not attend the University of Warsaw.	An outstanding black woman space scientist, Katherine Johnson, has worked on spacecraft such as the earth resources satellite.	Sophie Germain worked in number theory, and won several prizes for her work in mathematical physics.

Mary Somerville, mathematician, developed the beginning steps toward the concept of conservation of energy.	The prediction of the existence of the planet Neptune was made possible by Mary Somerville's work.	The interconnection of physical forces is founded on Mary Somerville's work.
The first Native American woman doctor in the United States was Susan LaFlesche.	Susan LaFlesche was the daughter of a chief of the Omaha Indian tribe.	After graduating from Medical school, Susan LaFlesche returned to practice medicine among her people, the Omaha Indian tribe.
Chien Shing Wu (Chee-en She-ung Woo) was promoted to full professor of physics at Columbia University and became the seventh woman member of the U.S. National Academy of Sciences.	When there were no female students allowed at Princeton, Chien Shing Wu (Chee-en She-ung Woo) was invited to teach nuclear physics there in 1943.	Chien Shing Wu (Chee-en She-ung Woo) designed an experiment that helped earn the Nobel Prize in Physics in 1957.
Because she was a woman, Sonya Kovalevski was denied admission to the French Academy of Sciences.	In 1874, after producing outstanding work in mathematics, Sonya Kovalevski received her Doctorate from the University of Gottingen in Germany.	Sonya Kovalevski made important contributions to the study of the shape and behavior of Saturn's rings.

Margaret Mead wrote *Coming of Age in Samoa* and other studies of South Sea societies.	Margaret Mead, anthropologist, studied primitive and modern societies.	By studying other cultures, Margaret Mead helped us to understand our own culture.
Even though she had discovered radium and polonium, Marie Curie was refused admission to the French Academy of Sciences.	The first person in the world ever to win two Nobel prizes was Marie Curie.	Rebecca Lee received her medical degree in 1864 from the New England Female Medical College.
After the Civil War, Rebecca Lee returned to the South and established her medical practice in Richmond, Virginia.	The first black woman doctor in the United States was Rebecca Lee.	Katherine Johnson was a recipient of a group achievement award presented by NASA's Lunar Spacecraft and Operations Team.
Katherine Johnson, space scientist studied the mathematics and physics of spacecraft travel.	Devoting her life to studying and teaching about healthful environments, Ellen Swallow popularized the word ecology.	The first woman admitted to M.I.T. was Ellen Swallow, but she was denied the Doctorate in Chemistry there because she was a woman.

Notes

Assessing Student Learning

Assessing learning is a key component of successful science instruction. In the context of this book, assessment will:

- **Evaluate students' understanding of scientific content and processes** before, during, and after instruction (e.g., Do students have prerequisite skills? Have learning objectives been met? Do students need additional instruction to obtain the objectives?)
- **Evaluate the effectiveness of instructional strategies** (e.g., Was this an effective way to facilitate student learning?)
- **Guide future instruction** (e.g., Which extensions will meet the needs of my students?)
- **Identify students' unmet learning needs** (e.g., Do the students understand the principle that has been taught? If not, what can be done to help them learn this principle?)

Assessment lets both you and the student determine whether the learning objectives have been met. It also provides a sense of accomplishment and directs further learning.

Assessment strategies can vary—depending on the age and skill levels of the students and instructional style of the teacher. The strategies you use are a matter of choice. Some methods, which work particularly well in inquiry-based science instruction, are described below.

Journaling

Students assess their own learning by recording their reflections about the **process** used to explore scientific principles, and the **generalizations** and **conclusions** they made from the experience. In addition, journals help students to **apply** what they learn to their home, school, and community. Possible journal entries are suggested in each *Fun with Physics* learning activity.

The following reflection was summarized from the journal of a 4th-grade student studying inclined planes:

> It seems to me that if the distance is longer, it makes it easier to do lifting. If the steepness is cut in half, it takes you longer, but it takes less effort.

Data sheets
As a way to determine students' **knowledge** of the principles being taught, teachers can collect and grade data sheets that are completed during scientific explorations. Data sheets may also ask students to **predict**, **summarize**, **draw conclusions**, and **identify applications**.

Presentations
To summarize what they've learned, individuals or teams of students present their **findings** to others, including **conclusions** drawn from the findings.

Interviews
The teacher conducts a one-on-one discussion with students, during which they can describe their **understanding** of what they have learned and **identify applications** to everyday life.

Quizzes
Quizzes are a quick and effective way of checking students' **knowledge** of scientific principles with objective testing. They do not, however, assess process skills (i.e., what students can *do*).

Hint: The design activities on pp. 55–86 may be especially valuable as performance assessments.

Teacher observations
As a **performance-based assessment**, teachers visually monitor students as they solve problems. Teachers can see students' abilities to **employ process skills**, **attain behavioral objectives**, **work in teams**, and more. Any of the *Fun with Physics* learning activities can be used to assess student learning through observation. The Observation Sheet on pp. 46–48 can be used to record students' knowledge of content and ability to employ process skills. In addition, the Performance Assessment Rubric on p. 49 can help you to quantify what you observe.

Teachers are encouraged to develop their own assessment tools to identify and record skills of their students. In addition, the authors have provided several assessment forms, which are included on the following pages of this section:

- Instructor's Class Record Sheet
- Individual Student Observation Sheet
- Performance Assessment Rubric

Instructor's Class Record Sheet

Instructions: Teachers can use this form to record what students have learned and what they can do.

1. Write each student's name in the column on the left.
2. List the learning areas to be evaluated (e.g., specific process skills, content knowledge, other applications to real-life physics problems) across the top row.
3. Assess each student's ability to use the listed knowledge and/or skills in solving physics problems, using the following standards:

   IN = student can apply content to solve problems independently

   WA = student can apply content with assistance

   CN = student can not apply content to solve problems

▼ **Student's Name** / Areas to be evaluated ▶								
			5.1					

Individual Student Observation Sheet Instructions

The Individual Student Observation Sheet lists the process skills for science. Open spaces are provided for additional, content-area objectives. This assessment tool can be used in the classroom to effectively:

- Guide teacher observation of specific process skills and knowledge of content.
- Document each student's progress.
- Measure the amount of individual student progress from previous work to the current learning activity.

Each student's progress is evaluated individually. Results should be used to plan future instruction. Observation sheets for individual students can also be useful in assigning students to homogeneous or heterogeneous teams for small-group instruction.

Hint: Using different colors of ink when completing each recording date and its data will make the sheet easier to use.

Instructions:

1. Create an Observation Sheet for each student.
2. Complete the "name" and "unit" blanks, e.g., the student's name and the unit or topic to be learned.
3. Before beginning a unit, observe students using the process skills listed and record findings in the column labeled "before." Be sure to date this column. Use the standards that follow or develop your own:

   IN = student can apply content to solve problems **in**dependently
   WA = student can apply content **w**ith **a**ssistance
   CN = student **c**an **n**ot apply content to solve problems

4. During the unit, make another observation and record findings in the "during" column. Use the same standards as you used in the pre-instructional observation. Remember to date it.
5. As the unit culminates, make another observation, recording findings in the "after" column. Again, use the same standards as you used in the pre-instructional observation and date it.
6. Analyze and compare the data obtained during observations.

Individual Student Observation Sheet

Student's Name ______________________________

Unit ______________________________

Instructions: See page 46.

Standards: IN = student can apply content to solve problems independently
WA = student can apply content with assistance
CN = student can not apply content to solve problems

Make one copy of this sheet for each student being assessed. Use a different color of pen each time you record your observations. Be sure to record the date when observing the learning.

Process Skills	**Date_____ BEFORE**	**Date _____ DURING**	**Date_____ AFTER**
Categorizing or classifying: Grouping or ordering objects or events according to an established scheme, which is based on observations.			
Communicating: Giving or exchanging information (e.g., insights, explanations, results of observations or inferences, measurement) to others verbally, pictorially, and/or in writing.			
Comparing: Relating one thing to another so that similarities and differences can be identified.			
Controlling variables: Manipulating one factor that may affect the outcome of an event while other factors are held constant.			
Experimenting: Using observations to collect and analyze data in order to draw conclusions and solve a problem..			
Hypothesizing: Stating a problem to be solved as a question that can be tested by an experiment.			
Inferring: Developing ideas based on observations and suggesting explanations, reasons, or causes for observed events.			

Process Skills	Date_____ BEFORE	Date ____ DURING	Date_____ AFTER
Interpreting data: Using the data collected during scientific investigations to answer questions about an investigation.			
Making models: Constructing a physical or mental representation to explain an idea, object, or event.			
Measuring: Comparing objects to arbitrary units that may or may not be standardized.			
Observing: Using one or more of the senses to gather information. May include the use of equipment.			
Ordering: Using observed characteristics to organize objects or systems in a sequence.			
Predicting: Forming an idea of an expected result, based on prior observations and inferences.			
Recognizing relationships: Interpreting interactions between different components of a system.			
Recording: Creating a written record of observations made during experimentation.			
Content-area objective: ______________________			
Content-area objective: ______________________			
Content-area objective: ______________________			
Content-area objective: ______________________			
Content-area objective: ______________________			
Content-area objective: ______________________			
Content-area objective: ______________________			

Performance Assessment Rubric

Score ▶ / Concept ▼	0	1	2	3	4	5
Procedure	Nothing stated	Problem restated but incorrect or no procedure given	Correct procedure; missing a number of parts	Correct procedure; missing a few parts	Correct procedure; hard to follow	Correct procedure; clearly stated with all parts organized
Strategy	No plan offered	Has a plan; clearly on the wrong track	A strategy that would work was started	Correct strategy used; incorrect answer given	Correct strategy used and clearly stated; correct answer not given	Correct strategy used and clearly stated; correct answer given
Data	None collected	Only given data recorded	Partial data collected and recorded	Data collected; disorganized and/or not labeled; no calculations	Data collected; disorganized and/or not labeled; calculations are shown	Data collected, organized and labeled; calculations are clear
Solution	Only incorrect answer is given	Incorrect answer given, with some justification	Correct answer given but it is not possible to tell how it was reached	Correct answer given but the solution process is unclear	Correct answer with no attempt to justify it	Correct answer is given and justified
Team Dynamics	No participation	Very little participation	Usually follows role but often does unrelated tasks	Follows given role but distracts the team from completing tasks	Follows given role and does not hinder the team	Follows given role and is an asset to the team's success

Summary

In this section, *Fun with Physics* writers have outlined and explained their most effective scientific learning strategies—inquiry-based learning, process-skill development, problem-solving skill development, gender equity in instruction, and assessing student learning. These writers suggest some *general* instructional practices, as well. We have summarized a small portion of that information for you below. Feel free to use any or all of these strategies to enhance your science-related instruction.

- **Determine what your students already know**, then help them to find answers to their questions. Support the concept of not having the answer, both with your students and in modeling the behavior yourself. Tell students that you will find the answer together, when you don't have the information either!

- **Know the activity**—make a sample, adapt instructions to meet your students' needs, gather and prepare materials, determine the best way to present the activity, and do a "dry run."

- **Make a web** or use a chart to show relevance and interrelationships.

- **Use K W L**: K—what do learners **k**now? W—**w**hat do you want them to know? and L—have students demonstrate their **l**earning.

- Remember the powerful statement: "**I see and I remember, I do and I understand**." It can remind you to use hands-on activities and collaboration in instruction.

- Accept that sometimes you must simply transmit information (e.g., safety considerations).

- **Vary instructional settings**: whole group, small group, and one-on-one activities, centers, demonstrations, displays, and technology.

- **Make cross-curricular connections**. Integration builds excitement, enhances understanding, and maximizes teacher resources.

- **Do real-world, performance-based assessment**.

- **Plan strategies for teacher intervention** ahead of time so you will be prepared when students need assistance.

- **Allow plenty of time for exploration.** It stimulates creativity, fosters comradery, and helps students practice the scientific process.

- **Build a home-school-learner connection.**

- **Make learning fun!**

The general strategies presented here, and many of those described in the foregoing pages of this section, can be integrated across the curriculum to enhance the overall learning environment.

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Notes

Fun with Physics

Real-Life Problem Solving for Grades 4–8

Learning Activities

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Notes

FUN with PHYSICS

Real-Life Problem Solving
for Grades 4—8

Exploring Problem Solving
Through Design

Exploring Problem Solving Through Design

Fun with Physics

Real-Life Problem Solving for Grades 4–8

Design Projects

Design projects encourage students to integrate knowledge of scientific principles with the process of solving problems.

Note: *Because design activities are, by nature, integrated and inquiry based, specific process skills and proficiency outcomes for each learning activity are not identified.*

Notes

About Design Projects

Rationale

If students are to function successfully in today's world, they must learn how to apply their varied academic knowledge and experiences to practical, real-life situations. Design projects provide opportunities for students of all ages to integrate the development of their problem-solving skills, process skills, and scientific principles through hands-on applications. Thus, teachers who provide students with frequent and ongoing opportunities to practice these skills are helping students prepare for later life.

Design Projects Help Students Integrate Scientific Knowledge and Process Skills

Design projects (i.e., learning activities that require students to **design a product**) offer some of the best problem-solving practice—especially for integrating learning around the sciences. Design activities not only help students investigate principles of physics, but they also let them practice math, communication, and multiple process skills. (See information concerning the importance of process skills, pp. 23–28). In other words, design activities help students practice many of the skills involved in the scientific process because they develop plans, implement them, evaluate the effectiveness of their designs, and make modifications.

Hint: Teachers are encouraged to provide adequate time for students to construct and modify their designs. Such time is well spent, as it affords students time to learn and enhance their scientific problem-solving skills.

Design projects encourage exploration—they are open-ended and inquiry-based. They do not prescribe a specific procedure (i.e., step 1 + step 2 + step 3 = correct answer). Instead, design activities encourage students to explore a variety of options and pick the best one. In some cases, the selected design must comply with constraints—resembling real-world design limitations.

The design activities in this section can help teachers meet the challenge of preparing students to solve real-world problems; it contains several design projects that can be used with students of most ages. In addition, some of the learning activities found in *Fun with Physics*, especially those about simple machines, involve students in designing something.

It is strongly recommended that teachers complete each design activity themselves before assigning them to students.

Recording Design Data

Because of the trial-and-error nature of the design process (i.e., the scientific process), students should record their actions, predictions, observations, and conclusions. When doing the design activities in this section, students can use one of the forms provided on pp. 59–60. Each is described on the following page. (These sheets can be used for just about any design activity.)

- The **Design Data Sheet** has space for each team member's name and descriptions of designs. Both teams and individual students can use this data sheet.

- The **Design Log** should be used when students are developing a design that will solve a given problem. Space is provided to sketch designs and describe the process used when refining the design.

Design Project Resources

Some excellent resources for additional design project ideas follow. Each book is described in the Resource List (Appendix B).

The Art of Construction: Principles and Projects for Beginning Engineers and Architects by Mario Salvadori. (Vocational Marketing Services, 1990)

Inventors Workshop by Alan McCormack. (Pitman Learning, Inc., 1981)

Kid Tech: Hands-on Problem Solving with Design Technology by Lucy Miller. (Dale Seymour Publications, 1998)

More Engineering Projects for Young Scientists by Pater Goodwin. (Frank Alin Watts, 1994)

Science Wise: Discovering Scientific Process Through Problem Solving, books 1, 2, and 3, by David Holley. (Critical Thinking Books & Software, Inc., 1996)

Why Buildings Stand Up: The Strength of Architecture by Mario Salvadori. (Vocational Marketing Services, 1983)

Pathways to Design-Related Careers

Design activities provide connections to design and research careers in engineering (e.g., civil, structural, industrial) and architecture, including designing consumer products, packaging for products, buildings, bridges, highways, and railroads.

Design Data Sheet

Construction Manager ________________________ Materials Manager ________________________

Recorder ________________________ Reporter ________________________

Instructions: Write about and/or draw your exploration of designs in the chart below.

Trial	Action (What we will do.)	Prediction (What we think will happen.)	Result (What happened.)	Conclusion(s) (Why we think it happened.)
1				
2				
3				
4				
5				

Conclusions:

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Design Log

Name(s) ______________________________

Instructions: Complete the following steps and record your actions on this log. Use extra paper if needed.

1. Define the problem in your own words.

2. Sketch and label 2 or more solutions.

3. Select the best solution and explain why you decided on this solution.

4. Do a final sketch of the solution and then **make it**.

5. Try out your model and make any final changes. Does your solution meet the given criteria?

6. Evaluate your solution. What do you like about it? What would you do differently next time? What new things have you learned?

Sturdy Rafts

About this design activity

Students will engineer a raft to carry the greatest load of pennies as it sails across a sink or tub of water.

Exploration activity

1. Have students draw a design of the raft they plan to build. Instruct them to use pencils so that changes can be made easily.

2. Provide ample time for students to build their rafts.

3. Have students test their raft designs by placing pennies on their rafts and sailing them across a sink or a tub of water.

4. Instruct students to record their findings on the Design Data Sheet.

5. Encourage students to improve their designs so the rafts can carry more pennies.

6. Have students test their modified rafts and record their findings. *(Hint: Making modifications is critical to students' success with the scientific process. Be sure to allow plenty of time for this step and to encourage and guide students, as needed.)*

7. Conduct a group discussion concerning the test results. Be sure to facilitate a discussion in a way that helps students recognize the scientific process at work in their experiments.

Explanation

Engineers are responsible for designing most types of water craft, from 6-foot rowboats to the largest aircraft carriers. Even though engineers have designed a variety of high-tech boats, many people still enjoy one of the most basic watercrafts—the raft.

Extension activity

* Challenge your students to design their own rafts.

Materials

- Standard-sized drinking straws
- Masking tape
- Modeling clay
- Pennies (if unavailable, other items can be used)
- Sink or plastic tub
- Design Data Sheet

Hint: These materials represent the minimum requirements for this activity. You may wish to let students select their own materials from a wide range of options to provide more design options and enhanced experimentation. However, if you feel it is important to limit the materials, use those listed.

Note: Students can work individually or in pairs. (Assign roles of materials manager, construction manager, recorder, and reporter if desired.)

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Build the Highest Tower

Materials

(for each student)

- 2 pieces of paper
- 10 paper clips
- Scissors
- Design Data Sheet or Design Log

Hint: You will also need a yardstick or measuring tape to measure tower heights. Alternatively, you can place a strip of masking tape vertically on a wall or doorjamb starting at the floor and extending about 5 feet; the names or initials of each student/student pair can be written at the respective tower heights.

Note: Students can work individually, in pairs, or in small teams. (Assign roles of materials manager, construction manager, recorder, and reporter if desired.)

About this design activity

Students will use nontraditional materials to build the highest tower they can.

Exploration activity

1. Give students the following instructions (and no other information):
   - Build a tower.
   - Only the materials provided may be used to build the tower.
   - The tower must be freestanding. It cannot lean against a wall or be held up.
   - Towers must be brought to the tape on the wall for measuring (optional).
   - Have students record their design process on the Design Data Sheet or Design Log.
2. Measure the height of each structure as it is completed. If you are using the masking tape measuring site, have students bring their towers to the wall and write their initials/names at the respective tower heights.
3. When all towers have been measured, announce the winners.
4. Have students examine all of the towers.
5. Facilitate a discussion about the design strategies that made some towers more successful than others. Be sure to relate building towers to building houses and office structures.

Explanation

There is no one right way to design a tower. Students will surprise you with their creativity! During discussion, help students recognize that their activities generally mirrored those of architects and engineers. You should also increase their awareness of how they used the scientific process in their experiments.

Extension activities

- ✱ Let students repeat the activity, but instruct them to take 15 minutes to experiment with scratch paper before they actually begin their second construction.

- ✱ Allow students to complete the exploration exercise with different materials. Instruct students that their goal is to build a structure as high as they can with some or all of the materials. Materials can include the following:

  - Use miniature marshmallows, spice drops, modeling clay, and/or dried peas that have been soaked in water as connectors.

  - Provide uncooked spaghetti, toothpicks, plastic rods, and/or straws for building materials.

- ✱ Have students work in pairs to design a bridge that will span the distance between the arms of a chair so that the center of the span will support a roll of toilet paper. Their goal is to do this with the fewest possible materials. Materials might include tongue depressors, pipe cleaners, plastic rods, paper clips, and/or straws.

- ✱ Challenge students to construct their tallest possible freestanding structure using no more than 25 building pieces (e.g., LEGOs®).

- ✱ Challenge students to construct their longest possible freestanding bridge using only newspaper (no other materials or equipment).

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Flying Machines

Materials

- Paper of different types and weights (e.g., notebook paper, copier paper, 80-pound paper, card stock, construction paper)
- Paper clips
- Design Data Sheet or Design Log

About this design activity

Students will practice solving problems by designing and carrying out flight experiments.

Exploration activity

1. Challenge students to make a single sheet of notebook paper travel as far as possible. Have students record their design process on the Design Data Sheet or Design Log.

2. Once paper airplanes are designed, give students plenty of time to experiment by flying their airplanes (outdoors), modifying their designs, and testing the modifications.

3. Be sure to encourage continued modification by monitoring students' activities and asking questions, making suggestions, and using similar facilitation techniques.

4. Facilitate a group discussion in which students can share their designs and results. Be sure to focus students on the science principles and scientific process at work in their experiments.

5. Give students 3 or 4 different weights of paper.

6. Have students fold a traditional-style paper airplane from *one* piece of paper of their choosing.

7. Give each student a paper clip to use as a rudder to improve the speed and height of the plane's flight.

8. Allow plenty of time for exploration.

9. (Optional) Take the students outside, to a parking lot or grassy area. Have each student test how fast his or her "best" plane design will fly.

10. Facilitate a discussion during which students develop generalizations about what factors helped and hindered flight effectiveness with questions like:
    - What is the farthest that we could make a paper plane go? Why?
    - Why do some planes work better than others?
    - Which kind of paper is better than the others? Why?
    - Which designs work better than the others? Why?

Explanation

See the explanation in the Flights of Fancy learning activity on p. 263.

Extension activities

- Conduct these activities as part of a lesson concerning Leonardo DaVinci's development of the flying machine.
- As homework, challenge students to improve on their designs. The next day, have students fly them again, noting the performance improvements and recommendations for further design improvements.

Notes

Inventions

Materials

- Design Data Sheet or Design Log
- It is best to provide students with a wide variety of "recycled" and "junk" materials for this activity. Use the following list for ideas and add your own materials.

Balloons (several shapes)
Beads
Blocks
Brad nails
Buttons
Cardboard
Craft or popsicle sticks
Dry spaghetti
Egg cartons
Empty thread spools
Empty boxes (e.g., cereal)
Empty film cans
Feathers
Fishing line
Magnets
Metal or plastic pipes
Milk cartons
Miniature marshmallows
Modeling clay
Mousetraps
Old panty hose or nylons
Packaging peanuts
Paint stirrers
Paper bags (several sizes)
Paper clips
Paper plates
Paper towel rolls
Parts of old machines
Plain paper
Plastic bottles
Plastic bag twist ties
Plastic lids
Potato slices
Rubber bands
Shoelaces
Small pieces of wood
Spice drops
Spring-type clothes pins
Straws
Thin metal coat hangers
Thumbtacks
Tin cans (filed edges)
Tinker Toys
Toilet paper rolls
Toothpicks
Unsharpened pencils
Various sizes of washers
Yarn and string

About this design activity

Students will develop a machine that will *do* something.

Prerequisite skills

Ideally, students should understand how simple machines (e.g., levers, pulleys, gears, inclined planes, wheels and axles) work. However, students can succeed at this activity without a background in simple machines.

Engagement activity

Some students may need some preparation for thinking creatively in the exploration activity. Therefore, encourage creativity by having students invent new uses for common items (e.g., brick, coat hanger, potato). *Hint: Have the class brainstorm uses for one or more items.*

Exploration activity

1. Have students examine the materials available for machine parts.

2. Instruct them to work individually or in pairs to design and build a machine that does something. Have students record their design process on the Design Data Sheet or Design Log.

   Hint: You can have students develop their own ideas or choose from the "Invention Options" listed in the next section. Help them develop their own ideas by circulating, observing, and providing support for those who appear to be having a hard time coming up with ideas. Use questions such as:
   - *What will your machine do?*
   - *How could you combine things to make your machine work?*
   - *How will it work; how will the parts interact?*
   - *What materials will be required to build it?*

3. Have students draw their machines. Then instruct them to describe their machines with words (e.g., What does it do? How does it function?).

4. Help students share their descriptions and drawings with a classmate/another team.

5. Tell them to name their machines (optional).

6. Instruct students to build their machines.

7. Once students have had ample construction time, have them demonstrate how their machines work.

Hint: Some students may want to develop a TV commercial that describes their invention.

Invention options

Students may need some help with invention ideas. Thinking about what their machines would do is the best starting place. They can create machines that will perform one or more of the following functions:

- Pick up dirt from the floor
- Retrieve a paper clip from a high shelf
- Look around a corner
- Sort mixed beans and rice into separate piles
- Measure time
- Move a piece of paper across a room
- Lift an object without touching it
- Crack an egg
- Water a house plant
- Toss dice
- Mash potatoes
- Turn pages in a book
- Trap a fly
- Catch a raw egg (without breaking it!)

Explanation

Machines and mechanical systems in the workplace and the home are actually a combination of two or more simple machines. Students can gain an understanding of how machines and mechanical systems work by designing and building them. Understanding how systems work is critical to understanding how to solve problems related to those systems.

Be sure to facilitate discussions after students complete either the exploration or extension activities that help them recognize learning, draw appropriate conclusions, and assimilate knowledge. Possible discussion questions include:

- What did you learn about engineering from your efforts? What were your frustrations? Were you proud of your results?
- What energy transformations take place in your machine? Is your machine high in efficiency?"

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Explanation

Refer to the explanations in the Exploring Simple Machines learning activities.

Extension activities

- ✱ Have students work in pairs to build a maze that will take a marble from the top to the bottom of a shoe box in 30 seconds.
- ✱ Help students design and build a "contraption" that will move a marble from one place to another. It should have at least 3 moving parts.
- ✱ Create an exercise in which students design and build a moving vehicle that is powered by air only.
- ✱ Have students design, build, and demonstrate Rube Goldberg-style contraptions. See pp. 159–167 for a complete learning activity.
- ✱ Divide students into pairs or small groups. Have teams design, build, and demonstrate a Rube Goldberg-type device that solves a problem with a minimum of 6 mechanical actions and reactions. Groups should brainstorm problem ideas (e.g, bursting a balloon, lighting a candle, turning on a radio, watering a plant, moving an object) and negotiate agreement among members for the group's choice.

Black Boxes

About this design activity

Students will enhance their process skills (e.g., observation, prediction, inference) by practicing logical thought processes in determining what is hidden in a box.

Engagement activity

Talk with students about machines that have hidden "works" (e.g., pencil sharpener, disposable camera, clock). Help them guess how these machines operate. Instruct them to draw what they think is inside (i.e., their guesses). Divide students into groups and let them disassemble some broken machines to analyze how they work. (You may wish to use the list of questions that teachers can ask students as they analyze systems, pp. 18–21.)

Exploration activity

1. Provide pairs of students with a sealed box that contains several loose items.
2. Explain to students that you will answer questions with "yes" or "no" only.
3. Have them determine what's inside by making guesses and then testing them (e.g., looking inside the box).
4. After students have explored several boxes, facilitate a discussion during which students can summarize what they learned. Be sure to help them recognize what skills they used properly when their guesses were correct, and how and when to use them consciously in the future. In addition, students should be given opportunities to ask questions, investigate topics about which they have questions, and find answers to their questions.

Explanation

Black box activities are structured so that students predict what is in the box. Such activities mirror the skills required (e.g., observation, inference, prediction) for making logical guesses about systems that are hidden from sight. Students need to develop these skills for job tasks such as troubleshooting, problem analysis and systems analysis.

Materials

- Boxes
- Masking tape for sealing boxes
- Hidden objects (e.g., metal washers or screws, straws, rubber balls, cotton balls, small beads, coins—use your imagination)

Extension activities

Hint: Pushrod boxes can be constructed with dowels, paint stir sticks, or tag board.

- Have students complete the "Mysterious Pushrod Boxes" activity described in *Inventor's Workshop*. (See Appendix B, p. 306.) In this activity, students examine how pushrods move in a sealed box to determine, through prediction and experimentation, how the rods are connected.

- After completing the first extension activity, help students create their own pushrod boxes and exchange them so they can determine how one another's boxes are configured.

- Challenge students to fix the rattle in The Rattle Box. Have students examine a black box that rattles when it is shaken. Instruct them to make and test hypotheses for fixing the rattle. Continue this process, giving students additional testing equipment that is comparable to advancements in technology and medicine (e.g., flashlight, magnet, probes, simulated x-rays, and simulated ultrasound). Developed for grades 6-12, The Rattle Box kit can be ordered through William Sheridan & Associates (See Appendix B, pp. 299–317).

- Have students analyze broken toys and machines. Once they discover how the broken items operate, have students suggest ways to fix them. This activity may involve the use of tools and measuring equipment. If appropriate, have students fix the items.

Engineering Basics: Shape vs. Strength

About this design activity

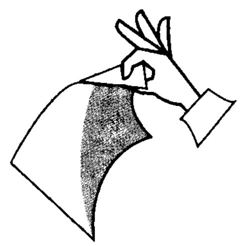
Students will investigate how several shapes influence the strength of structures. By participating in this activity, students will be better prepared to design structures that resemble those found in the real world.

Exploration activity #1

Conduct the following demonstration/discussion to help students gain insights into how materials can be made strong:

1. Hold up a piece of notebook paper by one end so that the paper droops.

   Ask, "What happened to the paper?" and "Would this paper support a load?"



2. Roll the paper into a cylinder and hold it up for the class to see.

   Ask, "What happened to the paper?" (Answer: It remains rigid)

   Ask, "Would this paper support any type of a load?" (Let students make predictions.)

3. Help students determine the ratio of the weight of the paper cylinder to the weight of the washers it can support by doing the following:
   a. Tape a piece of string to one end of the paper cylinder and tie a paper clip to the other end of the string. *(Note: The paper clip is the hook to which you will apply loads, i.e., washers.)*
   b. Add washers to the paper clip until the paper cylinder bends.
   c. Count the number of washers the cylinder was able to support.
   d. Have students compare the weight of the tube to the weight of the washers.
   e. Have students calculate the ratio of the weight of the paper cylinder to the weight of the washers supported (optional). *(Hint: Whether or not you have students make this calculation is up to you. Your decision should be made in accordance with your objectives for this activity. For example, if your objective for this activity is for students to compare the relative weight of the cylinder (i.e., very light) to the washers (i.e., heavy), you would delete instruction e. If you wish to integrate math concepts, include instruction e and provide necessary guidance.)*

Materials

Exploration activity #1
- 2 sheets of paper (e.g., photocopy paper or notebook paper)
- 1 large paper clip
- String
- Metal washers (relatively large-sized washers)
- Masking tape
- 1 spring scale or other type of scale (to weigh the paper cylinder and washers)

Exploration activity #2
- Masking tape, cut into 3-inch lengths (one piece per team)
- Several cereal boxes, cut into 1-inch wide strips (5 strips per team)
- Design Data Sheet or Design Log

Exploration activity #3
- Books (5–8 per team)
- Scissors
- Eggshell halves (4 halves per team)
- 1 spring scale or other type of scale (to weigh books and egg shells)
- Design Data Sheet or Design Log

4. Facilitate a class discussion by asking the following questions:

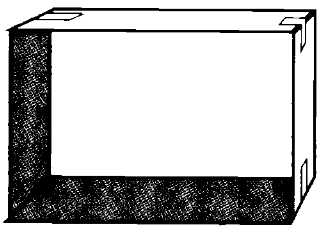
   - What caused this condition?
   - What did we change from the first part of the experiment to when we applied the load? (Answer: We rolled the paper into a cylinder.)
   - Did the weight of the paper change?

Then help students explore how shapes, when incorporated into designs, affect structure strength by facilitating the following learning activities:

Exploration activity #2

1. Divide class into teams of 2. Have teammates choose their roles as construction manager, materials manager, recorder, and reporter. Both team members will also be technicians.

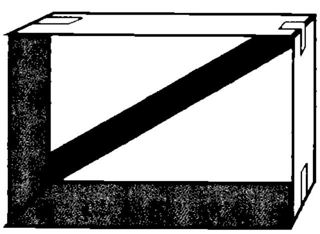
2. Have each materials manager get 3 inches of masking tape and 5 1-inch wide strips of a cereal box.



3. Instruct teams to record their experiments on their Design Data Sheet or Design Log. Encourage them to draw diagrams of their designs.

4. Challenge teams to construct an 8-inch x 12-inch rectangle and tape the corners with ½-inch of tape per corner.

5. To test the strength of the rectangle, stand it up, long side down, and gently push downward. Ask, "How easy was it to change the shape from a rectangle to a parallelogram?"



6. Instruct teams to measure and cut a cereal box strip long enough to go **diagonally** from one corner to another. (They should be able to see that two triangles have been created.)

7. Repeat step 5. Ask, "Was it easier or harder for the rectangle to change into the parallelogram?"

Exploration activity #3

1. Divide the class into teams of 4. Assign roles of construction manager, materials manager, recorder, and reporter. All team members are technicians.

2. Have materials managers get 5–8 books, a pair of scissors, a spring scale, and 4 eggshell halves. (Warn them to be careful to avoid crushing the shells.)

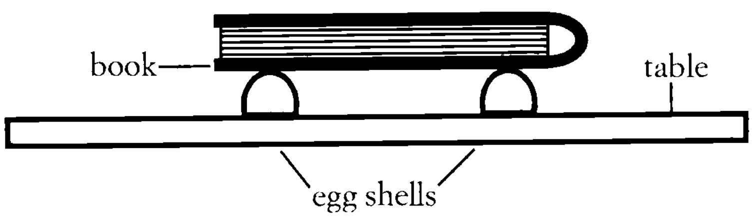
3. Have teams record their design process on the Design Data Sheet or Design Log. Encourage them to draw diagrams of their designs.

4. Direct the technicians to trim jagged edges from the egg shells with the scissors and to weigh the shells when they are finished trimming.

5. Have students place the shells on the table in a rectangular pattern, flat side down.

Note: The shells should be spread out so that when a book is placed on them, the shells will be visible around the outside edges of the book.

6. Have students place one book on top of the shells and observe what happens. *(Note: The shells should hold the weight of the book.)*



7. Have students stack books, one at a time, on the first book, until the shells collapse.

8. Weigh the books that were successfully supported by the shells.

Note: Do not weigh the book that made the shells collapse.

9. In a class discussion, ask the following questions:

   - Why could the eggshells be strong enough to hold books when we know they are fragile (e.g.,when we squeeze egg shells, they break very easily)?
   - What type of stress were the egg shells undergoing when the books where placed on them?
   - What type of stress does the egg shell experience when squeezed from the sides?

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Note: *Domes can carry more weight than any flat roof design.*

Explanation

Structures must hold their own weight plus the weight of a specified load. Therefore, designers must use shapes and other techniques to stabilize and strengthen buildings and structures. Certain pros and cons are inherent in specific shapes. For example, the triangle is very strong. That is why it is incorporated into structures that we encounter in many facets of our daily lives like bridges and skyscrapers.

The dome is also an important shape. During this learning activity, when the weight (load) of the books was applied to egg shells, the force followed the curvature of the shells to the table top. The dome shape also supported some parts of the shell by reinforcing other parts. The dome is very resistant to the stress called **compression**, which is the stress that is trying to lower the load toward the ground through gravity. This resistance allows architects to use the dome shape when constructing large structures such as the Houston Astrodome and the New Orleans Superdome. However, the dome shape has poor resistance to bending, as demonstrated when an egg shell is squeezed from the sides.

Extensions

* Have teams use the results from the exploration activities to develop a graph that shows a comparison of the weight of the eggshells to the weight of the books that they were able to support.

* Have students research and draw 5 different roof truss designs, and arrange them from strongest to weakest.

* Ask students to write narrative from the perspective of an architect. Have them describe and draw a diagram of a building that uses a dome to maintain its strength.

Engineering Basics: Columns & Structures

About this design activity

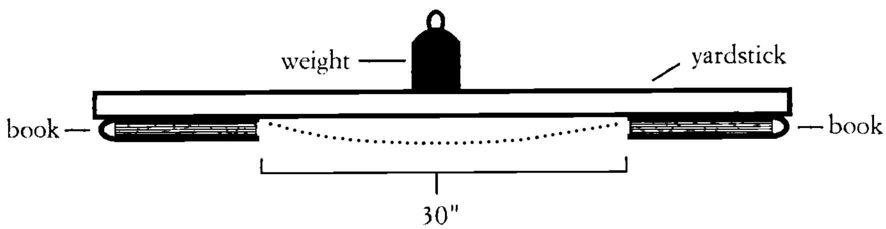
Students will construct models to investigate the effects of loading (i.e., stressing) columns. They will investigate systems that enhance the strength of columns. By participating in this activity, students will be better prepared to design structures that resemble those found in the real world.

Exploration activity #1

Conduct the following demonstration/discussion to show how a force can be applied to a beam (i.e., yard stick) and what can be done to strengthen the beam, by taking the following steps:

1. Place 2 supports (e.g., books, blocks) 30 inches apart on a table.

2. Place a yardstick on the supports, so the numbers are facing toward the ceiling.



3. Place a gram weight in the middle of yardstick. Ask students to observe what happens to the yardstick. Then add weights one at a time—having students make observations after each weight is placed. *(Hint: Be careful to avoid breaking the yardstick.)* Have one or more students record class observations on a data chart that is written on the chalkboard, using the categories described in this illustration.

Position of Yardstick	Weight Placed on Yardstick	Observations (e.g., how much the beam bent)

Materials

Exploration Activity #1

- 1 yardstick
- Supports (e.g., books, blocks)
- Gram weights
- 1 1-inch x 1 ½-inch section of a cereal box

Exploration Activities #2 and #3
(for each team)

- 1 yardstick
- 2 supports (e.g., books, blocks)
- 3 1-inch strips cut from a cereal box
- Masking tape
- Scissors
- Gram weights
- Small toy cars/trucks or other objects that can be used as a load
- 2 drinking straws
- Design Data Sheet or Design Log

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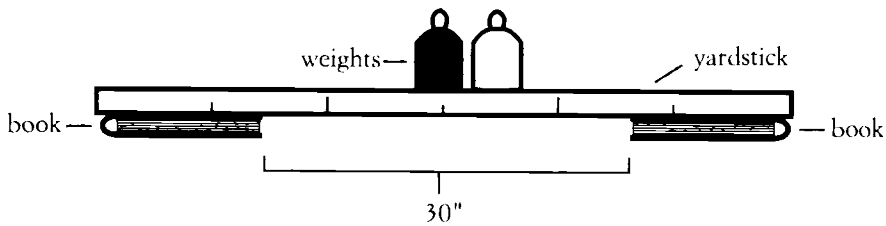
4. Repeat steps 1–3, but this time lay the yardstick on its edge (so the numbers are **not** facing the ceiling). Have students note how much the beam bends.



5. Have students compare the bending of the beams in each trial and draw conclusions. Facilitate a class discussion to help students understand that when beams bend (i.e., deflect), they experience 2 types of stress: *tension* and *compression*. Those stressors occur with any beam—despite the materials from which it is constructed. Ask the following questions:

   - How did changing the shape or orientation of the beam (yardstick) change its ability to support weight?
   - What might be done to keep the beams from bending as much as they did?

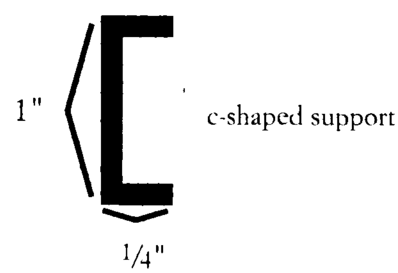
Now, take the investigation a step further by helping students discover how reinforcing beams with columns can strengthen them by taking these steps:

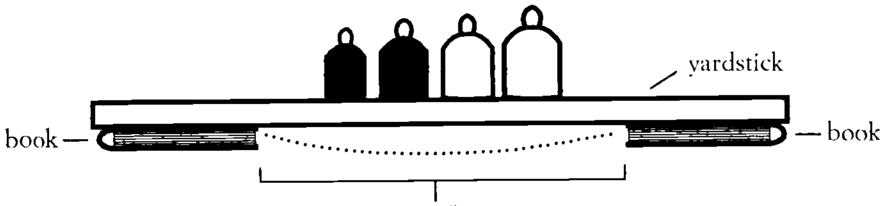
6. Return the yardstick to its step-2 position, with numbers facing upward. Apply the maximum load (i.e., weights) onto the center of the yardstick. (Careful! Don't break it!)

7. Ask, "What can be done to the yardstick to keep it from bending so much?" Encourage as many students as possible to make a guess.

Note: It will function as a structural column would.

8. After listening to students' suggestions, and trying a few if you wish, remove the load and bend a 1-inch x 1 ½-inch piece of cereal box material into a "c" shape.





9. Tape the c-shaped support (i.e., column) to the **bottom** center of the yardstick, then reapply the previous load.

10. Facilitate a class discussion, which can include the following questions:

    - Did the yardstick bend as much with the support as it did without the support?
    - Did the new addition to the column (i.e., the center support) help? How?
    - What do you think will happen if more supports are added?
    - Does a column's shape have a relationship to its strength?
    - What shapes can be used to make columns?
    - Can you predict the uses for and strengths of beams (i.e., horizontal parts that support floors)?

    In addition, encourage students to:

    - Identify sources and results of **tension** (i.e., the stress of being pulled apart).
      Example: What happens when a rubber band is pulled?
    - Identify sources and results of **compression** (i.e., the stress of being shortened by a load).
      Example: What happens when a rubber ball is squeezed?

Exploration Activity #2

Have teams of students take the following steps to test the strength of beams by taking the following steps:

1. Work in teams of 2. Select roles of construction manager, materials manager, recorder, and reporter. Both team members will also be technicians.

2. Record your actions throughout the exploration on a Design Data Sheet or Design Log.

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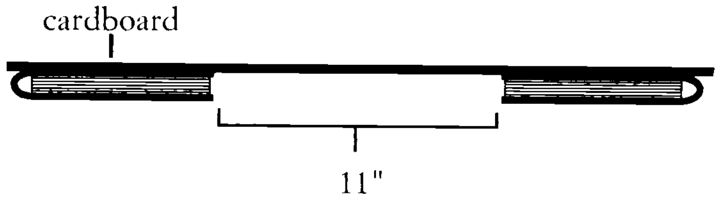
3. Get 3 strips of cereal box cardboard, a pair of scissors, 2 supports (e.g., books or blocks) and a 3-inch piece of masking tape.

4. Cut one of the strips into 8 equal pieces. Bend a ¼-inch tab on each end of those 8 pieces—so they form a c-shape.



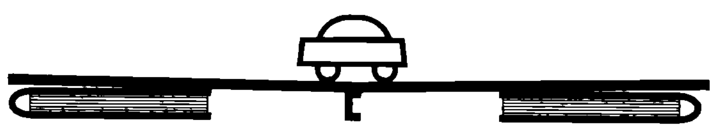
5. Place a full-sized strip of cereal box cardboard across two supports (e.g.,books or blocks) that are positioned 11 inches apart.

6. Predict what your team thinks will happen when a load is applied to the cereal box cardboard "beam."

7. Apply a load by placing a toy (or other object) in the center of cardboard strip.

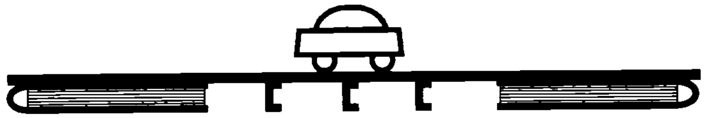
8. Observe the distance from the bottom of the strip to the tabletop and record observations on the data sheet.

9. Remove the load. Tape 1 of the c-shaped pieces to the bottom of the beam—at the center point.



10. Repeat steps 6–8.

11. Tape 3 c-shaped supports onto bottom of the beam—placing one in the center and one halfway between the center support and each end support (e.g., books, blocks).



12. Repeat steps 6–8.

13. Add more load to the beam, one piece at a time, until one or more of the **columns** start to bend. Be sure to record how the columns respond after each load is added to the beam.

14. Facilitate a discussion with the following questions:

    - Did the results of the experiment match your predictions?
    - What happened when you added supports?
    - Where might we see the use of columns in daily life?

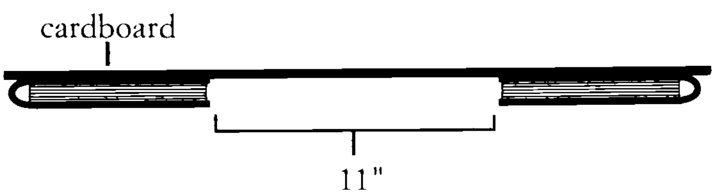
Exploration Activity #3

This learning activity expands upon the learning in the first exploration activity. Students will examine how the shape of columns affects beam strength. Give students these instructions:

1. Use the same setup as in activity #1. For this exploration, your team will need a 1-inch wide strip of cereal box cardboard (which will be used as a beam), 2 supports (e.g., books or blocks), masking tape, and 2 drinking straws.

2. Prepare the materials by cutting one of the straws into 8 1-inch pieces.

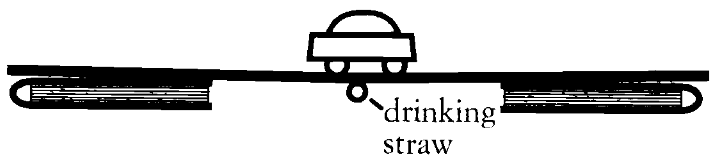
3. Place the plain strip of cereal box cardboard on 2 supports that are 11 inches apart.



4. Apply a load by placing a toy car or other object in the center of the cardboard strip.

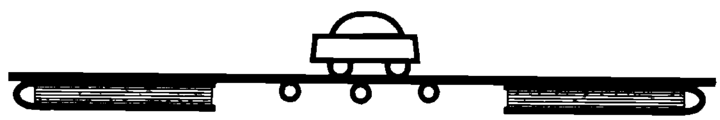
5. Measure and record the distance from the bottom of the strip to the table top.

6. Glue one of the straw pieces to the bottom of the beam at the center point.



7. Repeat steps 3–5.

8. Glue the supports onto bottom of the beam—placing one in the center and one halfway between the center support and each end support (e.g., books, blocks).



9. Repeat steps 3–5.

10. Continue to add load to the 5-column (step 8) beam until you see the **columns** start to bend.

11. Make observations and record your findings.

Facilitate a discussion with the following questions:

- How did the results of this experiment differ from the previous activity that used c-shaped cardboard as columns?
- Was the drinking straw design able to support more weight than the c-shaped cardboard design?
- Why do you think this design was better or worse than the cardboard support?
- How might these findings be applied to the design and construction of structures and objects found in our daily lives.

Explanation

The experiments in this learning activity help to explain what happens when loads are applied to beams and how columns help distribute the load.

All structures need to be designed with the sources and effects of tension and compression in mind. **Tension** is the stress of being pulled apart, e.g., what happens when a rubber band is stretched. **Compression** is the stress of being shortened by a load, e.g., what happens when a rubber ball is squeezed. Students can learn about compression for themselves by doing the following:

1. Form a circular rod shape from a piece of clay.
2. Place the rod vertically on a table top.
3. Push on the top of the clay column.
4. Observe how the sides swell as the column is shortened.

Note: Columns made from more rigid building materials don't react as severely.

The **column** is an integral part of our modern construction methods. Columns are the vertical members of a structure that supports roofs and floors. They are used to support bridges, floors of high rise buildings and our homes. Using columns, designers can span greater distances with and provide superior strength to structures. Columns enable us to efficiently utilize our natural resources while giving society maximum benefits.

The **shape** of a column can also effect its overall strength. Here are some common shapes used in construction.

Each is rated for its strength: ☆ = **poor**; ☆☆☆☆ = **excellent**.

☆☆ **Pipes**
High resistance to compression; poor reaction to bending

☆☆☆ **Square tubes**
High resistance to compression; poor reaction to bending

☆ **Solid round**
Poor reaction to bending

☆ **Solid rectangle**
Poor reaction to bending

☆☆☆☆ **I-beam**
Excellent resistance to both bending and compression
(I-shaped beams are the most-used shape in structures.)

Extensions

* Have teams take results from activities and develop a graph to show a comparison of the weight being applied to the amount the beam bends as columns are added.

* Have students research and draw 5 different shapes that could be used for columns. Have them arrange the columns from strongest to weakest.

* Have students write about the following:

  You are an architect. Describe and draw a diagram of a building that uses columns to maintain its strength.

Engineering Basics: Columns & Structures

Student Instructions

PROCEDURE: Working in teams, take the following steps to test the strength of beams:

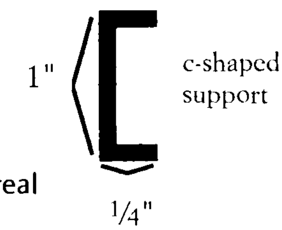
Exploration Activity #2

1. Work in teams of 2. Select roles of construction manager, materials manager, recorder, and reporter. In addition, you will both be technicians.

2. Record your actions throughout the exploration on a Design Data Sheet or Design Log.

3. Get 3 strips of cereal box cardboard, a pair of scissors, 2 supports (e.g., books or blocks) and a 3-inch piece of masking tape.

4. Cut one of the strips into 8 equal pieces. Bend a 1/4-inch tab on each end of those 8 pieces—so they form a c-shape.



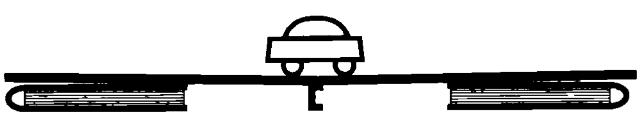
5. Place a full-sized strip of cereal box cardboard across two supports (e.g.,books or blocks) that are positioned 11 inches apart.

6. Predict what your team thinks will happen when a load is applied to the cereal box cardboard "beam."

7. Apply a load by placing a toy (or other object) in the center of cardboard strip.

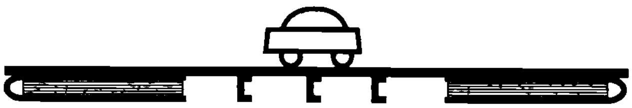
8. Observe the distance from the bottom of the strip to the tabletop and record observations on the data sheet.

9. Remove the load. Tape 1 of the c-shaped pieces to the bottom of the beam—at the center point.



10. Repeat steps 6–8.

11. Tape 3 c-shaped supports onto bottom of the beam—placing one in the center and one halfway between the center support and each end support (e.g., books, blocks).



12. Repeat steps 6–8.

13. Add more load to the beam, one piece at a time, until one or more of the **columns** start to bend. Be sure to record how the columns respond after each load is added to the beam.

14. Answer the following questions:

- Did the results of the experiment match your predictions?

- What happened when you added supports?

- Where might we see the use of columns in daily life?

Engineering Basics: Columns & Structures

Student Instructions

PROCEDURE: Working in teams, take the following steps to test the strength of beams:

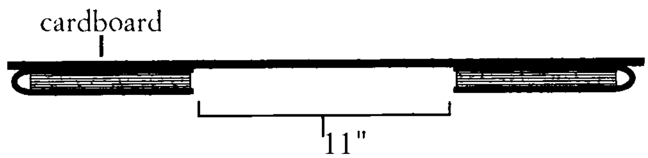
Exploration Activity #3

This learning activity expands upon the learning in the first exploration activity. You will examine how the shape of columns affects beam strength. Follow these instructions:

1. Use the same setup as in activity #1. For this exploration, your team will need a 1-inch wide strip of cereal box cardboard (which will be used as a beam), 2 supports (e.g., books or blocks), masking tape, and 2 drinking straws.

2. Prepare the materials by cutting one of the straws into 8 1-inch pieces.

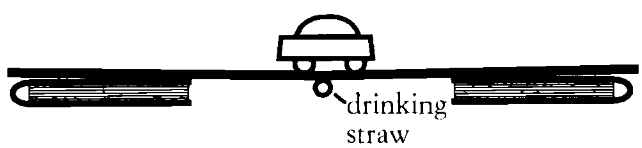
3. Place the plain strip of cereal box cardboard on 2 supports that are 11 inches apart.



4. Apply a load by placing a toy car or other object in the center of the cardboard strip.

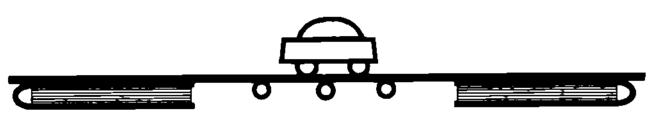
5. Measure and record the distance from the bottom of the strip to the table top.

6. Glue one of the straw pieces to the bottom of the beam at the center point.



7. Repeat steps 3–5.

8. Glue the supports onto bottom of the beam—placing one in the center and one halfway between the center support and each end support (e.g., books, blocks).



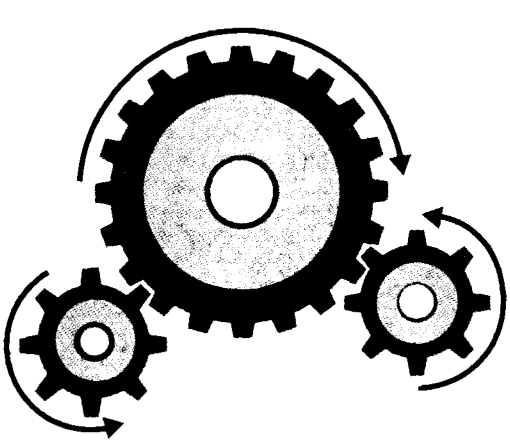
9. Repeat steps 3–5.

10. Continue to add load to the 5-column (step 8) beam until you see the **columns** start to bend.

11. Make observations and record your findings.

FUN with PHYSICS

Real-Life Problem Solving for Grades 4—8



Exploring Simple Machines

Exploring Simple Machines

Fun with Physics

Real-Life Problem Solving for Grades 4–8

Exploring Simple Machines

Learning Activities **Page**

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Simple Machines Vocabulary

Acceleration

Compression

Energy

- Kinetic Energy
- Potential Energy

Friction

Force

- Effort Force
- Resistance Force

Fulcrum

Mechanical Advantage

- Ideal Mechanical Advantage (IMA)
- Actual Mechanical Advantage (AMA)

Motion

Rate

Simple Machines

- Inclined Plane
- Lever
- Pulley
- Screw
- Wedge
- Wheel and Axle

Speed

Tension

Velocity

Notes

All About Simple Machines

About this learning activity

Students will identify 6 simple machines and explain how each works.

Key process skills

- Categorizing or classifying
- ● Communicating
- Comparing
- Controlling variables
- ● Experimenting
- Hypothesizing
- Inferring
- ● Interpreting data
- ● Making models
- ● Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

● 1   2   3   ● 4   5   6   7   8   ● 9   ● 10   11   ● 12

6th grade

● 1   ● 2   3   4   5   ● 6   ● 7   8   9   10

9th grade

● 1   2   ● 3   4   5   6   7   8   ● 9   ● 10   11   12   13   14   15   16   17   18   19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

Examples of items to illustrate the 6 simple machines or combinations of simple machines. Here are some suggestions:

scissors
pocket knife
nail
wood screw
chisel
door stopper
zipper
screw driver
hammer
tongs
staple remover
tweezers

bottle opener
pliers
wrench
nut cracker
bicycle wheel
tire jack
wheelbarrow
rake
fishing rod and reel
hand-operated pencil sharpener
brass tack

drill bit
bolt and nut
jar lid
floor fan
broom
skate board
in-line skate
bottle opener
egg beater
hand mixer
hand-operated can opener

Time estimates

(2–3 class periods)

Setup	5 minutes
Exploration	40 minutes
Cleanup	5 minutes

Key science principles

- Simple machines help us do work.
- Combinations of simple machines make up complex machines.

Hint: To catch students' attention, use some antique simple machines (e.g., food grinder, ice cream maker, hand-operated drill).

Safety tips

- Remind students about safety procedures in the classroom.

Engagement activity

An engagement activity has not been included in this lesson because the exploration activity provides an introduction to the rest of the simple machines learning activities. However, to arouse students' curiosity, teachers may wish to display a variety of simple machines for a few days before conducting this learning activity.

Exploration activity

This activity introduces students to the 6 types of simple machines (i.e., inclined plane, level, pulley, screw, wedge, and wheel and axle).

1. Display a variety of simple machines. (See the materials list for some suggestions.)

2. Divide the class into 6 teams. Assign each team 1 type of simple machine to explore.

3. Have teams present their machine type to the class. Be sure they include examples.

4. Draw a chart similar to the illustration on the chalkboard. Ask students to categorize displayed items (and possibly other items) according to the type of simple machine they represent. Encourage students to explain why the items fit into specific categories.
   Note: Some items may fit into several categories.

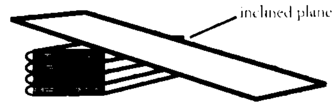
Inclined Plane	Wedge	Screw	Lever	Pulley	Wheel and Axle

5. Help students draw conclusions about how each type of machine helps us do work.

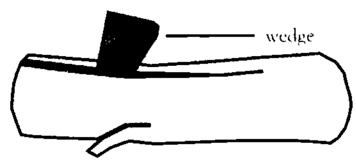
Explanation

A **machine** is a device that uses some kind of energy to perform work. The types of energy most important to machines are **potential energy** (which is stored energy) and **kinetic energy** (which is energy in motion).

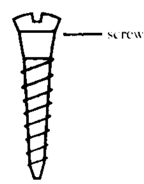
There are 6 **simple machines**: inclined plane, wedge, screw, lever, pulley, and wheel and axle. Each helps us do work with less effort. **Complex machines** are combinations of simple machines. Each type of simple machine is described below:



An **inclined plane** allows things to be moved with much less effort. For example, if you wanted to lift a lawn mower into the back of a pick-up truck, it would be much simpler to use an inclined plane. You would place a board from the back of the truck to the ground and wheel the lawn mower up the board. This would require much less effort that lifting the mower into the truck from the ground. The longer the board, the less effort it takes to move an object.



A **wedge** is 2 inclined planes put together and used to push something apart, such as a knife used to cut something apart. Other wedges found in everyday life include door stoppers, axes, thumb tacks, nails, teeth, and farming plows.



A **screw** is an inclined plane wrapped around a center post. Examples of screws include spiral staircases and wood screws.

A **lever** is a plane and a fulcrum. An example of a lever is a see saw, which is a board over a wedge that makes it easy to move a load. Levers are divided into 3 classes, as shown:

1st–class lever | 2nd–class lever | 3rd–class lever

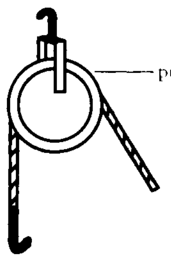
1st–class lever: MA varies
MA increases as E increases and R decreases

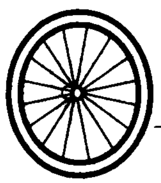
2nd–class lever: MA is always greater than 1

3rd–class lever: MA is always greater than 1; speed is gained

KEY
- △ = fulcrum
- R = resistance (load)
- E = effort
- MA = mechanical advantage

See p. 98 for a definition of mechanical advantage.





A **pulley** is a wheel (or spool) with grooves to hold a rope, chain, or cable. (It is actually a lever bent around a wheel.) The wheel turns as the rope is pulled and helps to lift the load. The wheel reduces friction and makes the work easier.

There are 2 kinds of pulleys: the **fixed pulley** and the **moveable pulley**. Examples of fixed pulleys include those at the top of a flag pole or a ship's mast, and those used to raise and lower a water well bucket. The pulley makes it easier to raise the load but does not decrease the effort needed.

A moveable pulley actually moves along the rope or cable and is attached to the item being moved. This decreases the effort (or work) needed but increases the distance needed to move the item. Moveable pulleys are sometimes used with fixed pulleys. Examples of moveable pulleys include those used by house painters to hoist themselves and a painting platform along the side of a house.

A **wheel and axle** is a pulley with a handle attached to it. A hand-operated pencil sharpener is 1 example.

Evaluation

Written test
Have students draw a picture of each type of simple machine, adding arrows to indicate forces (i.e., the direction in which the work is being done).

Test and/or discussion questions

- A piano key is an example of a lever. (T or F)
- Simple machines do work only when a force acts on them. (T or F)
- A pulley is really a lever wrapped around a bend. (T or F)
- An inclined plane allows movement of heavy objects by spreading the load over a longer distance. (T or F)
- List 10 simple machines that can be found in the classroom.
- Explain how a teeter totter works.
- Explain how machines help us conduct daily activities.
- List the 6 types of simple machines and give an example of each.

Journal entry
Choose 1 type of simple machine and explain how it helps work get done.

Performance assessment
Observe students as they investigate simple machines and make a team presentation. Use a copy of the following table to assess each student's knowledge. This table can be used as a pre-unit assessment if you wish.

Hint: Some teachers note students' achievement with √+, √, and √–.

Simple Machines Student Assessment

Student's Name ______________________ Date ____________

Simple Machine	Student demonstrated knowledge	Student explained machine	Student gave examples of machine	Student was able to answer questions about. . .	Comments
Inclined Plane					
Wedge					
Screw					
Lever					
Pulley					
Wheel & Axle					

Extension activities

* Have students prepare a chart similar to the one used in the exploration activity. Instruct them to take the chart home and find as many examples as they can of simple machines or combinations of simple machines (i.e., complex machines) around the house.

* Give each team of 3–5 students a machine in a brown paper bag. Have teams "act out" how their machines operate by having each team member become a part of the machine. Ask class members to identify the machine.

Hint: If you plan to conduct other design activities in this section, it may be premature and/or redundant to do this activity.

Hint: Save these parts. They can be used in building Rube Goldberg contraptions *(see pp. 159–167).*

Career pathways

Architect,
mechanical engineer,
industrial designer, and
engineering technician

Hint: Each of these books contain many excellent examples and pictures of simple machines.

- Have students design their own simple machine using a variety of materials such as scissors, tape, glue, string, wire, spools, cardboard, popsicle sticks, wheels, toothpicks, straws, rubber bands, brass fasteners, tacks, paper clips, construction paper, blocks, marbles, egg cartons, ping-pong balls, eraser wedges, screws, dowel rods, and a hole punch.

- Ask students to bring in a small machine to disassemble. *Note: Machines can include radios, telephones, clocks, and hair dryers.* You can also ask them to bring in tools (e.g., screw drivers, hammer, pliers). Once machines are disassembled, have each student separate the parts into 6 piles—1 pile for each type of simple machine.

Connections to other subjects

Social Studies. Have students research how machines have affected society, including manufacturing, household activities, leisure time, standard of living, and the national economy.

Resources for teachers and students

The Way Things Work by David Macauley (Houghton Mifflin Company, 1988)

Simple Machines (Hands-On Minds-On Science Series) by Jo Ann Merrell (Teacher Created Materials, Inc., 1994)

Simple Machines (Step-by-Step Science Series) by Toni Albert (Carson-Dellosa Publishing Co., 1994)

Work & Machines by Elizabeth Kellerman (Milliken Publishing Co., 1985)

Give Me the Advantage!

(Measuring the Mechanical Advantage in Sports)

About this learning activity

Students will:

- Identify the simple machines in the human body.
- Measure and calculate the mechanical advantage of sports equipment and the human arm.
- Identify what is gained and sacrificed when levers are used.

Key process skills

○ Categorizing or classifying
● Communicating
● Comparing
● Controlling variables
● Experimenting
● Hypothesizing
○ Inferring
● Interpreting data
○ Making models
● Measuring
● Observing
○ Ordering
● Predicting
● Recognizing relationships
● Recording

Ohio science proficiency outcomes

4th grade

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ● 9 ● 10
○ 11 ● 12

6th grade

○ 1 ● 2 ○ 3 ○ 4 ○ 5 ● 6 ● 7 ● 8 ● 9 ● 10

9th grade

○ 1 ○ 2 ● 3 ● 4 ○ 5 ○ 6 ○ 7 ● 8 ● 9 ● 10
○ 11 ○ 12 ○ 13 ○ 14 ○ 15 ○ 16 ○ 17 ○ 18 ○ 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Time estimates

(3–4 class periods)

Setup 5–10 minutes
Exploration
- 40 minutes (engagement activities)
- 40 minutes (collecting data on sports levers)
- 20 minutes (discussing results)
- 40 minutes (designing and conducting forearm experiment)
- 20 minutes (sharing and discussing results of the forearm experiment)

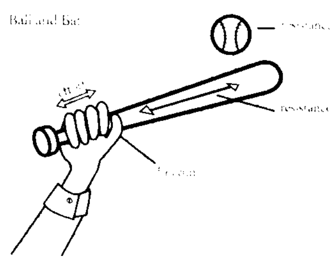
Cleanup 5–10 minutes

Key science principles

- Simple machines
- Levers
- Mechanical advantage
- Law of Conservation of Energy (i.e., work principle)

Safety tips

✚ Remind students not to swing the sports levers in class.



Materials

- A collection of sports levers and the objects they move (e.g., bats, tennis racquets, racquetball racquet, lacrosse sticks, golf clubs, hockey sticks, ping pong paddles, rowboat oars, croquet mallets, balls, pucks)
- Meter sticks (1 for each student pair)
- Calculators (1 for each student pair)
- Spring scales (1 for each student pair)
- Human Machines handout
- What Class? handout
- Give Me the Advantage! data sheet

Engagement activity

1. Introduce students to the human body parts that are machines.

   a. Divide students into teams of 2–4.
   b. Distribute the Human Machines handout and ask students to label the body parts that are machines.
   c. Discuss their classifications.

2. Introduce students to the levers used in sports.

   a. Distribute an assortment of sports levers to each team.
   b. Challenge teams to identify where the **resistance force** is placed, where the **effort force** is placed, and where the **fulcrum** is located. Also have students classify each lever.
   c. Have students identify the **advantage** of using each lever and what is **sacrificed** to get the advantage.

   Move from team to team to help students make their classifications.

3. Conduct a class discussion, which might include some of these questions:

   - In which levers is there a force disadvantage (i.e., sacrifice)? (In other words, which levers require you to apply more force?)
   - Why would you be willing to sacrifice force?

Exploration activity

1. Ask each team to select several sports levers to analyze.

2. Instruct students to complete activities a through c for each lever.

   a. Draw a sports lever.
   b. Measure the distance from the fulcrum to the effort force (which is where they place their hand) and record it on the Give Me the Advantage! data sheet.
   c. Measure the distance from the fulcrum to the resistance force (which is where the object hits or is placed) and record it on the data sheet.

3. Instruct students to weigh the **resistance** (e.g., baseball, puck, golf ball) that the sports lever will move. The resistance can be weighed with a spring scale as the lever is rotated up around its fulcrum.

4. Have students calculate the **actual mechanical advantage** (AMA) using the measurements recorded in items 2b, 2c, and 3.

5. In their teams, or with the whole class, have students discuss their results.

6. Have teams practice steps 2–4 with 1 or more other sports levers.

7. Facilitate a class discussion of the teams' sports lever results.

8. Challenge students to develop a method to measure the IMA and AMA of their own forearms. Have them write their procedure, make a diagram with labels, record data in a table, and compare the mechanical advantages of their forearms.

9. Facilitate a class discussion that includes some or all of the following questions, which are included on the Give Me the Advantage! data sheet.

   - Which levers have the highest mechanical advantage?
   - Which levers have the lowest mechanical advantage?
   - Why is the ideal mechanical advantage greater than the actual mechanical advantage?
   - What is the advantage of "choking up on the bat?"

Note: This information is provided for students on the Give Me the Advantage! data sheet, pp. 104–106.

Note: Teams will use these distances to calculate the ***ideal mechanical advantage*** *(IMA).*

Explanation

Machines are devices that help **do work** by modifying force in 1 of 3 ways:

- They change the **size** of the force that must be used.
- They change the **direction** of the force applied.
- They change the **speed** of the force.

Machines never save work, but they do make work easier. However, because of **friction**, machines always waste work. This is an example of the Law of Conservation of Energy (which is sometimes called the Work Principle). The **work input** is always greater than the **work output**—because of friction. The ratio of these 2 numbers is a measure of the efficiency of the machine.

Although machines waste work, they give many **advantages** too. However, the advantage always has a cost.

> *Example:* A rake may increase your speed at moving leaves; however, it takes more force to move a rake and leaves than to move the leaves without the rake. You gain speed, but you sacrifice force.

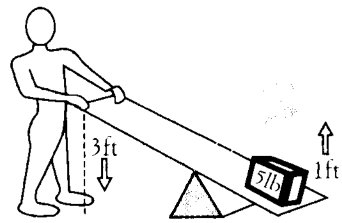
> *Example:* A crowbar may allow you to use less force to pry up a stuck window; however, you have to move the crowbar farther and do more work. You gain force, but you sacrifice distance.

Mechanical advantage measures the force gained by using a machine. It tells the number of times a person's force is increased by using the machine.

> *Example:* A machine with a mechanical advantage of 15 multiplies the force you put in by 15 times. If you push down with a force of 20.0N, the machine will lift 20.0N x 15 or 300.0N!

If the mechanical advantage is less than 1, the machine gives a **force disadvantage**. That means, force is sacrificed in order to gain something else.

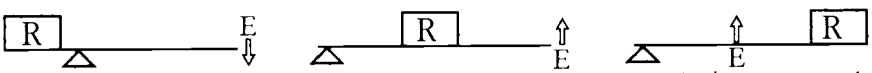
Mechanical advantage is measured in 2 ways:



- **Ideal mechanical advantage** (IMA) is calculated by dividing the distance the effort force moves by the distance the resistance moves.
- **Actual mechanical advantage** (AMA) is calculated by dividing the resistance force (or the weight of the object moved) by the effort force. The IMA is always larger than the AMA because of friction.

Simple machines are found everywhere—including in the human body. For example, teeth are wedges, the jaw is a lever, shoulders are wheels and axles, wrists are levers, and the spinal cord is a lever. Levers are also divided into 3 classes, as illustrated.

1st–class lever | 2nd–class lever | 3rd–class lever



MA varies
MA increases as E increases and R decreases

MA is always greater than 1

MA is always greater than 1; speed is gained

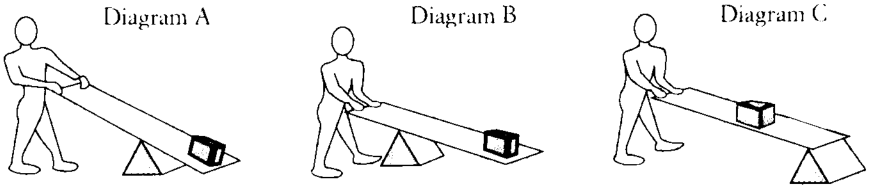
KEY
△ = fulcrum
R = resistance (load)
E = effort
MA = mechanical advantage

Evaluation

Test and/or discussion questions

? Summarize your findings on your data sheet and analyze your results during class and team discussions.
? Discuss efficiency and its calculation. The questions listed in the exploration activity can be used.
? How do our bodies, acting as machines, help us in everyday life?
? Archimedes is credited with saying, "Give me a lever long enough and a place to stand and I will move the earth." Is this accurate?
? In the following diagram, where should the fulcrum be placed for the highest mechanical advantage?

Diagram A | Diagram B | Diagram C



Journal entry
Describe the process you used to calculate mechanical advantage.

Performance assessment

- Give students an assortment of tools and ask them to classify the tool by simple machine type.
- Then ask them to classify the levers by class.
- Give students a shovel and ask them to calculate the IMA and the AMA.

Extension activities

✱ Direct students to classify each part of a Swiss Army knife or Leatherman tool and analyze what is gained and what is sacrificed with each tool.

✱ Have students calculate the size of lever needed to lift an elephant, a Mack truck, and/or a space shuttle.

Career pathways

Health care professionals (e.g., physical therapist), athletic trainer, mechanical engineer, manufacturing technician, and construction technician

Connections to other subjects

Art. Have students use the law of torques to create balanced mobiles.

Physical Education. Visit a gym and analyze how the levers contained in weight machines are used to build muscle.

Social Studies. Research the atl atl (i.e., the spear thrower) used in ancient civilizations. Have students build a model and discuss the advantages gained from the "newest technology" of that time.

Health. Have students examine the human muscles and bones found on a diagram and identify where the resistance, effort, and fulcrum are located.

Language Arts. Have students write puns or jokes depicting the uses of sports levers for purposes not intended or for exaggerated purposes.

Math. Mechanical advantage and efficiency are practical applications of ratios and percentages. Give students additional practice calculating IMA and AMA.

Resources for teachers and students

Physics by Douglas Giancoli (Prentice-Hall, Inc., 1980)
The Cartoon Guide to Physics by Larry Gonick and Art Huffman (Harper Perennial, 1990)
Life Science Physics by Joseph Kane and Morton Sternheim (John Wiley and Sons, Inc., 1978)
Modern Physics by F. E. Trinklein (Holt, Rinehart and Winston, 1992)
Physics for Every Kid by Janice VanCleave (John Wiley and Sons, Inc., 1991)
Machines and How They Work by David Burnie (Dorling Kindersley, 1991)
Machines How They Work by David Burnie (Sterling Publishing Company, Inc., 1994)
What's Inside? Great Inventions by Peter Lafferty (Dorling Kindersley, 1991)
Machines by Mark Lambert and Mark and Alistair Hamilton-MacLaren (The Bookwright Press, 1991)
The Way Things Work by David Macaulay (Houghton Mifflin Company, 1988)
The Way It Works by Philip Sauvein (New Discovery, 1992)
Machines by Janice VanCleave (John Wiley and Sons, Inc., 1993)
Machines At Work by Alan Ward (Franklin Watts, 1993)
Wheels at Work—Building and Experimenting with Models of Machines by Bernie Zubrowski (A Boston Children's Museum Activity Book of Beech Tree Paperback Books, 1986)

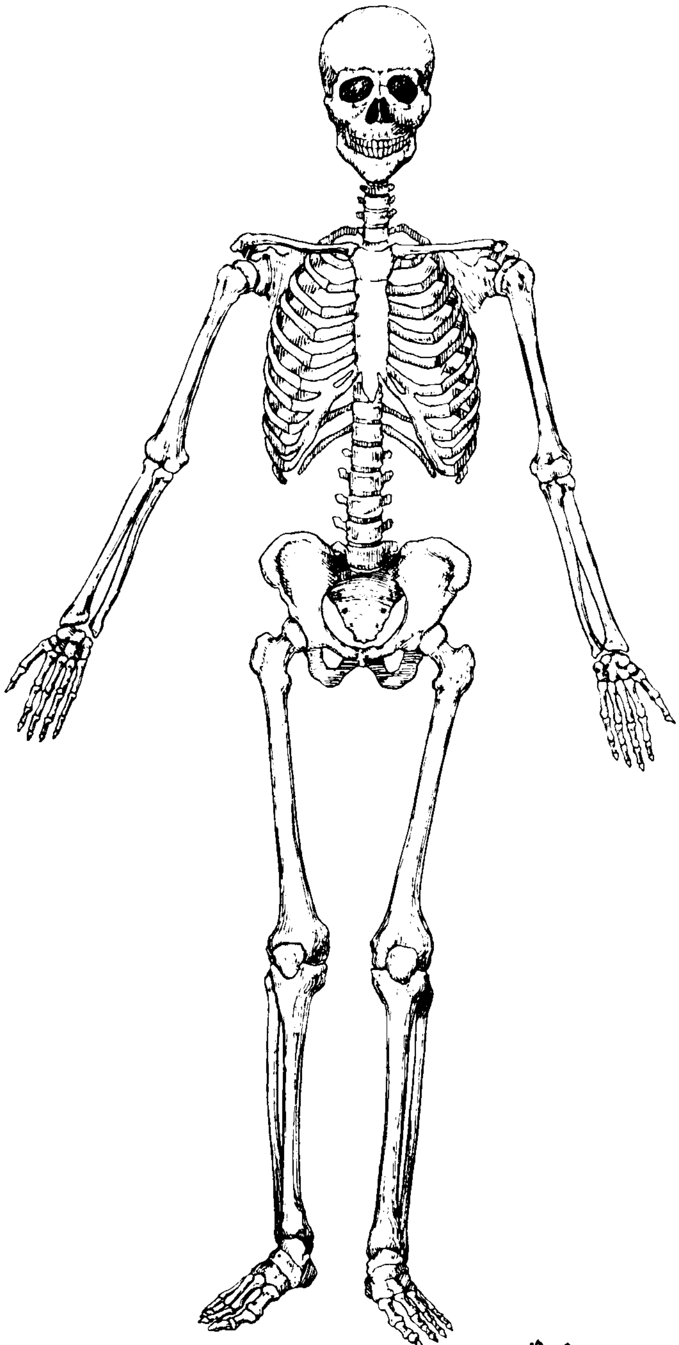
Notes

Human Machines

Names of Team Members ____

____

The parts of your body work together as a large compound (or complex) machine. Can you identify all of the simple machines in a human body? Label the simple machines on the diagram of the human body shown below.



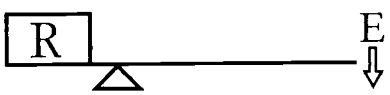
What Class Lever?

Names of Team Members ______________________________

____

Levers are classified into 3 different classes depending on the location of the **resistance** and the **effort**. These classes are shown below. Sort a collection of sports levers into classes.

1st–class lever

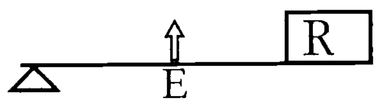


MA varies
MA increases as E increases and R decreases

2nd–class lever

MA is always greater than 1

3rd–class lever



MA is always greater than 1; speed is gained

KEY

- △ = fulcrum
- R = resistance (load)
- E = effort
- MA = mechanical advantage

1.What is the advantage of using a 1st-class lever?

2. What is gained by using a 2nd-class lever? What is sacrificed?

3. What is gained by using a 3rd-class lever? What is sacrificed?

Give Me the Advantage!

Data Sheet

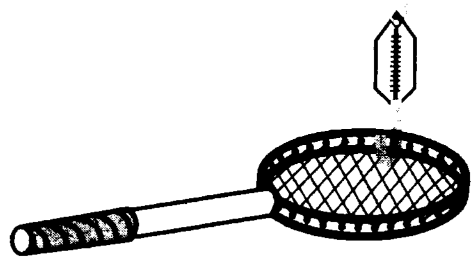
Names of Team Members ____

____

PURPOSE: To measure the mechanical advantage of various sports equipment and to compare it to the mechanical advantage of the forearm.

Materials:

- Assorted sports levers (e.g., bat, tennis racquet, racquetball racquet, lacrosse stick, golf clubs, hockey stick, ping pong paddle, rowboat oar, croquet mallet) and the objects they move (e.g., ball, puck)
- A spring scale
- A meter stick



Procedure, Part I:

1. **Choose** a sports lever and **draw** it on a separate sheet. **Label** the resistance, the effort, and the fulcrum. **Classify** the lever. Determine the **advantage** of using the lever. Determine what is **sacrificed** to gain the lever's advantage. Record this information beside your diagram.

2. Measure the distance from the fulcrum to the effort (where your hand applies the force) and record the measurement in the data table provided on this data sheet.

3. Measure and record in the table the distance from the fulcrum to the resistance (which is where the lever hits the object moved).

4. Calculate and record in the table the ideal mechanical advantage (IMA) using the formula:

$$\frac{\text{effort distance}}{\text{resistance distance}} = \text{IMA}$$

5. Use the spring scale to measure the weight (which is the resistance force) of the object moved. Record this measurement in the data table.

6. Hook the spring scale onto the lever. Use it to lift the lever, rotating it around the fulcrum asthe lever would be used in play. This action simulates the effort force.

7. Calculate and record the actual mechanical advantage (AMA) using the formula:

$$\frac{\text{resistance force}}{\text{effort force}} = \text{AMA}$$

8. Repeat steps 1–7 using at least 1 other lever.

Data Table

Lever	Resistance distance	Effort distance	IMA	Resistance force	Effort force	AMA

9. Answer the following questions about the levers studied:

a. Which levers have the highest mechanical advantage?

b. Which levers have the lowest mechanical advantage?

c. Why is the ideal mechanical advantage greater than the actual mechanical advantage?

d. What is the advantage of "choking up on the bat?"

Procedure, Part II:

With your teammate(s), design a procedure to measure the mechanical advantage of the forearm of each member in your team. Write the procedure, create a data table, record your results, and discuss your findings.

Faster than a Speeding Bullet—The Speed of Me!

About this learning activity

Students will measure their running time over different distances and calculate their speeds; they will explain the factors (i.e., forces) that affect running speed.

Key process skills

- Categorizing or classifying
- Communicating
- ● Comparing
- ● Controlling variables
- ● Experimenting
- ● Hypothesizing
- Inferring
- ● Interpreting data
- Making models
- ● Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

1 2 3 4 5 6 7 8 ● 9 ● 10
11 ● 12

6th grade

1 ● 2 3 4 5 ● 6 ● 7 ● 8 ● 9 ● 10

9th grade

1 2 ● 3 ● 4 5 6 7 ● 8 ● 9 ● 10
11 12 13 14 15 16 17 18 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Time estimates

(3 class periods)

Setup 5 minutes

Exploration

40 minutes (to introduce concepts, assign teams)

40 minutes (to measure distances, run, record times)

40 minutes (to calculate speeds, record class data, calculate averages, make graph, and discuss results)

Cleanup 5 minutes (to collect materials)

Key science principles

- Motion
- Speed
- Acceleration
- Newton's laws of motion

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Safety tips

- ✚ Students should wear running shoes or comfortable shoes for this activity.
- ✚ Provide a clear path for running and stopping so that students do not run into parked cars or other obstacles.

Materials

- Videotape clips that illustrate objects moving at different speeds (Examples: clips from track and field events or other sporting events, and clips from popular movies like *Speed, Superman, The Rocketeer,* and/or *George of the Jungle*)

For each team:

- 1 stopwatch
- 1 measuring tape or meter stick
- Calculators (at least 1 per team; 1 per student is best)
- Chalk to mark running distances

For each student:

- Graph paper
- Freeway Data handout
- Faster than a Speeding Bullet data sheet

Engagement activity

Help students enhance their understanding of speed and how speed is measured by guiding them through these steps:

1. Ask students to brainstorm **speeds** they know. These might include the speed limit of 55mph, the speed of light (186,000 miles per second or 3,000,000 meters per second).

2. Ask them to brainstorm various **units of speed** (e.g., seconds per minute, miles per hour, kilometers per hour).

3. Show video clips of objects moving at various speeds. Discuss the motion shown using the terms speed, acceleration, rate, fast, slow.

4. Ask each student to predict their own running speed. Introduce students to the concept of speed and how to calculate speed.

5. Confirm that students can operate a stopwatch and measure distance with a meter stick or metric tape.

Exploration activity

Help students explore speed by running specified distances and making appropriate measurements and calculations.

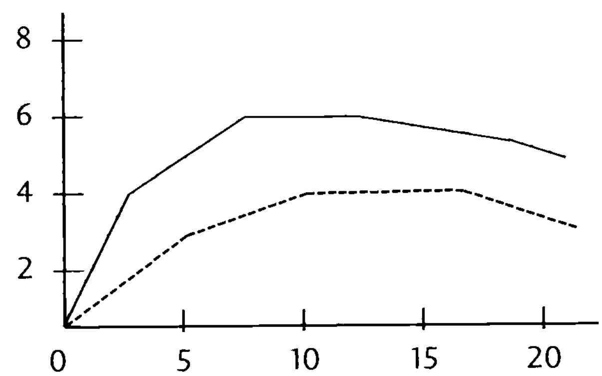
1. Divide students into teams of 3–4. Students will rotate through the roles of runner, timer, and recorder.

2. Move the class to the running area. Instruct teams to mark off their distances with chalk before they begin running and timing. Note: *If possible, students should run each distance multiple times. Teams can average their trials or record their best trial. Choose the instructions that are most appropriate for your situation.*

3. After all data is collected, have students follow the instructions on their data sheets—averaging their times and calculating their average speeds.

4. Once they have computed their team averages, students should record them on a class graph. See the example below.

Hint: Students can draw their graph on blank overhead transparency film or the chalkboard.



5. Direct students to calculate the class averages from the completed class graph, then construct a line graph that compares their average team results and the average class results.

Note: Be sure students understand that both sets of results should appear on the same line graph for comparison; distance will be plotted on the x-axis and speed on the y-axis.

6. Conclude the exploration activity with a class discussion. Have students study the data and the graph, then ask the following questions:

   - From your team data, which distance had the fastest runner?
   - From the class data, which distance had the fastest average speed? Why?
   - From the class data, which distance had the slowest average speed? Why?
   - What do you think will happen to the average speed as the distance increases? Explain.
   - From your graph, was your team faster or slower than the class average?
   - How did your actual speed compare with your predicted speed?

Explanation

Speed is the change of position of an object or body relative to a point of reference. Our usual frame of reference is the earth; hence, we normally measure our change in position over the surface of the earth. However, all speed is relative. Compared to a snail, human speed is very fast. Compared to an airplane, human speed is very slow. Compared to the rotation of the earth, an airplane's speed is very slow.

Speed is **measured** by measuring the amount of time it takes to travel a certain distance. Speed an be calculated by dividing the distance traveled by the time it takes to travel the distance. The formula for speed is: **speed = distance/time**. Speed can be measured in many different units including miles per hour, kilometers per hour or meters per second. For this activity, we measured speed in meters per second.

Note: Using shorter distances is a great equalizer in this activity.

Students should discover that they can run somewhere between 3 and 5 meters per second over these short distances. During the 5-meter interval, students are accelerating from a state of rest. Their force is used to overcome their inertia. **Inertia** is the resistance of a body to a change in motion. It takes **force** to change the motion of an object, whether it is at rest or in motion. (This is Newton's first law of motion: A body at rest wants to remain at rest and a body in motion wants to remain in motion at the same speed and in the same direction, unless acted on by an unbalanced force.)

The 5-meter distance is usually the slowest speed because students don't have enough time to attain maximum speed. For most students, their fastest speeds are at either the 15-meter or the 20-meter intervals, which gives runners time to accelerate to their maximum speeds. In fact, most student speeds become somewhat constant at the 15-meter and 20-meter ranges.

If students were to use starting blocks, Newton's third law of motion could be incorporated into the activity. (Newton's third law states that all forces occur in pairs; and, for every action force there is an equal and opposite reaction force.) Sprinters use blocks to get a faster start; blocks give them something better to push against. They push backwards against the starting block and the starting block pushes forward against the sprinter. With more force, there is more acceleration. (This is a great example of the first part of Newton's second law of motion: Acceleration of a body is directly proportional to the force applied to the body. The second part of the law is: Acceleration of a body is inversely proportional to the mass of the body.)

Note: If students were to run longer distances in this experiment, they would begin to slow down as they tired. The distance where they began to decelerate would depend upon their endurance and training.

Evaluation

Assessment activities

- Grade students' data tables, graphs, and written answers to data sheet questions as well as the analyses they record in their logs, and their comments during discussions.

- Have students discuss and analyze the motion of the cars presented in the graph in the Freeway Data handout. Ask them to determine when the cars are accelerating, slowing down, and going at a constant speed. Ask them to determine which car is the safest and why.

Hint: You can also ask students to recreate the conditions illustrated in the graph with toy cars.

- Ask, "What is a reasonable running speed for a teenager?" (Answer: 3.0–5.0 meters per second)

- Have students calculate the speed of an animal that travels 120 meters in 35 seconds. (Answer: 120 meters/35 seconds = 3.43 meters per second)

Extension activities

- ✱ Repeat the experiment by measuring speed at 1 of the distances with and without the use of starting blocks. Invite a track coach or high school sprinter to demonstrate/teach the students how to use the blocks. Then let students run with a block start and without a block start and compare their speeds.

Note: Students could extend the distance run to 100 meters or even longer for this comparison.

- ✱ Ask students to look up the running speeds of world class athletes or of animals and compare their own speeds to these. Have students create bar graphs to visually compare speeds.

Career pathways

Mechanical and civil engineer, engineering technician, and sports-related occupations

Connections to other subjects

Math. Have students convert the measurements recorded during the exploration activity to kilometers per hour and to miles per hour for studies in proportional reasoning. Averaging, graphing, and measurement are math connections.

Physical Education. Conduct this learning activity in conjunction with fitness testing activities or as part of a track and field event.

Social Studies or **Geography**. Have students investigate the speeds of various animals on different continents and determine which are the fastest animals in each region.

Language Arts. Have students write a poem in a shape that conveys speed or in the shape of the fastest animal.

Resources for teachers and students

Physics by Douglas Giancoli (Prentice-Hall, Inc., 1980)
The Cartoon Guide to Physics by Larry Gonick and Art Huffman (Harper Perennial, 1990)
Life Science Physics by Joseph Kane and Morton Sternheim (John Wiley and Sons, Inc., 1978)
Modern Physics by F. E. Trinklein (Holt, Rinehart and Winston, 1992)
Physics for Every Kid by Janice VanCleave (John Wiley and Sons, Inc., 1991)
The Science Book of Motion by Neil Ardley (Gulliver Books, HBJ, 1992)
Fastest and Slowest by Anita Ganeri (Aladdin Books)
Guinness Book of Olympic Records (Guinness Publishing Ltd., 1990)
The Order of Things by Barbara Ann Kipfer (Random House, 1997)
Animal Facts and Feats; A Guinness Record of the Animal Kingdom by Gerald Wood (Guinness Publishing Ltd., 1973)

Faster than a Speeding Bullet—The Speed of Me!

Data Sheet

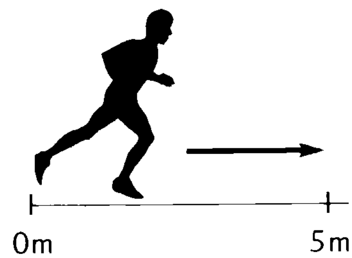
Name ______________________________

Names of Team Members ______________________________

____

Purpose: To determine the speed at which you and your team members run different distances

Materials: Stopwatch, meter stick(s), calculator



Procedure:

1. Pick a running track that provides plenty of stopping distance. Measure 4 running distances: 5 meters, 10 meters, 15 meters, and 20 meters. Mark each distance with chalk. Be sure to mark the starting line.

2. Using the stopwatch, time each team member as s/he runs each of the 4 distances listed in the table. *(Note: Runners may take their best time out of 3 trials.)* Record times in the table.

Members	5-meter time(s)	10-meter time(s)	15-meter time(s)	20-meter time(s)

3. Calculate each team member's speed for each distance using the formula: speed = $\frac{\text{distance}}{\text{time}}$

4. Record the speeds on the table below.

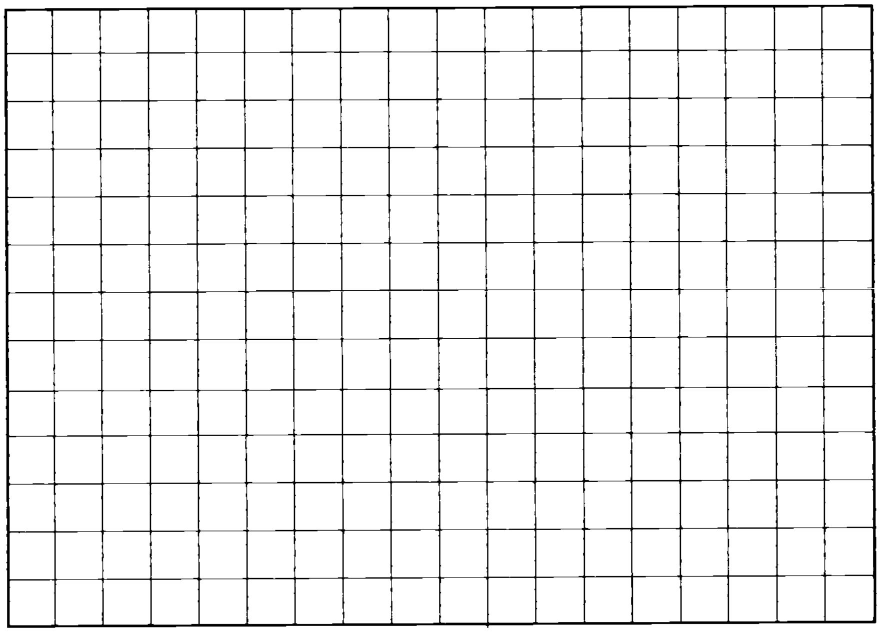
Name	5-meter time(s)	10-meter time(s)	15-meter time(s)	20-meter time(s)
Team Average Speed				

5. Record your average speed for each distance on a class data table (on the chalkboard).

6. Record class data on the table below.

Name	5-meter time(s)	10-meter time(s)	15-meter time(s)	20-meter time(s)
Average speed (m/s)				
Team 1 speed (m/s)				
Team 2 speed (m/s)				
Team 3 speed (m/s)				
Team 4 speed (m/s)				
Team 5 speed (m/s)				
Class average speed (m/s)				

7. In the space on the next page, make a line graph of your team data—speed (on the y-axis) versus distance (on the x-axis). On the same graph, plot the class averages in a different color.



8. On your own, answer the following questions. You can discuss your responses with your teammates if you wish.

   a. From your team data, which distance had the fastest runner?

   b. From the class data, which distance had the fastest average speed? Why?

c. From the class data, which distance had the slowest average speed? Why?

d. What do you think will happen to the average speed as the distance increases? Explain.

e. From your graph, was your team faster or slower than the class average?

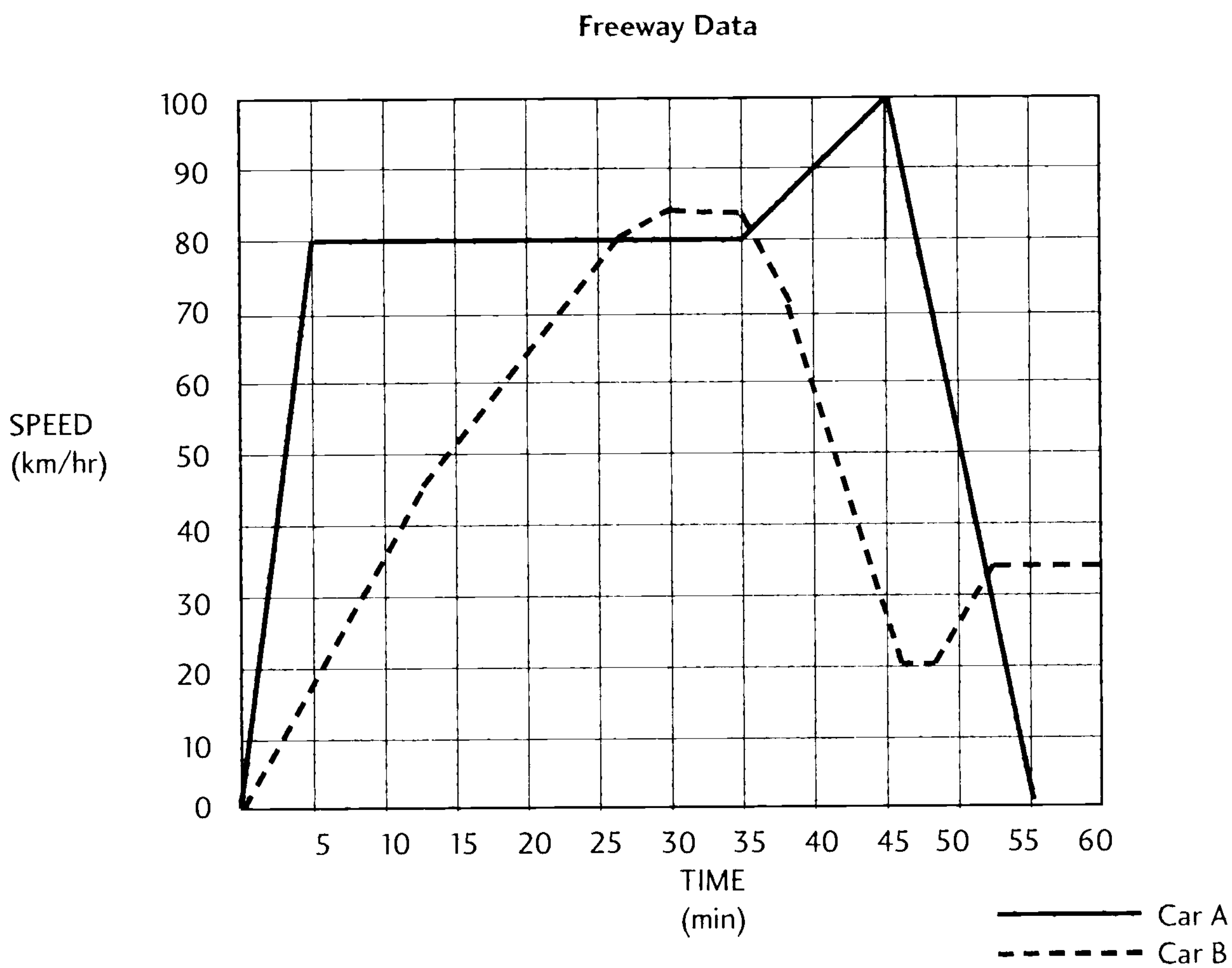
f. How did your actual speed compare with your predicted speed?

Freeway Data

Student Handout

Name ______________________________

The following graph shows the speed of 2 cars over time.



During which time interval:

- was Car 1 accelerating?

- was Car 2 accelerating?

- was Car 1 maintaining a constant speed?

- was Car 2 maintaining a constant speed?

- was Car 1 decelerating?

- was Car 2 decelerating?

Which car was fastest? Explain.

Which car do you think was safest? Explain.

What's a New York Minute?

About this learning activity

Students will construct a pendulum-type timing device that measures 1 minute and minimizes the error of measurement.

Key process skills

- Categorizing or classifying
- ● Communicating
- ● Comparing
- ● Controlling variables
- ● Experimenting
- ● Hypothesizing
- ● Inferring
- ● Interpreting data
- ● Making models
- ● Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

1 ● 2 ● 3 4 5 ● 6 7 8 ● 9 10
11 ● 12

6th grade

1 ● 2 ● 3 4 ● 5 6 ● 7 8 ● 9 ● 10

9th grade

1 ● 2 ● 3 ● 4 5 6 7 ● 8 ● 9 10
11 12 13 14 15 16 ● 17 18 ● 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

(for each team)

- 1 ring stand for hanging a pendulum
- A 55-cm length of cotton string (If a ring stand is not used, string length may need adjusted.)
- 1 or more weights *Hint: Fishing sinkers or washers are ideal.*
- 1 ruler
- 1 stopwatch
- What's a New York Minute? data sheet

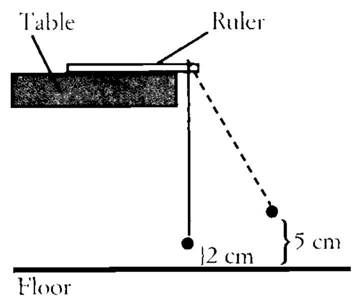
Time estimates

(2–4 class periods)

Setup	10 minutes
Exploration	40 minutes
Cleanup	5 minutes

Key science principles

- Mechanics
- Using measuring instruments accurately



Note: Other materials can be used if a ring stand is not available. For example, a string-and-weight pendulum can be hung from the end of a ruler that is masking taped over the edge of a table or desk.

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Engagement activity

To help students understand the importance of accurate measurement, facilitate an in-depth discussion by asking the following questions:

How does an Olympic judge determine who wins a race?

Why are lap times important to Indy Car drivers?

What criteria are used?

Note: Throughout the discussion, ask students to recall the concepts learned in the previous activity, Faster than a Speeding Bullet—The Speed of Me.

Why is it necessary to have criteria for measuring?

How do measuring instruments help determine the winner of the race?

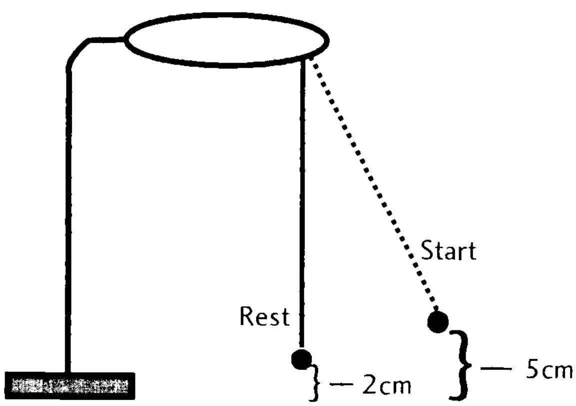
How could you graph the results of the winners? Have students give examples and/or make a class graph.

Exploration activity

Hint: Depending on the level of students' experience, teachers may wish to limit the variables that students can change. The variables of string length and/or mass of the weight can be modified.

Have students work in teams of approximately 4 to make and test a pendulum that measures 1 minute. Note: Students will modify the pendulum design so that it measures 1 minute from the time it begins (at the *start* position) until it swings a chosen number of times and then reaches the *rest* position.

1. Follow these instructions to assemble a pendulum:
   a. Tie the string to the weight.
   b. Attach the opposite end of the string to the ring stand.
   c. Adjust the string so that the bottom of the weight is 2 cm from the table or floor. This is the rest position.



2. Test the pendulum to make sure it can swing freely.

3. Raise the pendulum 5 cm from the *rest* position. This raised position is called the *start* position.

4. Release the pendulum from the start position. At the same time, begin timing with the stopwatch.

5. Observe the pendulum swinging and note where it is when one minute is reached.

6. Modify the design of the pendulum (e.g., lengthen or shorten the string and/or change the weight) and repeat steps 3–5 until the measurement is as close to 1 minute as possible, beginning at *start* and ending at *rest*.

7. Make a bar graph that represents the measurements in each trial.

8. Write a description of what the team did during this investigation. Be sure to include:
   - A drawing of the pendulum assembly.
   - A graph.
   - A list of problems the team encountered.
   - Explanations concerning how the team handled the problems encountered.

9. Draw conclusions about what was learned about pendulums. Specifically, describe how the speed of the pendulum is affected by changes made in the length of string and/or the mass of the weight.

Note: These instructions are provided to students on the Faster than a New York Minute data sheet, pp. 124–126.

Note: After the investigation, these conclusions can be discussed by the whole class.

Explanation

Measurement is an essential life skill. Students need to recognize the impossibility of absolute measurement. In general, people can measure as accurately as their instruments allow.

A **pendulum** is a device in which an object is suspended by a chain, rope, or string from a central pivot point. **Weight** is the force with which an object is pulled toward the earth by gravity. In addition, the time needed for a pendulum to complete 1 cycle of motion is called a **period**.

The **speed** of a pendulum can be modified by changing the length of the string and/or the mass of the weight. Longer string and/or heavier weights make the pendulum swing more slowly (i.e., it takes more time for 1 complete cycle). Shorter string and/or lighter weights make a pendulum swing more quickly (i.e., it takes less time for 1 complete cycle).

Evaluation

Assessment of the exploration activity
Use the following assessment guidelines to evaluate student performance of this activity:

Construct the pendulum	20 points
Set up on time	10 points
Accuracy	20 points
within ± 2 seconds—20 points	
within ± 5 seconds—15 points	
within ± 10 seconds—10 points	
within ± 15 seconds—6 points	
within ± 20 seconds—3 points	
Written report	20 points
Diagram	10 points
Graph	20 points
TOTAL	100 points

Journal entry
Describe to a friend how Robin Hood would measure the speed of his arrow.

Extension activity

- Using different materials than those used in the exploration activity, have students construct a machine that will measure 1 minute.

Connections to other subjects

Math.
- Have students research how measuring devices are kept standard and/or what measuring instruments are housed at the Bureau of Weights and Measures in Washington, D.C.
- Have students convert some English measure to metric and convert Fahrenheit temperatures to Centigrade.

Career pathways
Mathematician, engineer, architect, construction worker, design technologist, chemist, and pharmacist

Language Arts. Assign a short report in which students must describe 3 different devices that measure time.

Social Studies. Have students investigate measurement-related information such as:

- What Galileo did with water clocks.
- How the Ancient Greeks kept time.
- How, in earlier times, measuring devices were kept standard.
- How, in earlier times, Native American Indians calculated time.

Arts.

- Have students use appropriate symbols to make a chart of measurements.
- Using any medium, have students show how measurement is important to everyday life.
- Instruct students to investigate and describe how music depends on measurement.

Resources for teachers and students

Books:

Science Activities for the Visually Impaired/Science Enrichment for Students with Physical Handicaps (SAVI/SELPH) (Lawrence Hall of Science Center for Multisensory Learning, 1982)

Roller Coaster Science by J. Wiese (John Wiley & Sons, 1994)

The Way Things Work by David Macaulay (Houghton Mifflin Company, 1988)

More Engineering Projects for Young Scientists by Pater Goodwin (Franklin Watts, 1994)

Solids, Liquids, and Gases: From Superconductors to The Ozone Layer by Melvin Berger (Putnam's Sons, 1989)

Inventors Workshop by Alan McCormack (Pitman Learning, Inc., 1981)

Audiovisuals:

Science Image and Activity Bank by Videodiscovery, 1700 Westlake Avenue N, Suite 600, Seattle, WA 98109

Faster than a New York Minute

Data Sheet

Name ______________________________

Names of Team Members ______________________________

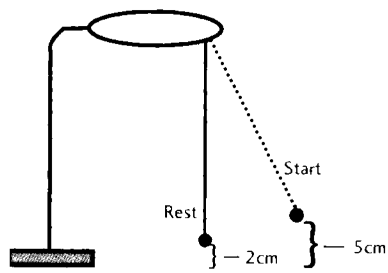
____

Purpose: To construct a pendulum that measures 1 minute.

Materials: 1 ring stand with clamp, a 55-cm length of cotton string, 1 or more weights, a ruler, and a stopwatch

Procedure:

Work in teams of approximately 4 to design and test a pendulum. Your team's goal is to modify the pendulum design so that it measures 1 minute from the time it begins (at the *start* position) until it swings a chosen number of times and then reaches the *rest* position.



1. Assemble a pendulum:
   a. Tie the string to the weight.
   b. Attach the opposite end of the string to the ring stand.
   c. Adjust the string so that the bottom of the weight is 2 cm from the table or floor. This is the *rest* position.
2. Test the pendulum to make sure it can swing freely.
3. Raise the pendulum 5 cm from the *rest* position. This raised position is called the *start* position.
4. Release the pendulum from the start position. At the same time, begin timing with the stopwatch.
5. Observe the pendulum swinging and note where it is when one minute is reached.
6. Modify the design of the pendulum (e.g., lengthen or shorten the string and/or change the weight) and repeat steps 3–5 until the measurement is as close to 1 minute as possible.

Trial	What we did to modify our design	Time from *start* to *rest* (seconds)
Trial 1		
Trial 2		
Trial 3		
Trial 4		
Trial 5		
Trial 6		

7. Make a bar graph that represents your measurements in each trial.

8. On other paper, write a description of what you did during this investigation. Be sure to include:
   - A drawing of your pendulum assembly.
   - Your graph.
   - A list of problems you encountered.
   - Explanations concerning how you handled the problems that were encountered.

9. Draw conclusions about what you learned about pendulums. Specifically, describe how the speed of the pendulum is affected by changes made in the length of string and/or the mass of the weight.

Gravity and Free-Falling Bodies

About this learning activity

Students will investigate the influences of gravity on free-falling objects.

Key process skills

- Categorizing or classifying
- ● Communicating
- ● Comparing
- ● Controlling variables
- ● Experimenting
- ● Hypothesizing
- ● Inferring
- ● Interpreting data
- Making models
- Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

1 2 ●3 4 5 6 7 8 ●9 10
11 ●12

6th grade

1 ●2 3 4 5 6 ●7 ●8 ●9 10

9th grade

1 2 ●3 ●4 5 6 7 ●8 ●9 ●10
11 12 13 14 15 16 17 18 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

- Items that can be dropped in experiments (e.g., tennis balls, golf balls, soccer balls, books, chalk, erasers)
- Gravity and Free-Falling Bodies data sheet

Time estimates

(1 class period)

Setup 5–10 minutes
Exploration 25 minutes
Cleanup 5–10 minutes

Key science principle

- Gravitational pull

Note: Items should be unbreakable.

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Hint: This discussion doesn't need to produce specific responses. It's simply a way to get students thinking about gravity-related issues. They will continue learning about free-falling concepts during the exploration activities.

Hint: This would be an ideal time to discuss the scientific process, including constants and variables.

Engagement activity

1. Unexpectedly, drop a book or other heavy object that makes a loud noise. (This will get students' attention!)

2. Next, drop something that is noticeably smaller in size and weight (e.g., chalk, eraser).

3. Pass around the dropped objects and let the students **feel** the differences in size and weight. Ask them questions such as:

   What differences exist between the items?
   Why do you think they dropped to the floor differently?
   If they were dropped at exactly the same time, which would you predict would reach the ground first?

Exploration activity #1

1. Give each student a data sheet. Have students work in teams of 2–4. Ask each team member to choose 2 objects from around the classroom.

2. Have students follow the instructions on the data sheet.
   Note: Remind students to make their predictions before beginning the experiment. Each member of the team will drop 2 items from a predetermined height while the other members record the outcome of the experiment. Each team member should repeat the drop 3 times.

3. Facilitate a class discussion about what happened. Help students draw accurate conclusions.

Exploration activity #2

Repeat the experiment conducted in exploration activity #1, but use 2 pieces of paper or aluminum foil—1 flat and 1 wadded into a ball. *Note: This activity can be done in teams or as a whole class.* Follow this procedure:

1. Ask for predictions of what will happen if a flat sheet and a wadded sheet are dropped at the same time.

2. Have students drop both sheets at the same time.

3. Have class members share their observations and discuss why the results of this experiment did not match the results of the experiment in exploration activity #1.

Explanation

Three hundred years ago, a scientist by the name Galileo proved that objects fall at the same speed—no matter how heavy or light they are. Heavier objects weigh more, but they also accelerate more slowly.

In exploration activity #2, air resistance acts upon the flat sheet, allowing it to fall slower than the wadded sheet. A parachute is a good example of how this principle works.

Evaluation

Grade data sheets to assess whether students understand the scientific principles and processes.

Journal entry
Describe the process you used in this experiment. Explain what you learned.

Connections to other subjects

Math. Have students make calculations using the following formula: *mass = weight/gravity, where gravity is* $9.8 m/s^2$

Resources for teachers and students

Books:
The Hidden World of Forces by Jack White
Physics for Every Kid by Janice VanCleave (John Wiley and Sons, Inc., 1991)

Internet site: Beakman

Career pathways

Research and design careers in engineering and architecture

Gravity and Free-Falling Bodies

Data Sheet

Name ______________________________

Team Members ______________________________

____

Purpose: To determine whether or not objects of different weight and size fall at the same rate.

Materials: Unbreakable items from around the classroom.

Procedure:

1. Each team member should choose 2 objects to test from those available in the classroom. List the 2 objects on the data chart below each team member's name.
2. Examine the objects by looking and touching. Predict what will happen if you drop the 2 objects at the same time from the same height. Write your predictions on the data chart.
3. One team member should drop his or her 2 objects from the same height at the same time. What happened? All team members should record the outcome on the data chart in the space for Trial 1. Then repeat the drop 2 more times, recording the outcome in the Trial 2 and Trial 3 spaces.
4. Did predictions match the outcomes? Explain the results on the data chart.
5. What conditions might account for any error in your experiment? Write your ideas in the last row of the data chart.
6. Repeat steps 1–5 until each team member has tested both of their objects 3 times.

Conclusions: What conclusions can you draw from this experiment? Write your conclusions below:

Name of team member				
Objects to be tested				
Prediction or hypothesis				
Outcomes or results • Trial 1				
• Trial 2				
• Trial 3				
Did your prediction match your outcome? Explain.				
What conditions/ variables might have affected your test?				

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Notes

For Every Action

About this learning activity

Students will construct a mouse trap car (i.e., *mousemobile*) and explain how it works.

Key process skills

- Categorizing or classifying
- ● Communicating
- Comparing
- ● Controlling variables
- ● Experimenting
- ● Hypothesizing
- ● Inferring
- Interpreting data
- ● Making models
- ● Measuring
- ● Observing
- ● Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

1 2 3 4 5 6 ● 7 8 ● 9 ● 10 ● 11 ● 12

6th grade

1 ● 2 3 4 5 ● 6 ● 7 8 ● 9 ● 10

9th grade

1 2 ● 3 4 5 6 7 ● 8 ● 9 ● 10
11 12 13 14 15 16 ● 17 18 ● 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

Engagement activity (for each team of 2–4)

- 3–4 balloons
- Scotch tape
- Plastic drinking straws
- A 3-meter length of string
- Safety goggles
- 1 standard mousetrap
- A 12- to 15-inch length of cotton string

Time estimates

(4–5 class periods)

Setup	5 minutes
Exploration	40 minutes
Cleanup	5 minutes

Key science principle

- Newton's laws of motion

Safety tips

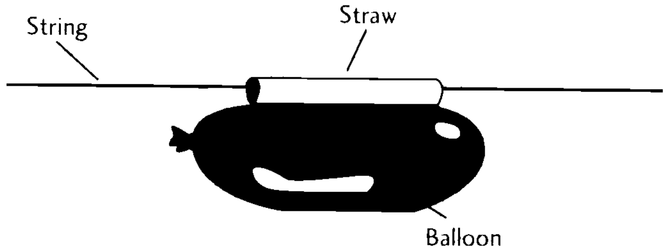
- Wear safety goggles, as appropriate.
- Watch your fingers as you set the traps!
- When using the ice pick, carefully push the pick through the lid and into a thick pile of newspaper.
- Use all tools as intended.

Exploration activity (for each team of 2)

- Safety goggles
- 1 standard mousetrap
- A 12- to 15-inch length of cotton string
- 4 plastic drinking straws
- 4 metal eye screws
- A 12- to 15-inch length of 1/4-inch dowel rod (or 2 city chicken sticks; usually free from the grocery's meat department)
- Newspaper
- Lids of any type to be used for wheels (Ask students to bring lids from home.)
- A set of tools that includes a screwdriver, ice pick, hammer, needle-nose pliers, paper punch, and scissors. *Note: Place the tool set in a central location for the entire class to use.*

Engagement activity

Divide the class into teams of 2–4 students. Help them observe Newton's laws of motion in action by guiding teams through these steps:



1. Thread the string through the straw.
2. Blow up a balloon and hold it closed.
3. Tape the straw securely to the balloon, still holding it closed.
4. Have 2 people hold the string taunt.
5. Let the balloon go.
6. Observe the behavior of the balloon.
7. Repeat steps 1–6.

8. Facilitate a class discussion concerning how this activity exemplifies Newton's laws of motion. Ask questions such as:

   - What happened to the balloon?
   - What direction did it travel?
   - Did it make a difference how you held the balloon? string? straw?
   - What tends to slow the balloon down?
   - What would happen if the string was not straight?
   - What would happen if we used a different type of string?
   - Can you identify the action-reaction pair of forces in this experiment? What is each force doing?

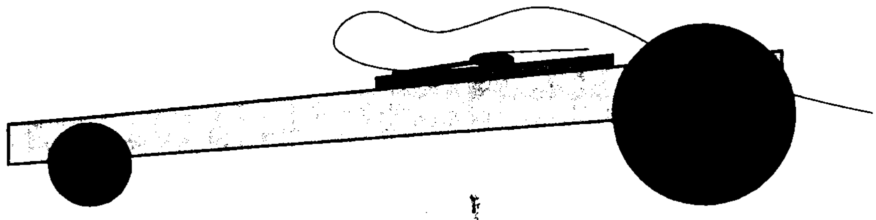
Exploration activity

Have students work in teams of 2 to construct and test mousemobiles.

1. Assign roles to team members (2 roles per team member):
   - **Facilitator**—organizes the team activities, keeps track of assignments, reminds the team to stay on task, and encourages positive feedback among members
   - **Materials manager**—obtains and returns all materials needed for project and organizes the cleanup of the work area
   - **Recorder**—records the data and makes diagrams throughout the experiment
   - **Reporter**—organizes and leads the team presentation of concepts learned

2. Challenge each team to build a race car from 12–15 inches of string, a mousetrap, 4 eye screws, 4 plastic straws, 1 piece of dowel rod, and 4 lids. (Each team member should bring in various types of lids to test as wheels.) After experimenting with various lids, team members must reach consensus concerning which lids to use for constructing their mousemobile. Allow students plenty of time to experiment with their car designs. (Remember: This is well-spent time—students are practicing the scientific process.)

Hint: Don't worry that directions to students aren't fully developed; this is an open-ended activity.



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Hint: Students will discover that to propel their cars they need to tie 1 end of the string to the pin and wind the rest of the string many times around an axle. When the trap is snapped, the car will move forward.

3. Have each team demonstrate its car for the rest of the class and report on the process used in developing its mousemobile.

4. Facilitate a class discussion. Ask some or all of the following questions:

   - From where in the mousetrap did the energy come?
   - Did the axle design make a difference?
   - Why did the type of wheel make a difference?
   - How did the size of the wheel affect performance?
   - Were 4 wheels required?
   - How did you transfer the energy from the trap to the axles?
   - How did you determine the direction the car travels?
   - What design features of your car allowed it to perform effectively?

Explanation

Newton's laws of motion state:

- For every action there is an equal and opposite reaction.

- Energy can never be destroyed (but it can change form).

- An object in motion continues to be in motion until acted upon by another source.

The car's energy source is the action of the mousetrap spring. Furthermore, dowel rod extensions help to distribute the energy across the car and the string transfers the energy to the axle.

Evaluation

Ideas for assessing student learning

- Grade the car design.
- Grade teams' oral reports that explain how and why the car moves.
- Have students write a report (minimum of 3 paragraphs) that explains how the team car works—in relation to Newton's laws.
- Have students record their experimentation of lids that were tested for wheels on a data chart.
- Have students sketch their mousetrap car, showing the direction of force.
- Have students list other examples of Newton's laws in action.

Journal entry
You are an engineer assigned to design a car of the future. Draw it, show the directions of force, and explain what design factors will make it an exceptionally fast car.

Extension activity

* Have students build a model rocket car:

  a. Design a pattern for your car from a styrofoam meat tray.
  b. Cut out a rectangle for the car and 4 wheels.
  c. Tape a straw to the car.
  d. Tape a balloon to the end of the straw.
  e. Attach the wheels to the vehicle with push pins.
  f. Inflate the balloon through the straw.
  g. Place the car on the floor and let it go!

  Once the rocket cars are complete and tested, have students write a report on the development of rocket cars. Reports should include a sketch of a rocket car and answer these questions:

  - Why didn't they become the average car buyer's choice?
  - What problems existed?
  - How were they solved?

Connections to other subjects

Math. Have students calculate the speed of their mousemobiles and measure the distance each traveled.

Social Studies. Have students research these topics:
- The effect of wheels on transportation throughout history
- The early automobile manufacturing process
- The construction of Roman chariots
- The use of Newton's laws in Indy Car racing
- The history of the tire industry

Art. Have students draw a blueprint or diagram of the mousemobile and/or a vehicle of the future. Ask them to indicate the direction of the forces.

Career pathways

This learning activity applies to all design-related careers. Have students interview an engineer to find out how engineers improve vehicle designs.

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Resources for teachers and students

Books:

Inventions—Breakthroughs in Science by Carol Amato (Smithmark Publishers, 1992)

Methods of Motion: An Introduction to Mechanics by Jack Gartrell (National Science Teachers Association Special Publications, 1989)

Evidence of Energy by Jack Gartrell, Jr. and Larry Schafer (National Science Teachers Association Special Publications, 1990)

How Things Work—Wheels at Work by Adam Dunn (Wayland Publishers, 1993)

The Way Things Work by David Macaulay (Houghton Mifflin Co., 1988)

Wheels at Work: Building and Experimenting with Models of Machines by Bernie Zubrowski (Morrow Publishing, 1986)

Audiovisual:

Science Sleuths: Science Image and Activity Bank by Videodiscovery, 1700 Westlake Avenue N., Suite 600, Seattle, WA 98109

On the Incline

About this learning activity
Students will investigate factors affecting an object's movement down inclined planes.

Key process skills

- Categorizing or classifying
- ● Communicating
- ● Comparing
- ● Controlling variables
- ● Experimenting
- ● Hypothesizing
- Inferring
- ● Interpreting data
- Making models
- ● Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

1 2 ● 3 4 5 6 ● 7 8 ● 9 ● 10
● 11 ● 12

6th grade

1 ● 2 3 4 5 6 ● 7 ● 8 ● 9 10

9th grade

1 2 ● 3 ● 4 5 6 7 ● 8 ● 9 ● 10
11 12 13 14 15 16 17 18 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials
(for each team)

- 1 board that can be used as a ramp (Corrugated cardboard, cut to approximately 6 inches x 30 inches, can be used if the ridges run the *length* on the board.)
- Books (Place these under 1 end of the board to provide an incline.)
- A variety of materials for covering the board (e.g., sand paper, towel, carpet pieces, rubber mat, plexiglass or plastic, waxed paper, aluminum foil, newsprint)
- 1 toy car or truck (e.g., Matchbox™ car)
- 1 meter stick, ruler, or tape measure
- 1 protractor
- 1 clock or stopwatch
- On the Incline data sheets

Time estimates
(1–2 class periods)

Setup	5 minutes
Exploration	40 minutes
Cleanup	5 minutes

Key science principles

- Angle of incline
- Friction
- Gravitational pull

Engagement activity

There is no specific engagement activity to accompany the exploration activity. It is assumed that students understand that an inclined plane is a simple machine and that they can identify how inclined planes help with completing work. If students need more learning about inclined planes, provide 1 or more engagement activities prior to conducting the following exploration activity. Learning activities described in the resources listed on pp. 299–317 may be useful.

Exploration activity

1. Have students work in teams of 4. Assign (or have students choose) roles of materials manager, dropper/timekeeper, catcher/measurer, recorder, and reporter. All team members are also design technicians.

2. Give each student a data sheet, which includes instructions to this open-ended activity.

3. Instruct teams to learn what they can about how to make their car move over an inclined plane. Encourage them to explore the variables of angle and surface area. Remind students to make their predictions before testing variables.

Hint: This would be an ideal time to discuss the scientific process, including constants and variables.

4. Facilitate a class discussion about teams' test results. Help students draw appropriate conclusions.

Explanation

As described in previous learning activities, the angle of an incline and the friction created by the surface directly affect the speed at which an object will travel. Refer to Appendix C, pp. 318–326, for the scientific principles involved in this exploration activity.

Evaluation

Grade data sheets to assess whether students understand the scientific principles and can follow the scientific processes.

Journal entry
Describe the processes you used in completing this experiment.

Extension activity

- Have students repeat the exploration activity. This time, keep the inclined plane the same and design/modify a car to travel over the plane as quickly as possible.

Connections to other subjects

Math. Have students calculate the velocity of the car as it travels over different surfaces and at different angles.

Resources for teachers and students

Physics by Douglas Giancoli (Prentice-Hall, Inc., 1980)
The Cartoon Guide to Physics by Larry Gonick and Art Huffman (Harper Perennial, 1990)
Physics for Every Kid by Janice VanCleave (John Wiley and Sons, Inc., 1991)
Machines and How They Work by David Burnie (Dorling Kindersley, 1991)
Machines—How They Work by David Burnie (Sterling Publishing Company, Inc., 1994)
The Way Things Work by David Macaulay (Houghton Mifflin Company, 1988)
The Way It Works by Philip Sauvein (New Discovery, 1992)
Machines by Janice VanCleave (John Wiley and Sons, Inc., 1993)
Machines At Work by Alan Ward (Franklin Watts, 1993)

Career pathways

Research and design careers in engineering and architecture

On the Incline

Data Sheet

Purpose: To explore some variables that affect the speed an object travels over an inclined plane.

Materials:

- 1 board that can be used as a ramp (Corrugated cardboard, cut to approximately 6 inches x 30 inches, can be used if the ridges run the *length* on the board.)
- Books (Place these under 1 end of the board to provide an incline.)
- A variety of materials for covering the board (e.g., sand paper, towel, carpet pieces, rubber mat, plexiglass or plastic, waxed paper, aluminum foil, newsprint)
- 1 toy car or truck (e.g., Matchbox™ car)
- 1 meter stick, ruler, or tape measure
- 1 protractor
- 1 clock or stopwatch

Procedure:

Learn about making a car move over an inclined plane by completing the following tasks:
- On your own, answer questions 1 and 2.
- With your team, decide who will take on the roles of materials manager, dropper/timekeeper, catcher/measurer, recorder, and reporter. All team members are also design technicians.
- Write your names in the spaces provided.
- With your team, explore how the variables of angle and surface texture affect the speed of the car. Write what you did and what you learned from your tests in the space provided on the data sheet. **Reminder: Be sure to make predictions before testing.**
- With your team, answer questions 3 through 7.

Materials Manager ______________________________

Dropper/Time Keeper ______________________________

Catcher/Measurer ______________________________

Recorder ______________________________

Reporter ______________________________

On the Incline Data Chart

Trial	Action (What we did.)		Prediction (What we think will happen.)	Result (What happened.)		Conclusion(s) (Why we think it happened.)
	Angle of inclined plane	Type of surface friction		Actual distance	Other observations	
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

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1. Explain how inclined planes make work easier. Include 1 or more diagrams.

2. Give an example of how inclined planes are used in daily life.

3. Did your team's predictions match the results? Explain.

4. What conclusions can you draw about how the angle of a plane affects how work is done?

5. What conclusions can you draw about how friction affects how work is done?

6. What conditions might account for any error in your experiment?

7. What else, if anything, did you learn about inclined planes and how they work?

Notes

Don't Slow Me Down Friction

About this learning activity

Students will explore factors affecting friction by:

- Measuring the effect of different surfaces on friction.
- Measuring the effect of weight on friction.
- Comparing the friction of different athletic shoes.

Key process skills

- Categorizing or classifying
- Communicating
- Comparing
- ● Controlling variables
- ● Experimenting
- ● Hypothesizing
- Inferring
- ● Interpreting data
- Making models
- ● Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

1 2 ●3 4 5 6 ●7 8 ●9 ●10
●11 ●12

6th grade

1 ●2 3 4 5 6 ●7 ●8 ●9 10

9th grade

1 2 ●3 ●4 5 6 7 8 ●9 ●10
11 12 13 14 15 16 ●17 18 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

Engagement activity

- Items that have been worn down by friction (e.g., old running shoes with holes, pencils, bike tires, jeans with holes in the knees, bearings)
- Corresponding new items (e.g., new shoes, newly sharpened pencil, new bike tire)
- Piece of plywood, cut as illustrated
- 1 bar of soap
- Spring scale
- 5x4x1-inch block of wood with a hook screwed into it (The hook will be used to attach the block to the spring scale.)

Time estimates

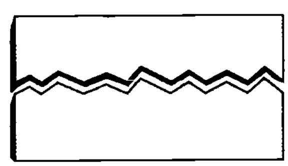
(2–3 class periods)

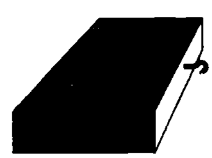
Setup 10 minutes
Exploration
- 20 minutes (to introduce the concept)
- 40 minutes (to test blocks with weights and make graph)
- 40 minutes (to test shoes and make graph)
- 20 minutes (to discuss results)

Cleanup 10 minutes

Key science principles

- Friction
- Gravity
- Weight
- Force
- Inertia
- Static friction
- Sliding friction
- Rolling friction





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Exploration activity
(for each team of students)

- Spring scale
- 5x4x1-inch wood block with a hook screwed into it (The hook will be used to attach the block to the spring scale.)
- Assorted weights (that can be combined to form increments of 100, 200, 500, and 800 grams)
- Approximately 20 round pencils
- Piece of sandpaper
- Assorted shoes (e.g., basketball, street, ballet, soccer, football, running, volleyball, roller blades)
- Rubber bands (These will hold weights on the spring scale if they are not hooked.)
- Don't Slow Me Down—Friction data sheets

Engagement activity

1. Introduce students to the concept of friction by asking them to examine an assortment of objects that have been worn down by friction. Have them compare a new shoe to a worn shoe, a newly sharpened pencil to a used pencil, and a new bike tire to an old bike tire.

2. Ask students to rub their hands together very quickly. Discuss the source of the heat they feel. Ask students to put hand lotion on their hands and rub their hands together very quickly again. Discuss the difference between the heat generated with and without the lotion. Discuss why there is a difference. (Answer: Lubrication reduces friction, which reduces the amount of heat energy that is generated.)

3. Demonstrate what friction looks—like at the atomic level—by holding up jagged pieces of plywood and rubbing the pieces across each other to show how they snag. Rub soap across the plywood to fill in the jagged spaces and demonstrate the difference in snagging (i.e., friction) with a lubricant.

4. Facilitate a class discussion by asking the following questions:

   What do all of these objects have in common?
   What is the difference between the new shoe and the old shoe?
   What is the difference between the newly sharpened pencil and the used the pencil?

- What force is responsible for this difference?
- What is a by-product of friction?
- How does a lubricant, like oil or grease, reduce friction?

Exploration activity

In this activity, students are given 2 interrelated opportunities to explore friction. First, they will test for friction with blocks of wood and varying weights. Second, they will create their own experiment to test the friction of assorted types of shoes.

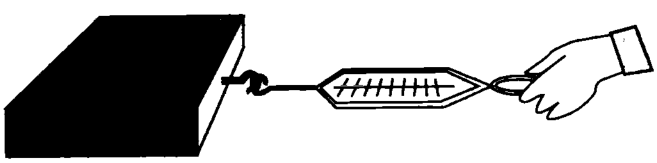
1. Demonstrate the procedure for using the spring scale to weigh the block and attaching weights to the block.

2. Divide students into teams of 2–4. Note: Working in pairs is especially effective. Distribute data sheets, weights, blocks, spring scales, sandpaper, and pencils to each team.

3. Instruct them to follow the directions on their data sheets. Procedures include:

   a. Weigh the block with a spring scale and record the weight.

   b. Hook the spring scale to the block and slowly pull the scale across the table until the block just begins to move. Measure how much force is required to just start the block moving. This force is called **static friction**. Record the weight (i.e., amount of force required) in the data table.



   c. Pull the spring scale with enough force to move the block across the table top at a steady speed. This force is the **sliding friction**. Record this weight in the data table.

   d. Pull the block at a steady speed across the table on top of some rollers (i.e., pencils). Measure how much force is required to keep the block rolling at a constant speed. This is **rolling friction**. Record this weight in the data table.

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e. Place the sandpaper on the table. Hold the sandpaper in place. Measure the force needed to pull the block at a steady pace along the length of the sandpaper. Record this weight in the data table.

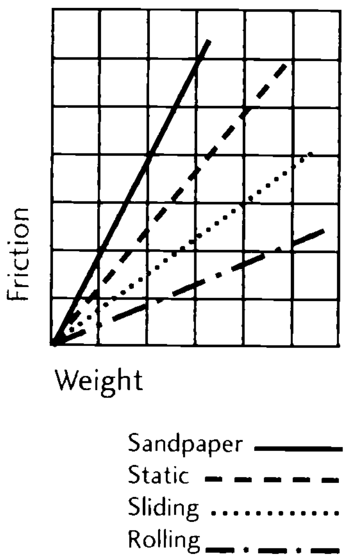
f. Repeat steps a–e with a 100-gram mass, a 200-gram mass, a 500-gram mass, and an 800-gram mass attached to the top of the block.

g. Graph the data collected in the table. Plot friction on the y-axis and weight on the x-axis. Start the origin at zero. Plot your data in 4 lines, using 4 colors:

- Plot a line of static friction versus weight.
- Plot a line of sliding friction versus weight.
- Plot a line of rolling friction versus weight.
- Plot a line of friction on sandpaper versus weight.

Note: Graphs should include 4 different lines with positive slopes.

Sample Graph



h. Using the graph, predict the forces needed to pull a 1000-gram mass in the 4 situations tested. Predict the forces needed to pull a 300-gram mass.

i. Answer the following questions:

How does static friction compare to sliding and rolling friction?

How is the force of friction affected by the nature of the surface?

How does the weight of a body affect the force needed to move the body horizontally across the surface of another body?

j. Draw a diagram of the friction situation in this lab. Label all the forces. Draw the forces with arrows and lines to show magnitude and direction of each force.

k. Draw conclusions about the exploration activity by making a general statement about the direction of any frictional force.

4. After discussing the wood blocks and weights experiment, ask students to work in their teams. *Note: If students did this experiment in pairs, have 2 teams work together for this part of the learning activity.* Instruct teams to:

   a. Brainstorm ideas for testing the friction of various types of shoes.

   b. Create a strategy and plan for performing the experiment the next day.

   c. Write their own procedure for the experiment.

   d. Bring in several different types of shoes to use in the experiment the next day.

   e. Test the shoes according to the strategy and plan outlined in step b; record the shoe test data.

   f. Graph the data from the shoe tests and use graphs to share test results.

5. Facilitate a class discussion about the shoe experiment by asking questions such as:

   - Which shoes had the most friction?
   - Which shoes had the least friction?
   - What were the controlled variables in your shoe experiment?
   - Were there any uncontrolled variables in your shoe experiment? How might you repeat the experiment to compensate for the uncontrolled variables?
   - What general statement can you make about the direction of any frictional force?

6. Have each team draw a diagram of the results of their shoe experiment, labeling all the forces. Have them draw the forces with arrows and lines to show magnitude and direction.

Important: As students work, move from team to team, reminding them to **keep the spring scale parallel to the surface** when they are testing friction. Also, check student data as it is collected. If static friction is not always **larger** than sliding friction, students are not doing the procedure correctly; have students retest the block, as needed. Students must look at the spring scale the instant before it starts moving to read the static friction. The reading on the scale after the block is in motion is sliding friction.

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Explanation

Friction is the force that opposes all motion; that is, its direction is opposite the direction of the motion. Friction is actually caused by electromagnetic force—1 of the 4 basic forces in nature.

At the microscopic level, **all** surfaces are rough and jagged. When rubbed across each other, they snag and pull and create friction. As in the plywood demonstration, if the surfaces are smoothed in some manner, friction is reduced. Friction can be reduced by sanding, aerodynamic design, adding lubricants (e.g., oil, soap, water, grease), and using rollers/wheels or ball bearings.

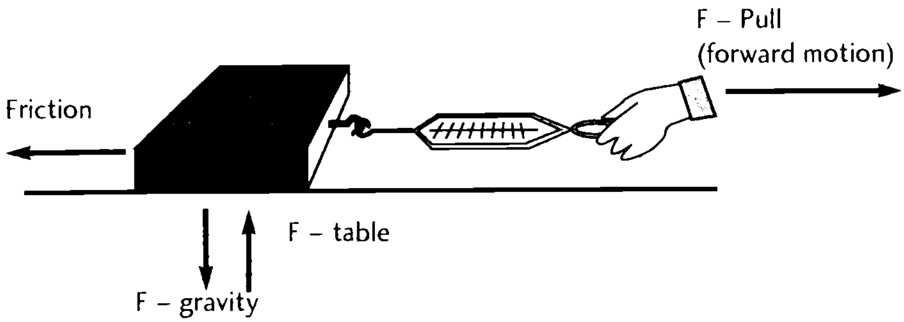
Friction is directly related to the **weight** of the object being moved. A heavier object pushes the jagged edges together and increases the friction. A lighter object can't push them together as much and therefore causes less friction.

Static friction is the amount of friction produced when an object just starts to move. **Sliding** friction is the amount of friction produced when the object is already in motion. Because inertia must be overcome, static friction is always greater than sliding friction. This is an excellent example of Newton's first law of motion: a body at rest will remain at rest and a body in motion will remain in motion in the same direction and at the same speed unless acted on by a force.

Round pencils act as rollers and therefore substantially reduce the amount of friction. (Some students may read zero friction when the block is pulled over rollers depending upon the precision of the spring scale.) Sandpaper increases the amount of friction because the surface is jagged.

Friction is often considered bad. Negative effects of friction include increased wear, lowered efficiency, production of unwanted heat, lowered speed and power. On the other hand, without friction, our clothes would fall apart, we couldn't change our motion (e.g., start, stop, accelerate, turn), and we couldn't write on the board!

Force Diagram



Evaluation

- Grade students' data sheets.
- Have teams present to classmates the information in data tables and graphs.
- Ask students to apply their knowledge by analyzing friction in an automobile where friction is good, where friction is bad, and how friction is increased or decreased.

Possible discussion and/or test questions

What force opposes all motion? (Answer: friction)
What is the direction of the force of friction?
(Answer: opposite to the direction of motion)
What happens to the amount of friction as the weight on a wagon is increased? (Answer: increases)
Name 3 ways friction can be decreased. (Answer: Several possible answers, including streamlining an item's design and using lubricants)
Give 3 examples of when friction is desirable.
(Answer: Several possible answers, including brakes, catching a ball, and holding clothes together)

Journal entries
Write the life story of your favorite pair of shoes—paying special attention to the effects of friction on them.

Describe 1 of the processes you used to investigate friction. Share 2 conclusions that you made as a result of exploring friction.

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Hint: *It's fun to do this with sports played at the Olympics!*

Extension activities

- Have students repeat the exploration activity, adding various lubricants to the testing surface. Students should bring in lubricants to test (e.g., Pam™, oil, soap).
- Ask students to make a chart listing 10 sports, how friction is reduced in each sport, and how friction is increased in each sport.

Sport	Type(s) of friction	Ways to decrease friction	Ways to increase friction

- Ask students to conduct an experiment to determine what shoe size means in terms of measurement. For example, what does a size 9B mean?
- Have students conduct research to learn how athletic shoes are tested.

Career pathways

Engineer, mechanic, coach, and athlete

Connections to other subjects

Math. Compare the cost of athletic shoes by brand, size, style, and type. Present the comparison in graph form. Use the graphs for extrapolation and interpolation.

Resources for teachers and students

Physics For Every Kid by Janice VanCleave (John Wiley and Sons, Inc., 1991)
Force and Motion by Peter Lafferty (Dorling Kindersley, 1991)
Force and Movement by Barbara Taylor (Franklin Watts, 1990)
The Super Science Book of Forces by Jerry Wellington (Thomson Learning, 1994)

Don't Slow Me Down Friction!

Data Sheet

Name ______________________________

Teammate's Name(s) ______________________________

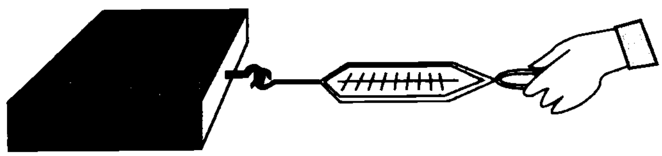
____

Purpose: To determine how weight and surface affect friction.

Materials:

- Spring scale
- 5x4x1-inch wood block with a hook screwed into it
- Assorted weights (that can be combined to form increments of 100, 200, 500, and 800 grams)
- Approximately 20 round pencils
- Sheet of sandpaper

Procedure:



1. Weigh the block with a spring scale and record the weight in the box.

2. Hook the spring scale to the block and slowly pull the scale across the table until the block just begins to move. Measure how much force is required to just start the block moving. This force is called **static friction**. Record the weight (i.e., amount of force required) in the data table.

3. Pull the spring scale with enough force to move the block across the table top at a steady speed. This force is the **sliding friction**. Record this weight in the data table.

4. Pull the block at a steady speed across the table on top of some rollers (i.e., pencils). Measure how much force is required to keep the block rolling at a constant speed. This is **rolling friction**. Record this weight in the data table.

5. Place the sandpaper on the table. Hold the sandpaper in place. Measure the force needed to pull the block at a steady pace along the length of the sandpaper. Record this weight in the data table.

6. Repeat steps 1–5 with a 100-gram mass attached to the top of the block.

7 Repeat steps 1–5 with a 200-gram mass attached to the top of the block.

8. Repeat steps 1–5 with a 500-gram mass attached to the top of the block.

9. Repeat steps 1–5 with an 800-gram mass attached to the top of the block.

	Weight with Static Friction	Weight with Sliding Friction	Weight with Rolling Friction	Weight with Sandpaper Friction
Block				
Block + 100g				
Block + 200g				
Block + 500g				
Block + 800g				

10. Graph the data collected in the table. Plot friction on the y-axis and weight on the x-axis. Start the origin at zero. Use 4 colors and develop a key. Plot your data in 4 lines, as follows:

- Plot a line of static friction versus weight.
- Plot a line of sliding friction versus weight.
- Plot a line of rolling friction versus weight.
- Plot a line of friction on sandpaper versus weight.

11. Using the graph, predict the forces needed to pull a 1000-gram mass in the 4 situations tested. Predict the forces needed to pull a 300-gram mass.

12. Answer the following questions in the spaces provided.

a. How does static friction compare to sliding and rolling friction?

b. How is the force of friction affected by the nature of the surface?

c. How does the weight of a body affect the force needed to move the body horizontally across the surface of another body?

d. Draw a diagram of the friction situation in this lab. Label all the forces. Draw the forces with arrows and lines to show magnitude and direction of each force.

e. Draw conclusions about the exploration activity by making a general statement about the direction of any frictional force.

Rube Goldberg is the Man

About this learning activity

Students will identify the 6 simple machines and will design, construct, and demonstrate a complex machine.

Key process skills

- Categorizing or classifying
- ● Communicating
- Comparing
- ● Controlling variables
- ● Experimenting
- ● Hypothesizing
- Inferring
- Interpreting data
- ● Making models
- ● Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

1 2 ● 3 4 5 6 ● 7 8 ● 9 ● 10 ● 11 ● 12

6th grade

1 ● 2 3 4 ● 5 6 ● 7 ● 8 ● 9 ● 10

9th grade

1 2 3 ● 4 5 6 7 ● 8 ● 9 ● 10 11 12 13 14 15 16 ● 17 18 ● 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

- Mousetrap™ game
- Video clips of Rube Goldberg machines
- *Apollo 13* videotape
- Copies of Rube Goldberg cartoons
- Rube Goldberg is the Man student instruction sheet
- Small balls, marbles, or ball bearings (1 for each team)

Time estimates

This is an extremely time-intensive activity. Students need time in class to brainstorm ideas, collect materials, and build a Rube Goldberg-type machine, unless these activities are assigned for completion outside of school. At least 1 class period is needed to test the machines.

Key science principles

- Simple machines
- Design parameters

Note: Students will choose their own materials for constructing their Rube Goldberg machines. Typical choices include drinking straws, pieces of wood, bats, lacrosse sticks, string, gloves, starting blocks, coat hangers, push pins, spools, bobbins, and magnets.

Safety tips

- Be sure to stipulate that nothing may be used in the machine that violates school policies (e.g. cap guns, fire crackers, rockets).
- Emphasize the 50-cm dimension restriction. Without this restriction, constructions will be too large to fit into the classroom and the testing will be too crowded.

Note: The inclusion of limitations imposes authenticity on the exploration project and its extension activities.

Note: If the design of this activity is too complex for your students, modify it to meet their abilities and needs.

Engagement activity

1. Begin the unit by setting up and demonstrating the Mousetrap™ game as a visual explanation of a Rube Goldberg machine. Share copies of the Rube Goldberg cartoons and show a video tape of a Rube Goldberg contest. (Annual compilations of the MIT Rube Goldberg engineering contests are especially good for visual explanations.) *Hint: Collections of cartoons are available from most libraries.*

2. Discuss the concept of design **parameters**—the real-life limitations that engineers must meet when designing new products or solving problems.

   Example: The engineers who design artificial heart valves have size and material parameters.

   Example: The engineers who design airplane runways have strength, length and materials parameters.

   Example: The movie *Apollo 13* has a terrific clip of engineers working with definite parameters. They have limited materials, limited space, a definite outcome, and limited time to solve their problem (i.e., to make their oxygen last)!

   Have students brainstorm the parameters that the engineers in each example must follow. Then let them brainstorm other situations with very restrictive parameters.

3. It may be appropriate to make sure students are familiar with the 6 types of simple machine and their related energy transformations.

Exploration activity

1. Distribute the Rube Goldberg is the Man student instruction sheet and review all of the design parameters of the project.

2. Divide the students into teams of 3–4. If you wish, assign roles of recorder, reporter, and materials manager. All team members are design engineers.

3. Ask students to brainstorm ideas for a Rube Goldberg machine they can design and build. Helpful questions to start the brainstorming include:

   - What practical functions could the machine perform?
   - What could you find around the house to use for each of the simple machines?
   - What toys do you have that could be integrated into the machine?

   After brainstorming, the team should decide upon a design that they will construct.

4. At the close of the team brainstorming session, ask each student to record his/her ideas in a journal or notebook. In addition, encourage students to refine their design ideas and find materials at home for building their machines.

5. Reconvene the teams to work on their machines as time permits. Emphasize the importance of each student keeping a written record of ideas, progress, failures, and frustrations. This project is very challenging, so expect significant frustration as students try out an invention and find it doesn't work. Encourage students to try again, explaining that failure and frustration are part of the scientific process. Also explain that the machines invented will be worth the frustration and students will feel tremendous pride if they persevere.

Hint: This is a great time to discuss the tenacity of Thomas Edison.

6. On demonstration day, give teams time to set up their finished machines and make final preparations for testing. Projects often get jostled in transport so be prepared to supply repair materials (e.g., tape, nails, stapler, marbles).

7. When most teams are ready, begin testing each machine. Students will want to watch other teams' machines. Ask teams to point out the parts of the machine. Use the assessment guidelines provided to record each part as it is explained. Measure dimensions and the distance the ball travels. Give each team 3 trials. (You might move on to test another project If the previous student needs time to set up again.) Lead the class in wild applause each time a machine works!

8. Facilitate a class discussion with questions including:

- What is the modern day connotation of a "Rube Goldberg"?
- What did you learn about engineering from your efforts? What were your frustrations? Were you proud of your results?
- What energy transformations take place in your Rube Goldberg machine?
- Is a Rube Goldberg machine high in efficiency?

Explanation

Rube Goldberg machines are highly **inefficient** complex machines designed to do a simple task in a ridiculously complicated manner. The term *Rube Goldberg* is used today to identify anything that is overly complex or complicated.

Student machines will vary wildly. Some may include spring-loaded levers to propel a ball through the air. Others may roll a marble through a tube wound in a spiral screw. Student machines might use a ball to raise a toy flag, cut butter, light a match, or operate an alarm clock.

The energy used to operate the machines will also vary wildly. Most machines will start with chemical energy from the student's body (i.e., food) and convert to mechanical energy (e.g., as a ball rolls and heats up from friction). Some machines may incorporate potential elastic energy in the form of a spring or rubber band. Others may use potential gravitational energy by starting a ball (or weight or car) at the top of an inclined plane.

Remember that students will use the 6 types of simple machines in constructing their Rube Goldberg machines. They may use spools of thread or bobbins for pulleys. Toy cars include wheels and axles. A spiral staircase is a screw.

Evaluation

Test
Have students compare the efficiency of a simple lever like a teeter totter to a very complex machine like a Rube Goldberg machine. (Answer: A teeter totter has a very high efficiency and a Rube Goldberg machine has a very low efficiency.)

Performance assessment
Construction of a Rube Goldberg project is an excellent performance assessment for a unit on simple machines. Use the guidelines provided to evaluate students' machines and their lab reports.

Journal entry
Students should keep a written journal of the entire design process.

Extension activities

- Have students create their own Rube Goldberg cartoons. Rube Goldberg was especially adept at poking fun at America's preoccupation with technology. Students could follow suit by designing an outrageously complex machine to do a simple task.

- Have students time the motion of a ball from start to finish and compare the results graphically.

- Conduct additional design projects with your class. See the Exploring Problem Solving and Designs section, pp. 55–86, for ideas.

Connections to other subjects

Social Studies. Have students study the political statement Rube Goldberg was making with his editorial cartoons. Help them discuss the impact of technology on society, including possible negative and positive effects.

Language Arts. Have students investigate how words take on different meanings and become integrated into our language (e.g., mouse). Ask each student to use a dictionary of new words to the English language and explain what event(s) caused the word to become integral to our language.

Career pathways

Engineer, construction worker, physicist, architect, scientist, inventor

Resources for teachers and students

Inventions—Breakthroughs in Science by Carol Amato (Smithmark Publishers, Inc., 1992)
How Things Work—Wheels At Work by Adam Dunn (Wayland Publishers Ltd., 1993)
More Engineering Projects for Young Scientists by Pater Goodwin (Frank Alin Watts, 1994)
The Best of Rube Goldberg by Charles Keller (1979)
Inventors Workshop by Alan McCormack (Pitman Learning, Inc., 1981)
Machines and How They Work by David Burnie (Dorling Kindersley, 1991)
Machines—How They Work by David Burnie (Sterling Publishing Company, Inc., 1994)
What's Inside? Great Inventions by Peter Lafferty (Dorling Kindersley, 1991)
Machines by Mark Lambert and Mark and Alistair Hamilton-MacLaren (The Bookwright Press, 1991)
The Way Things Work by David Macaulay (Houghton Mifflin Company, 1988)
Experiment With Movement by Bryan Murphy (Lerner Publications, 1991)
The Way It Works by Philip Sauvein (New Discovery, 1992)
Machines by Janice VanCleave (John Wiley and Sons, Inc., 1993)
Physics for Every Kid by Janice VanCleave (John Wiley and Sons, Inc., 1991)
Machines at Work by Alan Ward (Franklin Watts, 1993)
39 Easy Engineering Experiments by Robert W. Wood (Tab Books, 1992)
Wheels at Work—Building and Experimenting with Models of Machines by Bernie Zubrowski (A Boston Children's Museum Activity Book of BeechTree Paperback Books, 1986)

Rube Goldberg is the Man

Student Instruction Sheet

"Build a better mousetrap and the world will beat a path to your door." (Rube Goldberg)

Reuben Lucius Goldberg (1883–1970) was a graduate engineer who became a sportswriter and cartoonist. He received the Pulitzer Prize in 1948 for editorial cartooning. His cartoons show many simple machines linked together in roundabout, unusual, humorous, ridiculous ways usually to accomplish a simple task.

Your task is to build a Rube Goldberg machine. You will be combining the humor of Rube Goldberg with the conditions under which modern engineers and scientists work—specific, preset design **parameters**. Your device must:

- Contain at least 1 example of *each* of the 6 simple machines.
- Measure no more than 50 cm wide in any direction (this size restriction applies to the base).
- Move a ball at least 1 meter (distance measured after starting).
- Work unaided once it has been "started." (You may not touch anything on your device after you start the action.)
- Perform a practical function.
- Include no Mousetrap™ game parts.
- Include no explosives (such as firecrackers).
- Exhibit creativity in design, construction, and the use of materials.

Write a lab report that includes:

- **Title**—a name for your device.
- **Purpose**—what does your machine **do**?
- **Materials**—a list of all materials used.
- **Procedure**—a detailed description of how you constructed your device with diagrams/pictures to support your description.
- **Journal**—a dated journal with thoughtfully written entries of your progress, processes, thoughts, and frustrations; and a summary of what you learned.
- **Diagram**—a full page drawing of your device, with parts labeled and a Rube Goldberg key to operation.

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Rube Goldberg is the Man

Assessment Guidelines

Student's Name ______________________________

Rube Goldberg Machine

____ Contains all simple machine types (30)
- ___ lever
- ___ inclined plane
- ___ pulley
- ___ wedge
- ___ wheel and axle
- ___ screw

____ Moves a ball 1 meter (20)

____ Meets the size parameters (10)

____ Works on its own once started (10)

____ Performs a practical function (20)

____ Design is creative (10)

______ TOTAL (maximum of 100 points)

Lab Report

____ Title (2)

____ Purpose (3)

____ Materials (5)

____ Procedure (10)

____ Dated journal (50)

____ Diagram of machine with parts labeled and key to operation (30)

______ TOTAL (maximum of 100 points)

Roller Coasters: America's Favorite Amusement Park Ride

About this learning activity

Students will design and construct a marble roller coaster to explore Newton's laws of motion and more.

Key process skills

- Categorizing or classifying
- ● Communicating
- ● Comparing
- ● Controlling variables
- ● Experimenting
- ● Hypothesizing
- ● Inferring
- ● Interpreting data
- ● Making models
- ● Measuring
- ● Observing
- Ordering
- ● Predicting
- Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

1 2 ● 3 4 5 6 ● 7 8 ● 9 ● 10
● 11 ● 12

6th grade

1 ● 2 3 4 ● 5 6 ● 7 ● 8 ● 9 10

9th grade

1 2 ● 3 4 5 6 7 ● 8 ● 9 ● 10
11 12 13 14 15 16 ● 17 18 ● 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

- Pipe insulation (Insulation can be purchased from hardware stores. Cut 6-foot tubes in half lengthwise to make 2 6-foot long tracks that a marble can roll through. Give each team 2 6-foot long tracks.)
- Marbles (1 per team)
- Cotton balls
- Aluminum foil
- Salt or sugar
- Paper towels
- Masking tape (Ideally, each team should be given a roll.)
- Scissors (optional)

Time estimates

(1–6 class periods, depending on number of additional activities conducted)

Setup	5 minutes
Exploration	30–40 minutes
Cleanup	5 minutes

Key science principles

- Centripetal force
- Friction
- Gravity
- Inclined planes
- Inertia
- Kinetic energy
- Measurement
- Newton's laws of motion
- Potential energy

- Rulers and/or yard sticks (1 per team)
- Additional materials, if desired (e.g., empty toilet paper and/or paper towel rolls, string, plastic or styrofoam cups)
- Stopwatches (Watches with second hands can be used if stopwatches are not available.)
- Marble Roller Coaster data sheet

Engagement activity

Depending on the age and experience of the students, choose 1 of the following activities:

- Read *The Screaming Mean Machine*. (Use all or parts of this picture book to show why people have fun riding roller coasters and to discuss what makes a *good* roller coaster.)
- Ask students to recall their last ride on a roller coaster. Have them identify the things they liked about the design of the coaster. Have them describe how a roller coaster works and identify questions they might have about it. Tell them that they'll have a chance to explore many facets of roller coaster design in the exploration activity.

Exploration activity

1. Explain to students that they are architects in charge of designing a new roller coaster for the popular amusement park, Cedar Point. Their client wants them to top the newest coaster at a competing amusement park called Kings Island. Each team will cooperate to build a roller coaster that meets specific criteria and uses specific materials.

Note: Each team member may have more than 1 role.

2. Have students work in teams of approximately 4. Assign roles of chief engineer, materials manager, launcher, catcher, timekeeper, recorder, and reporter.

3. Challenge each team to design a roller coaster that they think people would like to ride. They must follow 1 of the design guidelines described below.

   Design #1 guidelines

   a. Use the materials available to make the marble, which is the car, go as **fast** as possible.
   b. The coaster must have at least 1 loop.
   c. The marble must have a soft landing at the end of the ride.
   d. Name your roller coaster (optional).

Design #2 guidelines

a. The marble, which is the car, must be released inside the top 1 inch of the pipe.
b. The coaster must have a least 1 dip or loop.
c. The marble must stop safely at the bottom of the ride, within 3 inches from the end.
d. Use materials provided; get additional materials only with the teacher's permission.
e. Name your roller coaster (optional).

Note: This option includes measurement.

Design #3 guidelines

a. Use the materials available to make the marble go as **slow** as possible.
b. The marble must stop within 3 inches of the end of the ride.
c. Name your roller coaster (optional).

Note: This option includes measurement.

4. Record information on the Roller Coaster data sheet. If calculations are involved, make them on the data sheet. (See formulas in the Connections to Math section on p. 173.)

5. After roller coasters are built, have each team demonstrate how its coaster works for the rest of the class. Encourage students to ask questions.

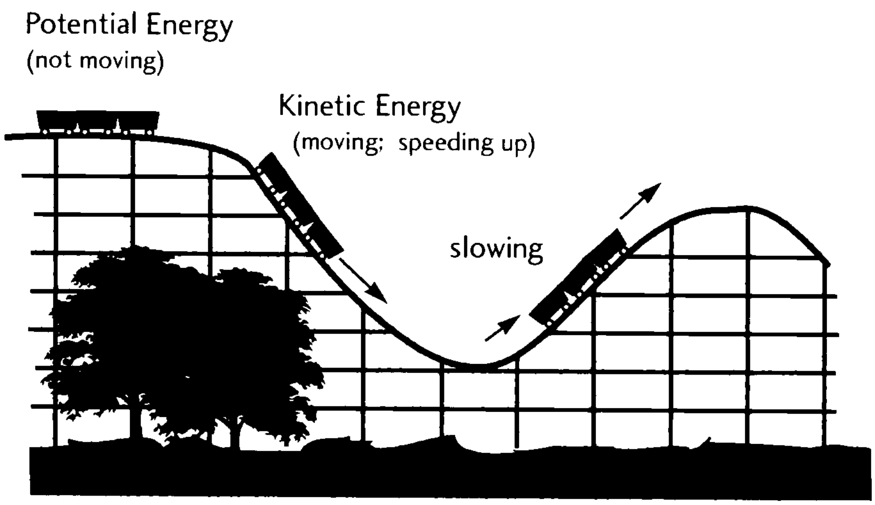
6. In a class discussion, identify what students learned by asking some of these questions:

- What made the marble go fast?
- What made the marble go slow?
- Does the length of the track make a difference?
- Does the height at which the marble begins make a difference?
- Does the angle of the track make a difference?
- When did the marble have potential energy? kinetic energy?
- How did friction affect the speed of the marble?
- What causes the marble to continue on its path?
- Does the marble speed up or slow down as it enters a loop?
- What happens if the loop is vertical?
- What is the marble's energy source?
- How would this explain how cars can race on a circular race track?
- How does this explain the motion you feel when you turn a corner on your bike, in a car, or on a bus?

Explanation

As students experiment with roller coasters, they observe how the angle of incline, the height of the track, and the friction present on the track affect the speed of the marble. For example, students will learn, through trial and error, that they can slow the marble down by adding friction or increasing the angle of the track. Furthermore, they will learn that the force of the marble will keep it on the track if the beginning level is high enough and the loops/dips are adjusted. Students should be able to track the energy throughout the coaster's track.

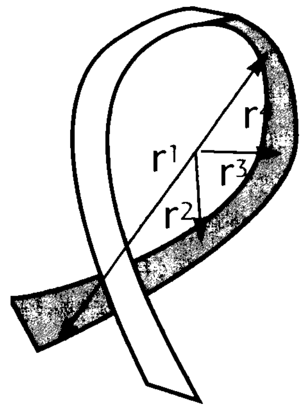
Energy is the ability to do work. Energy exists in many different forms, including **potential energy** (i.e., stored energy an object has because of its position, sometimes called gravitational potential energy), **kinetic energy** (i.e., the energy in a moving object), and **heat energy** (i.e., the energy in moving objects). **Energy transfer** occurs when energy changes from 1 form to another. The law of conservation of energy states that energy cannot be created or destroyed—it can only be changed from 1 form to another.



Does size or weight affect speed? Some students may think that the larger and/or heavier the marble, the faster it will move. Encourage them to experiment! Students will find that the faster marble will speed up more as it goes down the slope (due to gravity) but will slow down more when it travels uphill.

Adding loops helps the marble gain speed by generating **centripetal force**. A **force** is a push or pull in a particular direction. Centripetal force is a push or pull that makes an object move in a curved path—outward from the center of rotation. The object's direction is toward the center of the curved path. (Think about how water stays in a bucket that is being swung in a circular motion.) Just before the marble enters a curve in the roller coaster, it is moving along a straight path. According to Newton's law of motion, if no new force is exerted on the marble, it will continue along this straight path. For the marble to change direction and move in a circle (i.e., along the loop), a force must act on it. As the marble enters a loop, force from the track is exerted against it. The faster the marble moves, the greater the force of the track. At the top of the loop, the centripetal force must be greater than the force of gravity; otherwise, people would fall out of the roller coaster cars. When going around the loop, the force exerted on a car is constantly changing direction and requires a continuous force towards the center.

Roller Coaster Loop



r = radius

If you look at the **shape of roller coaster loops**, you'll notice that they are teardrop-shaped. (This shape is called the clothoid loop.) They are actually circles whose radii progressively decrease during the upward movement. The decrease in radii creates an increasing centripetal force.

See Appendix C, pp. 318–326, for explanations of other scientific principles involved in this activity.

Evaluation

Have students do some of the following activities:

- Summarize their findings in their data sheets and analyze their findings during the class discussion.
- On the diagrams of their best roller coaster (on the data sheet), have students label the forces with arrows—where potential and kinetic energy exist, where the marble sped up and slowed down due to gravity, where centripetal force is involved, and where inertia might cause riders to be launched off the coaster.
- Develop and deliver a television commercial aimed at convincing others to ride their coaster. Commercials should include: coaster name, coaster sketch, and reasons to ride the coaster.
- Write a report that includes answers to the following questions:
  What problems did your team encounter while trying to set up the roller coaster? List each problem and explain how you solved it.
  Observe the other teams' roller coaster models. What was different about the 1 with the fastest time? Slowest time? If models were actual roller coasters, which team's design would be the most exciting? Explain.

Hint: Some names students choose may mean death; who would want to ride a death machine?

- Why do designers make scale models before they build the actual roller coasters?
- What safety precautions would you need to consider in building an actual roller coaster?
- What name would you give to your roller coaster? Why? Why would you have to carefully choose a name?
- Why do you feel like you are being pushed to the outer part of the car whenever you go around a curve?
- When you go to the top of a hill, why do you feel weightless?
- What speeds you up as you go down a hill? What slows you down as you go up a hill?

Journal entry

Choose 1 or more writing assignments from the Connections to Language Arts section, p. 174.

Performance assessment

Observe students as they experiment with their roller coaster designs. Or observe students as they modify their coasters to incorporate what they learned through class discussion and observing other teams' roller coasters. Use the assessment guidelines on p. 43–49 to guide your observations.

Extension activities

* Using K'nex, have students build a roller coaster with a loop. Instruct them to observe the behavior of toy cars on the coaster path.

* Have students build a more complicated roller coaster.

* Tell students to build a roller coaster with plastic tubing—15–25 feet long, 3/8-inch or 1/2-inch inner diameter—and ball bearings that are 1/4-inch or 3/8-inch diameter. Challenge students to construct a roller coaster that has a total length of 1 meter from the beginning to the end, and to keep it within a 1-meter squared area. The only force they can use is gravity at the beginning. Option: Have students make the bearing travel through the tube a distance of at least 5 feet horizontally from where it starts and return it to the same vertical spot.

* Have students use different-sized marbles, balls, and/or bearings on their roller coasters. Challenge them to determine which one runs the course of the roller coaster the fastest and to draw conclusions from their exploration.

* Ask students to observe race tracks and cars by watching video tapes of Indianapolis 500 races.

* Invite an auto mechanic to speak to the class about why tire alignment is important.

* Take your class to an amusement park to experience centripetal force and other principles involved in rides. Have students make calculations such as velocity and centripetal force on specific rides, such as the Yo Yo, Double Loop, Silver Bullet, or Carousel.

Connections to other subjects

Industrial Arts.
- Have students design their own roller coasters from any type of material.
- Have students prepare a poster with antique and modern amusement park rides.
- Ask students to explain why some early amusement park rides were unsafe.

Math. Have students calculate:
- Speed = distance/time
- Acceleration = change in velocity/time
- Force = work/distance
- Circumference = diameter x 3.146
- Force = mass x acceleration
- Acceleration = force/mass
- Potential energy of the marble at the beginning of the ride: Ep = mgh, where m=mass, g=gravity, and h=height
- Kinetic energy of the marble at the bottom of the first hill: $E_k = \frac{1}{2}(mv^2)$, where m=mass and v=velocity (i.e., distance/time)

Ask students questions such as:

Where in the ride can you calculate velocity?
What is the average speed of the ride?
Where do you think the maximum speed will occur?
What factors might change your calculations?

Career pathways

Any occupation that develops designs or follows design plans, including architect, construction worker, and mechanical engineer

Language Arts. Assign 1 or more of the following writing projects:

- Describe your experience on a ride at an amusement park.
- Describe the sensations (e.g., what you feel at different speeds, in different directions, on different terrain) experienced as you ride in a car.
- Write about a day at an amusement park in 1920.
- Write a short story about a runaway roller coaster.
- Write a newspaper article telling the community about your new roller coaster.
- Interview family members about their favorite coaster or amusement ride. Draw a story strip about a coaster and let the family members write what they think is happening in the pictures.

Social Studies.

- Have students investigate the history of amusement parks.
- Have students investigate amusement park rides in different countries.

Resources for teachers and students

Books:

The Screaming Mean Machine by Joy Cowley and David Cox (Scholastic, Inc., 1993) Note: This picture book is out of print.

Raceways: Having Fun with Balls and Tracks by Bernie Zubrowski (A Boston Children's Museum Activity Book, 1985) Note: This book provides a wide variety of inquiry-based roller coaster activities related to straight tracks, circles and curves, flying and colliding balls, and Rube Goldberg machines.

Roller Coaster Science: 50 Wet, Wacky, Wild, Dizzy Experiments about Things Kids Like Best by Jim Wiese (John Wiles & Sons Publishing, 1994) Note: This book teaches many scientific principles of machines by exploring common toys, playground equipment, and sports/ recreational activities.

Geauga Lake Amusement Park Physics Day Program Packet, 1060 Aurora Road, Aurora, OH 44204

The Way Things Work by David Macaulay (Houghton Mifflin Co., 1988)

Modern Physics by F. E. Trinklein (Holt, Rinehart and Winston, 1992)

Evidence of Energy by NSTA (1990)

Physics for Every Kid by Janice Van Cleave (John Wiley & Sons, 1991)

Audiovisuals:

Newton's Apple Series: Physical Sciences (videodisc), National Geographic Society, 1145 17th Street NW, Washington, DC 20036

Physics At the Indy (Image and Activity Bank), Videodiscovery, 1700 Westlake Avenue N, Suite 600, Seattle, WA 98109

Marble Roller Coaster

Data Sheet

Chief Engineer ______________________ Materials Manager ______________________
Timekeeper ______________ Launcher ______________ Catcher ______________
Recorder ______________________ Reporter ______________________

Trial	**Action** (What we did.)	**Prediction** (What we think will happen.)	**Result** (What happened.)	**Conclusion(s)** (Why we think it happened.)
1				
2				
3				
4				
5				
6				
7				
8				

Conclusions

Explain how roller coaster design affects the speed of the marble. Give at least 3 examples and identify the scientific principles involved.

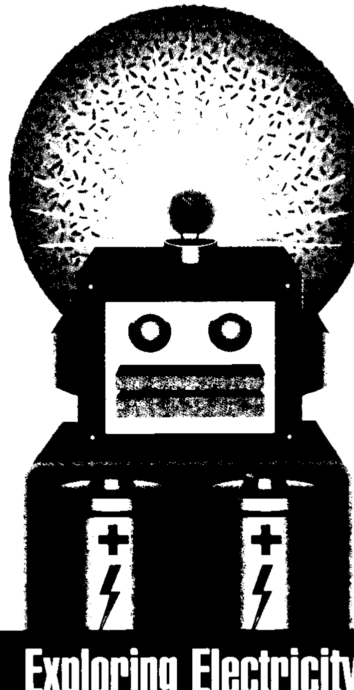
In the space below, draw a diagram of your best roller coaster. If your coaster has a name, write it above the diagram. Label the locations on the track where the marble went fastest and where it slowed down. Label other parts as instructed by your teacher.

Notes

Notes

FUN with PHYSICS

Real-Life Problem Solving for Grades 4—8



Exploring Electricity

Exploring Electricity

Fun with Physics

Real-Life Problem Solving for Grades 4–8

Exploring Electricity

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Electricity Vocabulary

Circuit

- Series circuit
- Parallel circuit

Conductor

Connector

Electron

Insulator

Load

Magnet

Motor

Power source

Resistance

Notes

Conductors vs. Insulators

About this learning activity

Students will test objects for conductivity by inserting them into a working circuit. They will identify conductors and insulators of electrical current.

Key process skills

- ● Categorizing or classifying
- ● Communicating
- ● Comparing
- ● Controlling variables
- ● Experimenting
- Hypothesizing
- ● Inferring
- Interpreting data
- Making models
- Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

● 1 ● 2 3 ● 4 5 6 ● 7 8 ● 9 10
11 ● 12

6th grade

● 1 ● 2 ● 3 4 5 6 7 ● 8 ● 9 ● 10

9th grade

● 1 2 ● 3 4 5 6 7 8 9 ● 10
11 12 13 14 15 16 17 18 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Time estimates

(1–2 class periods)

Setup	10 minutes
Exploration	30 minutes
Cleanup	10 minutes

Key science principles

- Electrons flow easily through materials that are conductors.
- Electrons do not flow easily through materials that are insulators.

Hints: If you don't have access to bulbs or bulb sockets, you can substitute strands of mini-Christmas tree lights. Simply cut the strands halfway between each bulb and strip the ends. (The drawback is that the wires may be too short.)

If you have bulbs, but don't have access to bulb sockets, you can have students tape wires directly to the bottom (i.e., conductor) of their bulbs with masking tape. If the conducting surface is too small, place a penny between the bulb and the wires.

Battery and bulb materials can be purchased from William Sheridan and Associates, listed on page 315 of the Resource section.

Note: This engagement activity is brief. Teachers are encouraged to allow students extra time to explore circuits and how they work, if possible. You can use Circuit Worksheets I and II on pp. 188–189 to facilitate additional exploration.

Safety tips

- Students should not stick the ends of the wires into any outlet!
- Depending on grade level, remind students of safe ways to handle the materials.

Materials

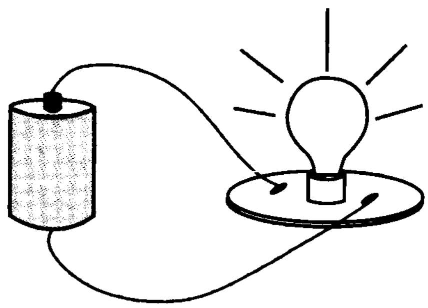
(for each team)

- 1 small light bulb (flashlight size)
- 1 bulb socket
- 1 battery (D-cell or 9-volt)
- 2 pieces of coated copper wire (10–12 inches long, with ends stripped)
- Masking tape
- 2 paper clips
- A variety of materials to test conductivity (solids and/or liquids; some options are listed below)
  - Solids such as a feather, a wooden pencil, an eraser, a metal spoon, a paper clip, a penny, a rubber band, a wooden block, a glass bead, a brass fastener, a rubber glove, a plastic spoon, salt, sugar, a lemon, an orange
  - Liquids such as distilled water, hydrogen peroxide, rubbing alcohol, sugar water, salt water, lemon juice, and/or tap water
- Conductors vs. Insulators data sheet

Engagement activity

Have students complete steps 1 through 4 to gain an understanding of electrical circuits and how electrons flow through them.

1. Screw a light bulb into a socket.
2. Discuss why the bulb does not light. (Answer: It lacks a power source.)
3. Using two pieces of insulated wire, connect one end of each piece to the socket. Then connect the other ends of both wires to the battery ends.



Complete Circuit

4. Discuss what happened by asking the following questions:

   Why did the bulb light up? (Answer: Because students built a complete circuit.)

   What is a circuit? (Answer: A circuit is an electrical path that allows current to flow from the power source and return to the power source.)

   What parts are necessary for a complete electrical circuit? (Answer: Power source, load, and connector—or conductor)

What kinds of sources can you think of? (Answer: Batteries, which supply direct current and electrical outlets, which supply alternating current)

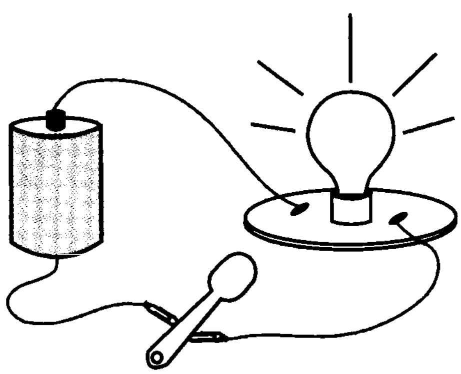
What kinds of loads can you think of? (Answer: Anything that uses electricity to operate, such as lamps, fans, clocks, computers, and car engines)

5. Help students link their learning in this activity to the exploration activity by explaining that they will learn about types of connectors—or conductors—which are materials that allow electrons to move from source to source through the load (where they "deposit" their energy) and back to the power source (where they get energized or "refuel").

Exploration activity

Have students work individually or in pairs to construct a working circuit and to test the conductivity of various materials.

1. Construct a circuit as described in the engagement activity.
2. Disconnect one end of the wire from the bulb socket.
3. Add a third wire to the circuit by taping it to the battery.
4. Twist each wire end around a paper clip to create the probes that will be used to test items for conductivity.
5. Select items for testing to see whether they are conductors or insulators.



6. Test the selected items one at a time, using the following method:

   a. Predict whether the material will conduct electricity (i.e., answer the question, "Will the material allow electrons to flow through it to light the bulb?"). Record the prediction on the Conductors vs. Insulators data sheet.
   b. Test your prediction by using the material to complete the circuit.
   c. Record your observations on the data sheet by indicating which items conducted electricity and which acted as insulators.

7. After the testing, ask students to generalize about materials that are good conductors. Facilitate a discussion that includes some or all of the following questions:

   - Which materials were conductors?
   - Which materials were not conductors (i.e., were insulators)?
   - What general statements can you make about materials that conduct and materials that do not conduct electricity?
   - What is the load in your experiment?
   - What is the source in your experiment?
   - What is the connector in your experiment?
   - Why should you never touch a downed electrical wire? Why should you keep your umbrella closed during an electrical storm?
   - Is the human body a good conductor of electricity? How can you protect yourself when working with electricity?

8. Have students write their own definitions of *conductor* and *insulator.*

Explanation

Every electrical circuit has three parts: an energy source, an unbroken path for the current to flow through (or along), and an energy user. The battery in this activity is the *source* of energy for the electrons; it energizes the electrons and pushes them through the unbroken path. An electrical *circuit* conducts an unbroken electrical current or a stream of moving electrons, moving from positive to negative. The bulb is the *load* of the circuit; it uses the electrical energy from the electrons and transforms it into light energy.

The electrons are carried from place to place by conductors. *Conductors* are substances that allow electrons to flow through them easily. In this activity, we tested the conductivity of several materials.

Materials differ in their ability to conduct electrons. The best *conductors* are metals like platinum, silver, gold, copper, and aluminum. Materials that do not conduct electrons are called *insulators* or nonconductors. These materials have a high resistance—they oppose the flow of electrons. Materials like mica, glass, rubber, plastic, and dry air are all good insulators.

Some liquid solutions are also good conductors of electricity. These liquids are called *electrolytes*. They are solutions of ions or charged atoms. Atoms become negatively charged by gaining electrons and positively charged by losing electrons. For example, salt water is a solution of ions. It contains positive sodium atoms or ions and negative chlorine atoms or ions from the dissolved salt or sodium chloride. The ions are free to move in the solution and they carry the electrons. Acids, bases, and salts are known as electrolytic solutions. Some liquid solutions do not conduct electricity. These are called *nonelectrolytes*, and include sugar solutions, alcohol, and glycerine.

Refer to Appendix C, pp. 318–326, for additional information about electricity.

Evaluation

Have students summarize their findings on the data sheet, then analyze their results by answering the data sheet questions.

Performance assessment

- Give students an assortment of materials and ask them to sort them into conductors and nonconductors.
- Have students build the circuits drawn on Circuit Worksheets I and II, pp. 188–189.

Possible pre- and post-test questions

1. A wooden pencil is a good conductor of electricity. (T or F)
2. All metals are conductors of electricity. (T or F)
3. ____________ stop the flow of electrons.
4. ____________ allow electrons to flow through them.
5. Glass is a good insulator of electricity. (T or F)
6. What is necessary to form a complete electric circuit?
7. A material with a high electrical resistance would be classified ______________.
8. Solutions that conduct electricity must contain ________________.

Journal entry

Imagine you are an electron. Describe your experience as you flow through a circuit.

Answers

1. False
2. False (Only iron-like metals conduct electricity; aluminum is not iron-like.)
3. Insulators
4. Conductors
5. False
6. Source, load, connector
7. An insulator or a nonconductor
8. Ions

Extension activities

- Have students make a list of the things they see around the house that are insulators and conductors of electricity.
- Tell a group of students to disassemble an old solar calculator; have them (and/or the entire class) identify the source, load, and connectors.
- Have a group of students disassemble an old stereo receiver or similar appliance; allow them (and/or the entire class) to observe the various resistors and note the complexity of the wiring.

Career pathways

Electrical occupations, including electrical engineer, construction technician, and electronics technician

Connections to other subjects

Social Studies. Direct students to study the development of the battery. They can start by looking at the invention of the voltaic cell and the life of Alesandro Volta. Discuss the limitations of batteries and how these limitations affect technology like the computer, the CD player, or the electric car.

Health. Have students explore the electrolytic solutions and electrical circuits found in the human body. Display some drinks used by athletes to replenish their electrolytes and identify the ions in each.

Language Arts. Have students write a fairy tale that illustrates the concept of source, load, and connector.

Resources for teachers and students

Electricity & Magnetism by Phil M. Parratore (Creative Teaching Press, Inc., 1996)

Magnets & Electricity by Karen Lee Siepak (Carson-Dellosa Publishing Co., Inc., 1995)

Super Science with Simple Stuff by Susan Popelka (Dale Seymour Publications, 1997)

What's Inside? Great Inventions by Peter Lafferty (Dorling Kindersley, 1991)

The Way Things Work by David Macaulay (Houghton Mifflin Company, 1988)

Physics for Every Kid by Janice VanCleave (John Wiley and Sons, Inc., 1991)

Experimenting with Batteries, Bulbs, and Wires by Alan Ward (Chelsea House Publishers, 1991)

Fun with Simple Science: Batteries and Magnets by Barbara Taylor (Warwick Press, 1991)

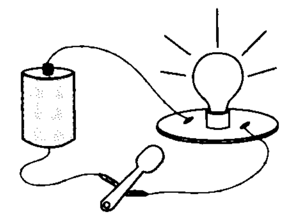
The Science Book of Electricity by Neil Ardley (Harcourt Brace Jovanovich, 1991)

Conductors vs. Insulators

Data Sheet

Name(s) ______________________________

Design an experiment to determine what kinds of materials conduct electricity, and which are insulators to electricity. First, record the procedure for your experiment in the space provided. Then conduct the experiment and record your data in the table below.



Our procedure is:

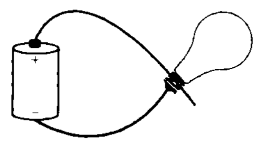
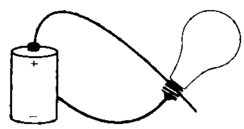
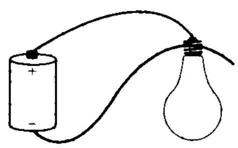
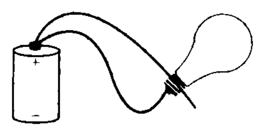
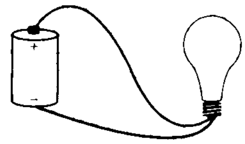
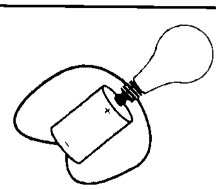
Item	Prediction (Will the bulb light?)	Bulb lit ("Yes") (Conductors)	Bulb did not light("No") (Insulators)

Answer these questions on the back of this data sheet or on a separate sheet of paper:

1. Which materials were conductors?
2. Which materials were not conductors (i.e., were insulators)?
3. What general statements can you make about materials that conduct and materials that do not conduct electricity?
4. What is the function of the bulb?
5. What is the function of the resistor?
6. What is the load in your experiment?
7. What is the power source in your experiment?
8. What is the connector in your experiment?

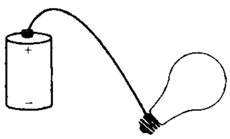
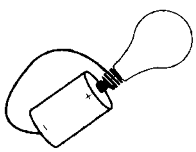
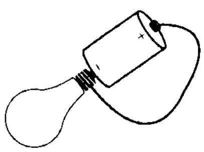
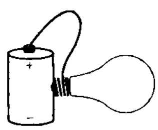
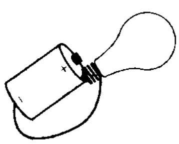
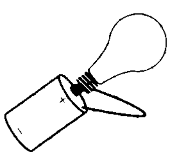
Circuit Worksheet I

Name ____

	yes 	no 
		
		
		
		
		
		

Circuit Worksheet II

Name ______________________________

	yes 	no 
		
		
		
		
		
		

Notes

Quiz Master

About this learning activity

Students will demonstrate their understanding of how a circuit works by constructing a Quiz Master game, which is a working circuit board, and explaining how it works.

Key process skills

- ● Categorizing or classifying
- ● Communicating
- ● Comparing
- Controlling variables
- ● Experimenting
- Hypothesizing
- ● Inferring
- Interpreting data
- ● Making models
- Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

● 1 ● 2 3 ● 4 5 6 ● 7 8 ● 9 10
11 ● 12

6th grade

● 1 ● 2 ● 3 ● 4 5 6 7 ● 8 ● 9 ● 10

9th grade

● 1 2 ● 3 4 5 6 7 8 9 ● 10
11 12 13 14 15 16 17 18 ● 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Time estimates

(1–2 class periods)

Setup	10 minutes
Exploration	45 minutes
Cleanup	10 minutes

Key science principle

- Flow of electricity through simple circuits

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Hint: *You can substitute plastic coated wires (with stripped ends) for foil strips.*

Hint: *You can substitute a flashlight bulb for the mini-tree light.*

Hint: *You can substitute a manila file folder for the cardboard.*

Hint: *Tearing or cutting tape into pieces and sticking it to the side of the materials table (before commencing activity) prevents commotion and allows quicker access to tape.*

Materials

(for each student)

- 1 piece of paper, from which 10 rectangles of paper (at least 1 inch x 2 inches) can be cut
- Scissors
- Markers
- Masking tape
- 1 pencil
- Aluminum foil (Each game board requires 5 strips, approximately 1 inch x 12 inches.)
- 1 small bulb* (flashlight size)
- 1 bulb socket*
- 1 piece of cardboard or tag board (approximately 8 inches x 11 inches)
- 12 paper clips
- 1 battery (A 9-volt battery is preferred, but 2 D-cells that are taped together—positive to negative—can be used.)
- 3 coated copper wires* (10–12 inches each, with 1 inch of insulation stripped from each end)

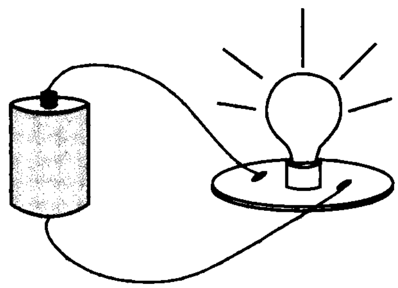
Safety tips

Discuss electrical safety procedures, including the following:

- ✚ Do not put together more than 4 batteries. The heat generated can cause a burn or a small explosion.
- ✚ Do not puncture batteries. Batteries can explode and leak acid, causing burns to eyes or skin.
- ✚ Do not use batteries which show signs of acid leakage (e.g., rust-colored deposits on the top or bottom of a battery).
- ✚ Never attach any of the equipment used in learning activities to an electrical outlet.
- ✚ Household electricity can cause severe shock and burns.
- ✚ Water and electrical current are a dangerous combination; make sure hands are dry before conducting learning activities.
- ✚ Always insert a load (e.g., a bulb, buzzer, or motor) into the circuit. Connecting only wire to the battery will cause the wire to overheat; this is called a short circuit.

*William Sheridan and Associates stocks batteries-and-bulbs materials and an automatic wire stripper/cutter that is very easy to use. Refer to the Resources section, p. 315.

Engagement activity



Help students explore the components of a circuit by taking the following steps:

1. Screw the bulb into the socket.

2. Discuss why the bulb does not light. (Answer: The circuit lacks a power source.)

3. Using 2 pieces of insulated wire, connect 1 end of each wire to the bulb socket.

4. Connect the other ends of both wires to the battery ends. (Note: Students can use masking tape to hold the wire to D-cell batteries.)

5. Discuss why the bulb lights up. (Answer: It is a complete circuit. A circuit is an electrical path that allows current to flow from the power source and returns to the power source.)

Note: If you already conducted the previous learning activity, Conductors vs. Insulators, you may wish to skip this engagement activity.

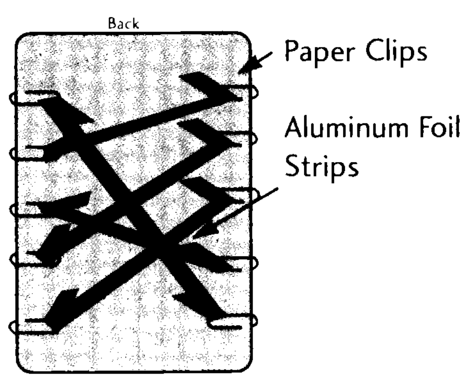
Exploration activity

A Quiz Master game is a working circuit board with questions on one side and answers on the other. Students must touch a probe to both a question and its correct answer for the bulb to light. Have students work individually or in pairs to make a Quiz Master game board by taking the following steps:

1. Clip 5 paper clips onto the **right** edge of the cardboard.

2. Use the aluminum foil strips to make *wires* for your game's circuits. To do this, cut 5 strips of aluminum foil (about 1 inch x 12 inches). Fold each piece of foil **lengthwise** into fourths.

3. Slide an end of one foil strip under each paper clip. Bend the foil strips about 1 inch and pinch the foil so each strip stays attached to its clip.



4. Turn the cardboard over, so you no longer see the foil strips. (This will be the **front** of the Quiz Master board.)

5. On the front of the board, use a pencil to lightly mark a number (i.e., 1 through 5) next to each paper clip. (These clips will hold the quiz **questions**.)

6. Place 5 paper clips on the other (i.e., right) side of the Quiz Master board—each clip directly across from a question-side clip. (These clips will hold the quiz **answers**.)

7. Decide which answer paper clip (on the right side) will correspond to each question paper clip (on the left side).
   Example: 1 — 4
   2 — 5
   3 — 1
   4 — 2
   5 — 3

8. Number the answer paper clips lightly with a pencil.

9. Turn the cardboard over, so you see the foil strips.

10. Using the foil strips, "stretch" the foil strips between the paper clip pairs with corresponding numbers. Slide the ends of the foil strips under the paper clips and bend the foil over the appropriate clip. As you work, cover each strip with masking tape—**one at a time**. This will insulate the wires, so that current doesn't flow from one to another. Pinch the foil so each strip stays attached to its clip.

11. Now it's time to prepare a **circuit**—as you did in the engagement activity. Use a battery, 3 wires, a bulb socket, and a bulb. Attach a paper clip to the ends of two wires—to use as probes. (See the diagram on p. 195.)

12. **Test** your board to make sure it works correctly. You can test each circuit by touching the two matching paper clip probes at the same time. If the bulb lights, the circuit is complete. If the bulb doesn't light when it should, do troubleshooting to check the Quiz Master circuits as follows:
    - Are the wires tightly touching the battery's + and – contacts?
    - Are any of the foil strips on the back of the board broken?
    - Is the bulb dead?
    - Is the battery dead?

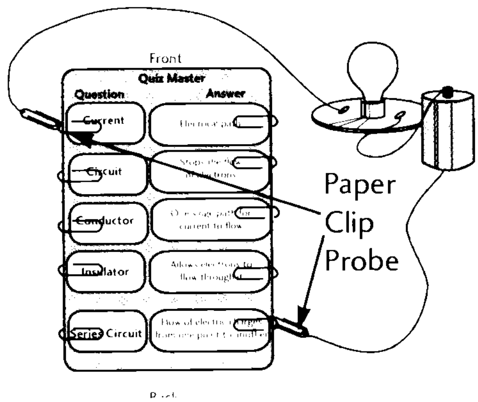
Hint: You may also want to number the answer paper clips on the back side of the board.

Note: Use masking tape on the back of the board only—do not tape the foil that is wrapped around the paper clips.

Hint: Stretching a wide rubber band around the ends of the battery will help keep the wires securely connected to the ends of the battery.

13. Once your Quiz Master game board is working properly, place it front side up.

14. Now it's time to prepare **questions** for your Quiz Master.



Hint: Teachers may wish to have students use electricity-related questions to help them synthesize and review concepts that have been studied. Some of the questions and definitions provided in the evaluation and explanation sections of this learning activity can be modified for use with Quiz Masters.

   a. Cut out 10 rectangles from a piece of paper. They should be approximately 1 x 2 inches. (They can be bigger if desired.)
   b. On the 10 separate pieces of paper, write 5 game questions and an answer to each question (e.g., 5 vocabulary terms and their definitions, 5 math problems and their solutions, or 5 questions about electricity and their answers).
   c. Slide 1 question under each paper clip on the left side of the board.
   d. Slide the answer to each question under the paperclip with the corresponding number on the opposite side of the game board (e.g., attach the answer to question #1 to the answer-side paper clip labeled #1).
   e. Erase your pencil-written numbers from the front-side of the game board.

15. Test your Quiz Master again by touching one end of the wire to the foil by question #1 and touching the other wire to the foil by the answer to that question. The bulb should light. If it doesn't, troubleshoot as you did in step 10.

When all Quiz Masters are functioning properly, have the students trade game boards and play another classmate's or team's game. Encourage students to trade games several times, if possible.

Explanation

The **circuits** on the game board lengthen the complete circuit made by the battery, wires, and bulb. Since the aluminum foil used on the back of the circuit board is a **conductor**, the foil allows the electricity to pass through it—to the bulb. The bulb lights when the wires touch two paper clips that are connected (by way of the foil on the back of the circuit board). Non-connected paper clips will not light because they do not complete the circuit.

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Hint: The definitions can be used for students' Quiz Masters.

These definitions of related electrical terms will help you guide students through this learning activity.

- **Current** is the flow of electric charges from one point to another.
- A **circuit** is the electrical path through which current flows *from* the source and *back to* the source.
- A **series circuit** provides one single path for current to flow along.
- A **conductor** is a material that allows electrons to move through it.
- An **insulator** does not allow electrons to move through it, so it stops the flow.
- Every electrical circuit has three parts: a **power source** (e.g., battery), **conductors** (through which the electrons are carried from place to place in an unbroken path) and a **load** (that uses energy).

Refer to Appendix C, pp. 318–326, for additional information about electricity.

Evaluation

- Have students explain how the Quiz Master works in writing. Then have them pair up to explain to each other how their circuit board works.
- Have students draw an example of a series circuit using one, two, and three light bulbs and write a brief description of why each one works.

Performance assessment
Have each student play a classmate's Quiz Master game and—without looking at the back of the circuit board—draw a diagram of the back side of that game.

Journal entry
How did you feel when you completed your Quiz Master?

Possible questions for an electricity-review quiz

What components make up a circuit?
What is a complete closed circuit?
An electrical current is the flow of ______ from one place to another.
What is an electron?
You can complete a simple circuit by connecting the ends of a wire to a battery and a light socket. (T or F)
What is a series circuit?
What is the difference between an insulator and a conductor? List 3 conductors.
How can you test the conductivity of a material?
Why does the Quiz Master light the bulb when you get the right answer?

Extension activities

- Encourage students to replace the light with a buzzer, which will sound each time the circuit is completed.
- Have students examine some printed circuit boards (e.g., calculators, computers, radios). Help them recognize that these circuit boards have lines that carry electricity from one part of a machine to another.
- Have students examine several types of holiday lights (e.g., bulbs that screw in and bulbs that connect with wires). Have students make predictions about which string of lights will continue to light if a bulb is removed from each strand and which will not light.

Connections to other subjects

Language Arts. Have students develop language arts questions for their Quiz Masters (e.g., books/authors, characters/books).

Social Studies. Have students develop social studies questions for their Quiz Masters (e.g., states/capitals, rivers/countries).

Math. Have students develop math problems and answers for their Quiz Masters.

Art. Have students decorate their Quiz Master game boards.

Resources for teachers and students

Electricity & Magnetism by Phil M. Parratore (Creative Teaching Press, Inc., 1996)
Magnets & Electricity by Karen Lee Siepak (Carson-Dellosa Publishing Co., Inc., 1995)
Electricity by Jason Cooper (The Rourke Corporation, 1992)
Switch On, Switch Off by Melvin Berger (HarperCollins, 1989)
Super Science with Simple Stuff by Susan Popelka (Dale Seymour Publications, 1997)
Experimenting with Batteries, Bulbs, and Wires by Alan Ward (Chelsea House Publishers, 1991)
Fun with Simple Science: Batteries and Magnets by Barbara Taylor (Warwick Press, 1991)
The Science Book of Electricity by Neil Ardley (Harcourt Brace Jovanovich, 1991)
Wonder Science, March 1995 issue (American Chemical Society/American Institute of Physics)

Career pathways

Engineering maintenance technician and electrical occupations, including electrical engineer, construction technician, and electronics technician

Notes

Series/Parallel Circuits

About this learning activity

Students will assemble parallel and series circuits and explain how they work.

Key process skills

- ● Categorizing or classifying
- ● Communicating
- ● Comparing
- ● Controlling variables
- ● Experimenting
- Hypothesizing
- ● Inferring
- Interpreting data
- ● Making models
- Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

● 1 ● 2 3 ● 4 5 6 ● 7 8 ● 9 10
11 ● 12

6th grade

● 1 ● 2 ● 3 ● 4 5 6 7 ● 8 ● 9 ● 10

9th grade

● 1 2 ● 3 4 5 6 7 8 9 ● 10
11 12 13 14 15 16 17 18 ● 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

(for each team)

- 3 small bulbs (flashlight size)
- 3 bulb sockets
- 1 9-volt battery (or 2 D-cell batteries taped together, positive to negative)
- 4 pieces of insulated copper wire (with ends stripped)
- Masking tape
- Series/Parallel Circuits data sheets

Time estimates

(1–2 class periods)

Setup	10 minutes
Exploration	60 minutes
Cleanup	10 minutes

Key science principles

- Flow of electrons
- Parallel circuits
- Series circuits

Hint: If you don't have access to bulbs or bulb sockets, you can substitute strands of mini-Christmas tree lights. Simply cut the strands halfway between each bulb and strip the ends. (The drawback is that the wires may be too short.)

Hint: If you have bulbs, but don't have access to bulb sockets, you can have students tape wires directly to the bottom (i.e., conductor) of their bulbs with masking tape. If the conducting surface is too small, place a penny between the bulb and the wires.

Hint: Battery-and-bulb materials can be purchased from William Sheridan and Associates, listed on page 315 of the Resource section.

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Safety tips

Discuss electrical safety procedures, including the following:

- Do not put together more than 4 batteries. Heat generated can cause a burn or a small explosion.
- Do not puncture batteries. Batteries can explode and acid can burn eyes or skin.
- Do not use batteries that show signs of acid leakage (e.g., rust-colored deposits on top or bottom of a battery).
- Never attach any of this equipment to an electrical outlet. Household electricity can cause severe shock and burns.
- Water and electrical current are a dangerous combination; make sure hands are dry before conducting learning activities.
- Always insert a load (e.g., a bulb, buzzer, or motor) into the circuit. Connecting only wire to the battery will cause the wire to overheat; this is called a short circuit.

Engagement activity

There is no engagement activity for Series/Parallel Circuits.

Exploration activity

In this learning activity, students will build series and parallel circuits, then draw conclusions about what they learn.

1. Give each student a Series/Parallel Circuits data sheet.

2. Have students work in teams as they follow the data sheet instructions.

3. Once students have had ample time to complete the exploration activity, facilitate a discussion by asking some or all of the following questions:

   - What makes a circuit complete?
   - In a circuit, identify the power source, conductors, and resistors. Trace the flow of electricity through the circuit (i.e., away from negative and toward positive).
   - In which direction does electricity flow? How do you know?
   - How do you think switches affect the flow of electricity through circuits?
   - What is the difference between parallel and series circuits? What are the advantages of each?
   - Are homes wired in parallel or in series? How could you confirm your prediction? What would happen if homes were wired using the other method?

4. Ask students to share any questions about electricity and electrical circuits that they listed on their data sheets but haven't found the answers for yet.

Explanation

Electrical **current** is the flow of electrical charges from one point to another. It is measured in *amperes*. Current is the *rate* at which electrons flow through a conductor.

Batteries are a **direct current** (DC) power source. The electricity running through homes and businesses is an **alternating current** (AC) power source.

Electricity flows through **conductors**—materials that allow electrical energy to pass through them.

The amount of *work* required to drive a current through a conductor (against resistance) is measured in terms of **voltage**. In other words, some resistors require more voltage—or a larger load—than others.

Series circuits provide a single path for current to follow. In a series circuit, when one light goes off, they all go off because the circuit is broken. **Parallel circuits** provide the same amount of electricity to each resistor, allowing current to follow multiple paths. The brightness of the bulbs in parallel circuits remains the same because the voltage is the same for each bulb. Homes are wired in parallel circuits so that when one light goes off, the remainder stay on. Parallel circuits allow all lights and appliances to operate at the same voltage—even when some are disconnected from the circuit.

Resistance is the opposition a material offers to the flow of electric charges. Almost all conductors offer some resistance. Resistance is measured in **ohms**. **Ohm's laws** describe the relationship between voltage (V), amperage (I), and resistance (R) using the formula $V = I \times R$.

Refer to Appendix C, pp. 318–326, for additional information about electricity.

Evaluation

Possible questions for a discussion or a quiz

- Are our homes wired in series or parallel circuits? Why?
- A string of holiday lights is a __________ circuit.
- In a _________ circuit, each light is dependent on the other lights in the circuit.
- What is a complete closed circuit?
- What is the difference between an insulator and a conductor?
- What is a series circuit?
- What is a parallel circuit?
- What is an electron?
- Compare and contrast AC and DC power.

Possible activities for a quiz

- Draw and label a simple circuit. Include power source, wires, and one bulb.
- Draw and label a circuit with bulbs in parallel.
- Draw and label a circuit with bulbs in series.

Performance assessment
Have students draw an example of a parallel circuit using three light bulbs, then build the circuit and write a brief description of how it works.

Journal entry
- Imagine you installed a door bell in your home. After installation, you try the bell and it doesn't work. How could you troubleshoot (i.e., figure out) the problem?
- Describe what kind of circuits are used in homes. Explain what would happen if your home was wired in a series circuit?

Extension activities

✱ Challenge students to make a variety of circuits. Using a data sheet with the categories shown below, have them record what they did and what they learned from their exploration.

Sample Circuits Exploration Data Sheet

Diagram (What we will do.)	**Prediction** (What we think will happen.)	**Description** (What happened.)	**Conclusions** (What we learned from our observations.)

✱ Have students build additional circuits and practice electrical troubleshooting by completing one or more of the activities in the Tops™ *Electricity* book, which is described on p. 307 of the Resource section.

✱ Working together as architects (in teams of 2–4), instruct teams to design buildings that use recycled boxes as their frames (e.g., cereal boxes) and include electricity-driven features (e.g., lighting). When all buildings are complete, teams should explain their design to the rest of the class. In addition, all teams' buildings can be positioned to create a "city of lights."

Career pathways
Electrical occupations, including electrical engineer, construction technician, electrical service technician, and electronics technician

Connections to other subjects

Language Arts and Social Studies. Assign a written report about early pioneers of electricity (e.g., Thomas Edison).

Resources for teachers and students

Electricity & Magnetism by Phil M. Parratore (Creative Teaching Press, Inc., 1996)

Magnets & Electricity by Karen Lee Siepak (Carson-Dellosa Publishing Co., Inc., 1995)

Super Science with Simple Stuff by Susan Popelka (Dale Seymour Publications, 1997)

Electricity in the TOPS™ Learning Series by Ron Marson (TOPS Learning Systems, 1982)

Experimenting with Batteries, Bulbs, and Wires by Alan Ward (Chelsea House Publishers, 1991)

Fun with Simple Science: Batteries and Magnets by Barbara Taylor (Warwick Press, 1991)

The Science Book of Electricity by Neil Ardley (Harcourt Brace Jovanovich, 1991)

Notes

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Series/Parallel Circuits

Data Sheet

Name ____________________

Name(s) of team member(s) ____________________

____

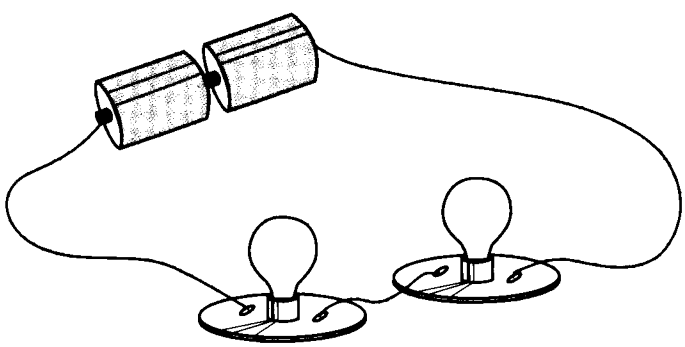
1. **Circuits**
   a. Make a bulb light using: 2 wires, 1 battery, 1 bulb socket, and 1 bulb.

   b. In the space below, describe (and/or draw) how electricity flows through the circuit.

   c. What happens if you remove one end of a wire? Explain below.

2. **Parallel and Series Circuits**
   Discuss with your teammate(s) how parallel and series circuits are different. Summarize your conclusions below.

3. **Series Circuits**
   a. Set up a series circuit as illustrated in the diagram.



b. What do you notice about the brightness of both bulbs? Record your observations below.

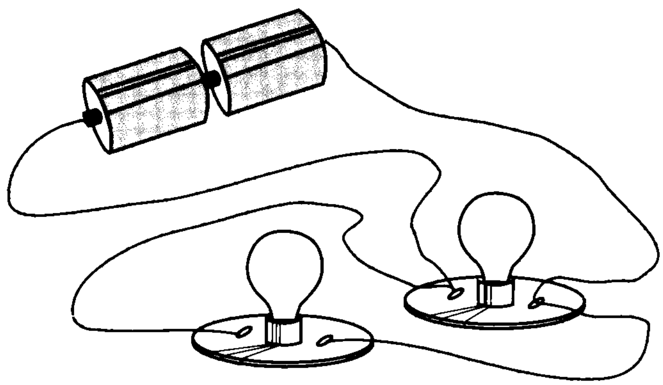
c. What do you think will happen if you unscrew one of the bulbs? Record your prediction below.

d. While both bulbs are lit, unscrew one of the bulbs. Record your observations below.
CAUTION: Bulbs may get hot!

4. Parallel Circuits

a. Set up a parallel circuit as illustrated in the diagram.

b. What do you notice about the brightness of both bulbs? Record your observations below.



c. What do you think will happen if you unscrew one of the bulbs? Record your prediction below.

d. While both bulbs are lit, unscrew one of the bulbs. Record your observations below.
CAUTION: Bulbs may get hot!

5. **Conclusions**

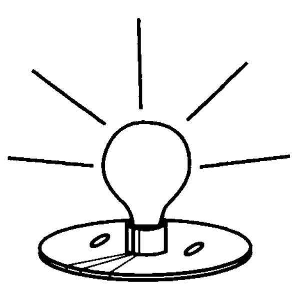
a. What conclusions can you draw about the differences between parallel and series circuits? List your conclusions below.

b. Do homes have parallel or series circuits? Explain below.

6. **Questions**

a. List any questions that you might have about electricity and electrical circuits.

b. Discuss these questions with your teammate(s) and/or bring them up during the class discussion of this learning activity.



Notes

Magnetic Materials

About this learning activity

Students will explore common materials that possess magnetic properties. They will also make their own magnets.

Key process skills

- ● Categorizing or classifying
- ● Communicating
- ● Comparing
- ● Controlling variables
- Experimenting
- ● Hypothesizing
- Inferring
- ● Interpreting data
- Making models
- ● Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

● 1 ● 2 3 ● 4 5 6 ● 7 8 ● 9 10
11 ● 12

6th grade

● 1 ● 2 3 4 ● 5 6 ● 7 ● 8 ● 9 10

9th grade

● 1 2 ● 3 4 5 6 7 8 9 ● 10
11 12 13 14 15 16 17 18 ● 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Time estimates

(1 class period)

Setup	10 minutes
Exploration	25 minutes
Cleanup	5 minutes

Key science principle

- Magnetic properties

Safety tips

- ✚ Remind students to be cautious with nails.

Materials

Engagement activity (for each team)

- 1 or more magnets (semi-strong)
- Items that can be tested for their attraction to magnets, including items made from:
  - aluminum, such as a soda can and/or aluminum foil
  - wood, such as a pencil, a block, and/or a spoon
  - rubber, such as a glove, a washer, an eraser, and/or a ball
  - plastic, such as a toy, a spoon, and/or a pen cap
  - ferrous (iron-based) metal, such as a paper clip, a nickel, a dime, and/or a nail
  - non-ferrous metal (e.g., aluminum, copper, lead, stainless steel, titanium, magnesium), such as a penny, an aluminum nail, and/or a brass washer or nail
- Magnetic Materials I data sheet

Exploration activity (for each team)

- 1 magnet (semi-strong to strong)
- 6 nails
- Approximately 50 paper clips
- Magnetic Materials II data sheet

Engagement activity

Challenge students to learn everything they can about magnets and the materials they do and do not attract.

1. Divide students into groups of 2–4. If desired, assign roles of materials handler, recorder, reporter, and tester. Distribute the Magnetic Materials I data sheet.

2. Let students select materials to test for their attraction to magnets.

3. Instruct students to test each item for its magnetic attraction by following this process:

   a. Choose an item to test.
   b. Predict whether the item will be attracted by the magnet or not. Record your prediction on the data sheet.
   c. Hold the item to the magnet. Record your observations on the data sheet.

4. Ask students to discuss what they learned with their teammates and record their conclusions on the data sheet.

5. After the experimentation, facilitate a discussion by asking some of the following questions:

   What is a magnet?
   How do magnets work?
   Do magnets work on all things? Why not? Explain.

6. If you think students will benefit from reinforcement of what was learned, have them separate items into two categories—items magnets attract and items they don't attract. Have them practice this process skill (categorizing) by placing items in two separate piles.

Exploration activity

Have students make a magnet to explore magnetic strength.

1. Ask students to work in teams of 2–5. If desired, assign roles of materials handler, recorder, reporter, and tester.

2. Ask the questions, "Can you make your own magnet?" and "If so, what material(s) would you use?"

3. Instruct teams to write their hypotheses (guesses) for these questions.

4. Have teams make a magnet by taking these steps:
   a. Check to see if the nail is magnetic by testing to see if it will pick up a paper clip.

   b. Rub the nail across the magnet 10 times—**in one direction only**. Check its magnetic strength by seeing how many paper clips it can pick up. Record your observations on the data sheet. **Note: Do not rub the nail in opposite directions! If you do, the experiment will fail**.

   c. Repeat the experiment, *using a different nail each time* and increasing the number of movements over the magnet in increments of 10 until the nail has crossed the magnet 50 times.

5. Remind students to record their predictions, observations, and conclusions on the Magnetic Motion II data sheet.

6. Have students throw the nail onto the ground several times, then check its magnetic strength by seeing how many paper clips it can pick up. Remind them to record their observations on the data sheet.

7. Repeat step 6 until the magnetism disappears.

8. Instruct teams to record their conclusions, including an explanation of why the nail lost its magnetism after throwing it down and why the experiment worked.

9. Facilitate a discussion by asking some or all of the following questions:

   - What materials do magnets attract?
   - What do these materials have in common?
   - What do materials that don't attract to a magnet have in common?
   - Can you name several things that are magnets?
   - What makes magnets strong?
   - What causes a magnet to lose magnetic energy?

Explanation

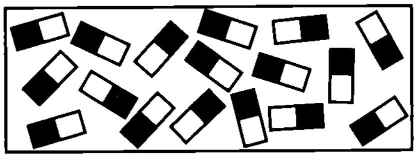
Magnets are objects that attract anything that contains iron. Since some metals do not contain iron or iron-like materials, all metals are not magnetic. There are basically two types of metals:

- **Ferrous metals**, which contain iron or iron-like material (e.g., steel, cast iron). Magnetite, often called lodestone, is a naturally magnetic material.

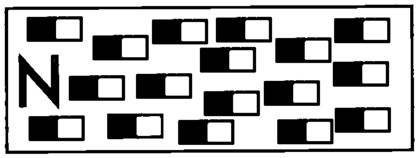
- **Non-ferrous metals**, which contain no iron (e.g., aluminum, lead, stainless steel, copper, brass, titanium, magnesium).

Magnetism is caused by the flow of electric charges through an object. The directional property of magnets (e.g., used in compasses) comes from the polar quality of magnets, which we call **north and south poles**. The magnetic forces are strongest at the poles (or ends) of magnets. Magnetic forces *attract* (i.e., pull toward themselves) objects that are of opposite polarity (e.g, north pole of one magnet and south pole of another) or *repel* (push away) objects that are of identical polarity (e.g., north poles of 2 magnets).

Items made from ferrous metals contain **magnetic domains**. When an item made from ferrous metals is magnetic, these domains all point in the same direction. When these domains are going in different directions, the item is not magnetic—but it is still *attracted* to magnets.



Unmagnetized



Magnetized

In this learning activity, dragging the magnet across the nail 40 times or so aligns the magnetic domains—turning it into a magnet. Then, throwing the nail on the ground disturbs the magnetic domains, creating a misalignment—which causes the loss of magnetism.

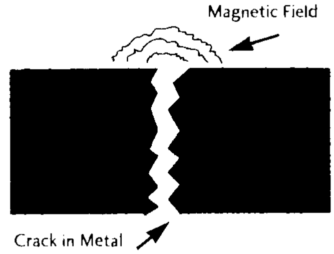
Magnetism, or magnetic energy, helps with daily living in many ways. For example:

- Junkyards use large electromagnets to lift and move cars and other metal items.

- Magnets play a big part in our recycling efforts by separating the metal from the other trash.

- Magnets are used in motors and generators that produce electricity, which we commonly take for granted. Note: Many third-world countries still cannot rely on electrical power to power lights, refrigerators, washers, and other conveniences.

- Magnetism is used in industry to check for cracks in ferrous metal parts (e.g., engine blocks) using a process called *magnaflux*. The process begins by magnetizing the engine block, then spraying onto it water that contains phosphorescent iron particles. If a block has a crack, it will form a positive and a negative pole that attracts the iron particles. When a black light is applied to the surface of the engine block, the iron particles that the magnetic energy attracted to the crack become visible.



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Evaluation

Have each team present the data from their exploration in chart form, describing how powerful the magnet became on each step.

Journal entry
Explain magnetism and describe how it is used at home and other places.

Extension activities

Hint: Encourage prediction; will it be 10 sheets? 25 sheets? 50 sheets?

- Locate magnets of different strengths. Be sure to provide 2 magnets for each strength. Have students compare the differences in magnets' strength by testing how many pieces of paper they can place between two like magnets and still have enough magnetic pull to pick up a paper clip. Have students test each set of magnets in this way, recording the results after each test. Then have students compare the results.

- Have students find magnetic items at home and report their findings in class. Examples include radios, televisions, computers, doorbells, refrigerators, telephones, and items that use electric motors.

Career pathways

Geologists, meteorologists, and various electrical occupations such as electrical engineer, construction technician, and electronics technician

Connections to other subjects

Social Studies. Have students investigate how magnets are used in industry and describe their impact upon society.

Resources for teachers and students

Electricity & Magnetism by Phil M. Parratore (Creative Teaching Press, Inc., 1996)

Magnets & Electricity by Karen Lee Siepak (Carson-Dellosa Publishing Co., Inc., 1995)

Super Science with Simple Stuff by Susan Popelka (Dale Seymour Publications, 1997)

Fun with Simple Science: Batteries and Magnets by Barbara Taylor (Warwick Press, 1991)

The Science Book of Electricity by Neil Ardley (Harcourt Brace Jovanovich, 1991)

Magnetic Materials

Data Sheet I

Name ______________________________

Name(s) of Team Member(s) ______________________________

____

Instructions:

1. Select items that your team will test for their attraction to a magnet. Write them in the left-hand column.
2. One at a time, predict whether or not you think the item is magnetic and mark the appropriate column with a √.
3. Test each item and mark your observations.
4. When you're tested all of the listed items, write your conclusions in the space provided.

Item	**Prediction** (Do we think it will be attracted to the magnet?)		**Observation** (Was the item attracted to the magnet?)	
	YES	NO	YES	NO

Conclusions:

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Magnetic Materials

Data Sheet II

Name ______________________________

Name(s) of Team Member(s) ______________________________

Materials: 1 magnet (semi-strong to strong), 6 nails, approximately 50 paper clips

Instructions: Make 6 magnets of different strengths. For each magnet, move a nail across a magnet the number of times indicated in the left column of the table below (e.g., 0 strokes for the first nail, 10 for the second nail). Use a new nail for each magnet. **Important: Be sure to rub the nail in only one direction!** Test the strength of your magnets by seeing how many paper clips each of your 6 magnets will pick up. You will conduct 2 more experiments with the 50-stroke magnet; follow the instructions listed in the last two rows of the left column below.

Action taken (e.g., number of times the nail is rubbed	**Prediction** (e.g., number of paper clips you think moved across the magnet)	**Observation** (e.g., number of paper clips the nail will attract)
0 strokes		
10 strokes		
20 strokes		
30 strokes		
40 strokes		
50 strokes		
Throw the 50-stroke nail on the ground 2 times		
Throw the nail on the ground 2 more times		

Conclusions:

Motors in Motion

About this learning activity

Students will construct a simple electric motor and explain how it works.

Key process skills

- Categorizing or classifying
- ● Communicating
- Comparing
- ● Controlling variables
- ● Experimenting
- Hypothesizing
- ● Inferring
- Interpreting data
- ● Making models
- ● Measuring
- ● Observing
- Ordering
- Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

● 1 ● 2 3 ● 4 5 6 ● 7 8 ● 9 10
11 ● 12

6th grade

● 1 ● 2 3 4 ● 5 6 ● 7 ● 8 ● 9 10

9th grade

● 1 2 ● 3 4 5 6 7 8 9 ● 10
11 12 13 14 15 16 17 18 ● 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

(for each student)

- A sample or picture of a motor
- 1 battery (D-cell)
- 2 paper clips
- 1 wide rubber band (to hold the wire to the ends of the battery)
- 60-cm length of enameled or varnished copper wire (22–28 gauge)
- ½- or ⅜-inch dowel (to coil wire around) *Note: A broom stick could be used.*
- Electrical tape (to tape the copper wire coil together)
- 1 small piece of sandpaper (to remove the enamel from the top of the copper wire ends)
- 1 magnet (flat; square or round; ceramic or rubberized)

Time estimates

(1–2 class periods)

Setup	10 minutes
Exploration	45 minutes
Cleanup	10 minutes

Key science principles

- Magnetism
- Energy transformation (i.e., the Law of Conservation of Energy)

Engagement activity

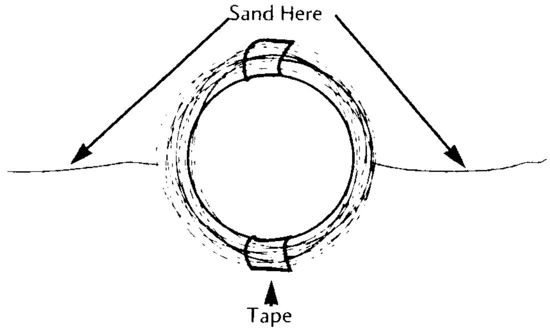
Show students an old motor from an appliance as a visual aid as you talk about motors. (If a motor is not available, use a picture.) Have students brainstorm places where electric motors are used—and list them on the board. Then, as a class or in small groups, challenge students to think of alternatives for accomplishing the daily tasks that typically require electric motors (e.g., drying clothes on a line instead of using an electric clothes dryer). Encourage class discussion.

Exploration activity

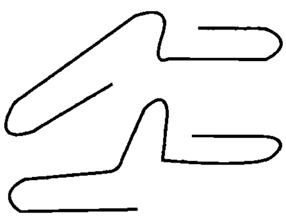
Important: Before assigning this exploration activity to students, build a motor yourself. It will help you understand how it is constructed, so you can support students throughout the learning activity.

Have students construct motors that are similar to the one invented by Michael Faraday.

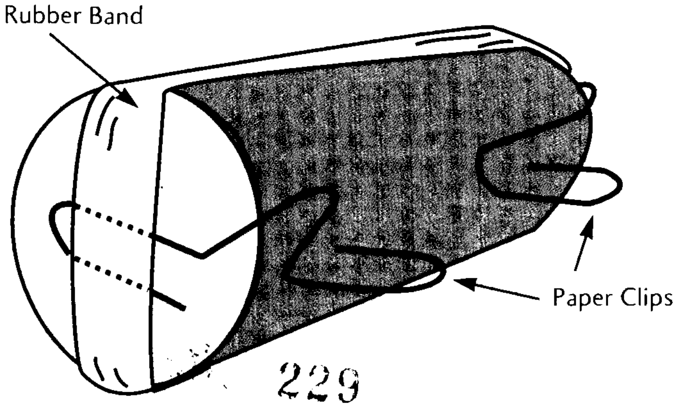
1. Wrap the enameled (or varnished) copper wire tightly around a dowel— making a coil and leaving 2–3 cm on either side extending straight out. Hold the wires in place with two small pieces of tape.



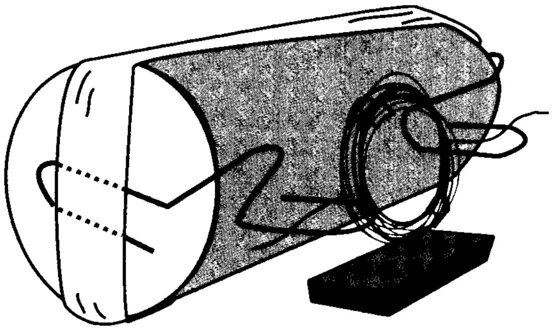
2. Use sandpaper to remove the enamel coating from the **top only** of the two wires that extend out from the coil.
3. Bend the two paper clips to act as supports for the coil of wire.



4. Hold the small ends of the paper clips to the poles of the D-cell battery with the wide rubber band.



5. Rest the wires extending from the coil through the loops on the paper clip supports.



6. Put a magnet beneath the coil.

7 Give the coil a flip with your finger and watch the motor spin.

8. Facilitate a class discussion by asking some or all of the following questions:

   - What will make your motor turn faster?
   - Can you make the motor turn the other way?
   - Can you use two magnets to make the motor turn? If so, where should you place them?
   - What items must any electric motor contain in order to work?

Note: The class discussion will help students generate motor modification ideas. Be sure to give them time to test their ideas.

Explanation

The electric motor is based on the interaction of magnets and electricity. In 1821, Michael Faraday built the world's first electric motor. It was a very simple motor, consisting of a magnet in a tube filled with mercury and a wire with a charge running through it. (Mercury is a very good conductor of electricity, but it is a poisonous substance and is not used for these types of experiments today.)

An electric motor requires three components: a **source of current**, a **magnet**, and one or more **loops of wire** that are free to turn within the magnetic field of a magnet. Commercial motors may run on either direct current or alternating current. In addition, they may use permanent magnets or electromagnets, and may contain more than one coil.

In this learning activity, the motor worked when the circuit was closed, which allowed current to flow through the circuit—producing a current in the copper wire. When the pole of a magnet was placed beside (or below, in this case) an electric current, the lines of force pushed the pole of the magnet in a circular direction around the current. The loop, which carried the current in a magnetic field, had forces applied to it that caused it to turn. When the current flowed in one direction without interruption, the force deflected the coil in one direction and it stayed in position.

Evaluation

Observations

- Observe during the learning activity to see if each student can make the electric motor operate.
- Note students' responses to the discussion questions.
- Note whether students modify their motors.

Journal entry

Explain how you built your electric motor and describe how it works.

Extension activities

✱ Have students invent something that lets their electric motors complete some useful work. (See the learning activities in the Simple Machines section for suggestions.)

✱ Ask students to investigate the professional life of Michael Faraday. (He built the world's first electric motor; see the explanation section for more information.)

✱ Tell students to find a book about electricity and try to follow its instructions for building a more complicated electric motor. (See the books suggested at the end of this learning activity, and others listed in Appendix B.)

Note: You will find that by touching and retouching one wire to the case while the other wire is firmly held in place, you can make the needle spin like a tiny motor.

✱ Have students build a very simple motor with a magnetic compass in a metallic case, two wires, and two D-cells in a series. Provide these instructions:

1. Connect one wire to each end of the D-cell series.
2. Hold the end of one wire against the side of the compass.
3. Briefly touch the other wire to another place on the case. You should see the needle turn.
4. Experiment with other places on the case to touch the two wires.

Connections to other subjects

Language Arts.

- Have students write a story about a world with no electric motors, including a discussion of how their lives would be different.
- Have teams of students write an advertisement for the first electric motor.

Social Studies.

- Have students research the methods used to complete tasks 150 years ago—before Faraday's invention of the electric motor. Which of these tasks can be performed today without an electric motor?
- Have students investigate how the electric motor and the ability to generate electricity changed the lives of the people of Faraday's time.

Math. Have students calculate the number of spins per minute on their motors. Then instruct them to experiment with their motors to determine if adding another D-cell doubles the number of rotations. Have them calculate the number of spins per minute after doubling the number of wraps of the wire coil. Tell students to graph their results.

Resources for teachers and students

How to Make and Use Electric Motors by A. G. Renner (Putnam, 1974)
The Way Things Work by David Macaulay (Houghton Mifflin, 1988)
Electricity & Magnetism by Phil M. Parratore (Creative Teaching Press, Inc., 1996)
Magnets & Electricity by Karen Lee Siepak (Carson-Dellosa Publishing Co., Inc., 1995)
Electricity by Jason Cooper (The Rourke Corporation, 1992)
Switch On, Switch Off by Melvin Berger (HarperCollins, 1989)
Super Science with Simple Stuff by Susan Popelka (Dale Seymour Publications, 1997)
Experimenting with Batteries, Bulbs, and Wires by Alan Ward (Chelsea House Publishers, 1991)
Fun with Simple Science: Batteries and Magnets by Barbara Taylor (Warwick Press, 1991)
The Science Book of Electricity by Neil Ardley (Harcourt Brace Jovanovich, 1991)

Career pathways

Automotive engineer, automotive technician, mechanical engineer, and electrical occupations such as electrical engineer, construction technician, and electronics technician (See also, career pathways listed in the Magnetic Materials learning activity.)

Notes

FUN *with* PHYSICS

Real-Life Problem Solving for Grades 4–8

Exploring Heat

Exploring Heat

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Fun with Physics

Real-Life Problem Solving for Grades 4–8

Exploring Heat

Learning Activities **Page**

Exploring Heat Vocabulary

Absorption

Condensation

Conduction

Evaporation

Friction

Heat

Insulation

Molecules

Temperature

Thermometer

Notes

Some Like It Hot

About this learning activity
Students will use thermometers to measure the sun's heat on different objects and colors. They will draw conclusions about the resistance and absorption of heat.

Key process skills
- ● Categorizing or classifying
- ● Communicating
- ● Comparing
- ● Controlling variables
- ● Experimenting
- Hypothesizing
- ● Inferring
- ● Interpreting data
- Making models
- ● Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes
4th grade

1 2 ● 3 4 5 6 ● 7 8 ● 9 10
● 11 12

6th grade

1 2 3 4 ● 5 6 7 ● 8 ● 9 ● 10

9th grade

1 2 ● 3 ● 4 5 6 ● 7 8 9 ● 10
11 12 13 14 15 16 17 18 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials
(one set for each team of students)

- 5 identical clear jars with lids (large enough for thermometer to fit inside with a lid on)
- 5 thermometers
- Black paper
- White paper
- Soil
- Water
- Sand
- Some Like It Hot data sheet

Time estimates
(1–2 class periods)

Setup 5–10 minutes
Exploration 90 minutes
Cleanup 5–10 minutes

Key science principles
- Thermal resistance (i.e., opposition to the flow of heat energy)
- Law of thermodynamics (i.e., heat energy always flows spontaneously from hot to cold)

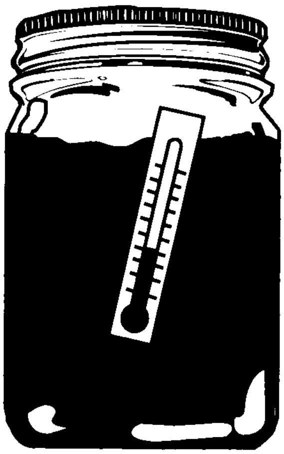
Hint: If lids are unavailable, cover each jar tightly with aluminum foil.

Hint: Identical tin cans that are covered with colored construction paper can be used instead of glass jars.

Safety tips

- ✚ If concerned about breakage, use plastic jars and plastic thermometers.

Hint: If you prefer, you can assign roles. Also, it's a good idea to have students take different roles for different activities.



Engagement activity

Take students outside to feel the heat of the ground in a sunny place and a shady place. Ask them to discuss their observations (e.g., which place feels hotter? cooler? why?). Then explain that they will learn more about heat during the exploration activity.

Exploration activity

1. Form teams of 3–5 students each. Have them choose the roles of thermometer reader, recorder, reporter, and materials manager(s).

2. Ask students to make the following predictions:

   - Which color will absorb the most heat and become the hottest?
   - Which color will resist the heat and stay the coolest?
   - Will the water, soil or sand absorb or resist the sun's heat?

3. Record and tally the predictions made in step 2 on newsprint or a chalkboard.

4. Have students prepare their five jars.

   a. Insert different materials into jars as follows:
      - Place a piece of black paper around the inside perimeter of one jar.
      - Place a piece of white paper around the inside perimeter of one jar.
      - Fill one jar with dry soil.
      - Fill one jar with water.
      - Fill one jar with sand.

   b. Position 1 thermometer in each jar so that each can be read without removing the lids.

   c. Cover each jar with a lid.

5. Place all jars in a sunny location (e.g., window sill, parking lot) and leave them for about an hour.

6. After an hour has passed, have teams read their thermometers and record the temperatures on a Some Like It Hot data sheet.

7. Have students discuss their findings and draw conclusions.

8. In a class discussion, have students report and discuss which materials were the hottest. Encourage them to draw conclusions about why some colors and materials absorb heat more than others. Be sure to compare students' results against their predictions.

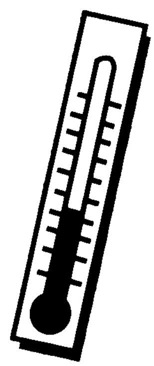
Explanation

Thermal resistance means opposition to the flow of heat energy. The dark soil, rough sand, and black paper absorb the sun's heat more quickly than the shiny water and white paper because the latter are more resistant to the sun's heat. The faster the heat energy moves from one molecule to another inside a material, the less resistance occurs.

Evaluation

Use some or all of these questions to create a quiz or test.

- Would the inside of a car stay cooler if it had a white or black interior?
- Would you rather walk barefoot in the sand or in the soil on a hot day? Why?
- Why do thermos bottles have silver linings?
- Why are baked potatoes often cooked in aluminum foil?
- What does home insulation do?
- How does a stove burner transfer heat to a pot or pan?
- Which color of T-shirt would you wear on a hot sunny day? Why?
- If you lived in Arizona, what color would make a good choice for your car? Why?



Journal entry
Think about how the colors in our experiment absorbed or reflected the heat. Based on what you learned, which color might you wear outside in the winter? Why? Would you wear the same color in July? Why or why not?

Performance assessment
Have students design a device that would keep warm things warm and/or cold things cold. Have them share and explain their devices.

Career pathways

Retail store manager (e.g., clothing), marketing specialist, clothing designer, fabric manufacturer, and meteorologist

Hint: Use books, videos or other visual aids to illustrate clothing and terrain.

Extension activities

* Have students choose objects made of different materials (e.g., metal, wood, glass, plastic, foam) and complete the Some Like it Hot learning activity with them.
* Make *sun treats* to observe the effect of the sun's heat on different foods. For example, line 1/2 of the cups in a muffin tin with foil baking cups and the other 1/2 with paper baking cups. Place 1 marshmallow and 1 chocolate square in each cup. Place the muffin tin in direct sunlight and observe how the ingredients respond. Observe which treats are ready to eat first, those in the paper or foil cups. Enjoy!
* Set a glass aquarium covered with a glass lid in the sun. After an hour, feel the inside of the aquarium. Help students explain how some of the energy from the sun gets trapped inside the aquarium. Apply this knowledge to students' daily lives by facilitating a class discussion about why pets should not be left in closed vehicles.

Connections to other subjects

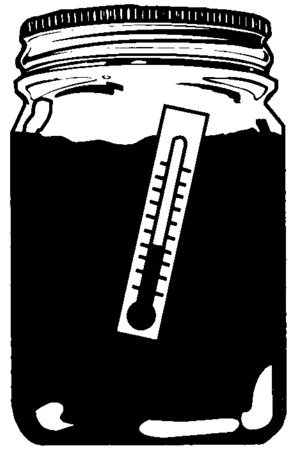
Geography. Help students find desert regions on the globe. Discuss the type and color of clothing people in these regions wear. Describe the color of the land and surroundings.

Resources for teachers and students

The Science Book of Hot & Cold by Neil Ardley (Gulliver Books, 1992)
Science Sensations by Diane Willow (Addison-Wesley Publishing Co., 1989)
Science Experiments with Water by R. Rosenfeld

Some Like It Hot

Data Sheet



Reporter's Name ______________________________

Recorder's Name ______________________________

Thermometer Reader's Name ______________________________

Material Manager's Name(s) ______________________________

Question: Which color of material will absorb the most heat and become hottest?

Prediction: Predict which color of material will become hottest and why you think this will happen.

We predict ______________________________

____

____

Experiment: Draw a picture of your experiment.

Results:

Temperature in the jar with ______________________ was ______________________
Temperature in the jar with ______________________ was ______________________
Temperature in the jar with ______________________ was ______________________
Temperature in the jar with ______________________ was ______________________
Temperature in the jar with ______________________ was ______________________

Conclusion:

We found that the jar with ______________________ was hottest, so it absorbed the most heat. Explain below.

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Notes

Ice Scream

About this learning activity

Students will observe how heat is transferred by making ice cream.

Key process skills

- Categorizing or classifying
- ● Communicating
- Comparing
- Controlling variables
- Experimenting
- Hypothesizing
- ● Inferring
- ● Interpreting data
- Making models
- ● Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

1 2 ● 3 4 5 6 7 8 ● 9 10
● 11 12

6th grade

1 ● 2 3 4 5 6 7 8 ● 9 ● 10

9th grade

1 2 ● 3 ● 4 5 6 7 8 9 10
11 ● 12 13 14 15 16 17 ● 18 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

Engagement activities

- Food coloring liquid or paste
- Water
- 2 100-ml beakers
- Hot plate or heat source
- Colored ice cubes (prepare a day in advance)

Time estimates

(1 class period)

Setup 10 minutes
Exploration 30 minutes
Cleanup 10–15 minutes

Key science principles

- Thermodynamics; heat transfer
- Temperature
- Conduction
- Radiation

Hint: Food coloring paste, which is more concentrated and long-lasting than regular food coloring, is available from cake decorating suppliers.

Exploration activity (for each team of students)

- 1 thermometer
- 1 teaspoon vanilla
- 3 tablespoons sugar
- ½ cup whole milk
- 1 zip-type freezer bag (sandwich size)
- 1 zip-type freezer bag (gallon size)
- ½ cup rock salt
- 1 cup crushed ice cubes
- 4 plastic spoons
- 4 small paper cups (Hint: Cupcake cups work well)
- Newspaper (to insulate the ice cream mixture)

Safety tips

- Be sure to handle the hot beakers with clamps.
- Wear safety goggles.
- Carefully drop ice into water with tongs.
- Be sure students close each bag tightly.
- Salt can be a skin irritant. Have students wash their hands after handling the rock salt.

Engagement activity #1

1. Preparation: Add food coloring to water in an ice cube tray and freeze it (at least a day in advance).

2. Ask students to observe an energy transfer as you conduct the following demonstration:

    a. Heat water in one beaker to 90°C. Keep the water in the other beaker at room temperature.
    b. Carefully drop 3 colored ice cubes into each beaker.
    c. Observe the process of energy transfer.
    d. Optional: Take a temperature reading of the water in each beaker.

3. Begin a class discussion by asking students to describe what they observed in the 2 beakers. Help them identify ways that the changes were the same by asking questions like, "What do each of the examples have in common?" Then ask, "Do these changes affect the nature of the substance? How?"

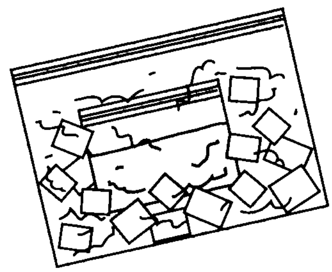
Engagement activity #2

Instead of, or in addition to, the first engagement activity, place 1 teaspoon of ice melt (which is used for melting ice on sidewalks and driveways) into a zip-type sandwich bag. Add a small amount of water or an ice cube. Seal the bag and have students observe what happens by looking and touching. (The heat transfer is very obvious!) Then help students draw conclusions about the transfer of heat.

Exploration activity

1. To help students experience the principles of heat transfer, have them make ice cream by taking the following steps:

   a. Distribute the ingredients for making ice cream.
   b. Mix vanilla, sugar, and milk in a sandwich-size zip-type bag.
   c. Use the thermometer to measure the temperature of the mixture; record it.
   d. Zip the bag shut tightly.
   e. Mix ice and rock salt in a gallon-size bag.
   f. Place the milk mixture (in the sandwich bag) into the center of the rock salt and ice. Zip the gallon zip-type bag shut.
   g. Wrap the entire gallon bag in newspaper.
   h. Take turns shaking for about 15 minutes.*
   i. Open the package; measure and record the temperature of the mixture.
   j. Pour the product into paper cups and enjoy. (Yum!)



   * While shaking the ice cream (step h), facilitate a class discussion. You can begin by explaining that ice cream was probably introduced to Europe in 1295 when Marco Polo returned to Italy with a recipe for a frozen dessert from the Far East. Later, Virginia Cavaliers took the *cream ice* recipe to America. First Lady Dolly Madison reversed the name to ice cream so that it was easier to read on the White House menu. Currently, over 1 billion gallons of ice cream are sold in the U.S. each year.

2. While enjoying the ice cream, ask questions such as:

   How are flavors added to ice cream? (If appropriate, you could have students invent names for new flavors of ice cream.)
   Compare the temperature of the mixture before and after mixing. Why do you think the temperature changed?
   What would you imagine are the scientific principles involved in making large quantities of ice cream?
   Is there an advantage to making ice cream in gallon sizes?
   What is the difference between soft serve and ice cream?

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Explanation

The ice cream mixture freezes as it melts the ice; the salt reduces the freezing point of the water and the ice. This is an example of heat transfer, where the heat of the ice cream mixture transfers to the ice and salt. The milk mixture loses energy and changes state to become ice cream.

All things, whether hot or cold, contain heat. Heat, or thermal energy, is created by the movement of many particles. Heat energy can be transferred from one object to another. In accordance with the law of thermodynamics, heat always flows spontaneously from warmer objects to cooler objects. This flow of energy can be used to do work. In addition, physical changes may occur as the temperature changes (e.g., water changing to ice, a liquid evaporating to become a gas).

Evaluation

Quiz or journal entry
Using the scientific concepts in the experiment, have students write a paragraph that explains how to keep milk from spoiling. Make sure you include data from the Ice Scream experiment.

Extension activities

- Have students research and explain how a refrigerator works.
- Have students research and explain the mechanics of an air conditioner.
- Have students research and explain why cars need antifreeze in their cooling systems.

Connections to other subjects

Math.
- Help students discuss how they could split or double the ice cream recipe.
- Have students calculate the cost of producing their ice cream and compare that price to store bought ice cream.

Language Arts. Tell students to write a paragraph titled, "My Favorite Place to Eat Ice Cream."

Social Studies. Create class projects around one or more of these topics:

- Discuss the Far East adventures of Marco Polo.
- Investigate and report on how ancient civilization created refrigeration.
- Research food preservation techniques.
- Study refrigeration to understand why it is a major component of food preparation and storage.

Arts.

- Help students design a factory that manufactures ice cream.
- Have students design advertisements for various flavors of ice cream.
- As a class, conduct a mock interview of Marco Polo on a TV show.

Resources for teachers and students

Books:

Simple Physics Experiments with Everyday Materials by Judy Breckenridge (Sterling Publishing Co., 1993)

Dictionary of Physics by Chris Oxlade et al. (Usborne Publishing Limited, 1986)

Science Explained by Curt Suple (National Geographic Society, 1996)

The Science Book of Heat and *The Science Book of Motion* by Neil Ardley (Gulliver Books, 1992)

Science Experiments You Can Eat by Vicki Cobb (Harper & Row, 1972)

More Science Experiments You Can Eat by Vicki Cobb (Harper & Row, 1979)

The Greenhouse Effect: Life on a Warmer Planet by Rebecca Johnson (Lerner Publishing Co., 1990)

Physics for Every Kid by Janice Van Cleave (John Wiley and Sons, Inc., 1991)

Audiovisuals:

Heat and Energy Transfer (film and video) by Coronet/mti, 108 Wilmot Road, Deerfield, IL 60015

Heat, Molecules in Motion (film and video) by Videodisc/AIMS Media, 9710 DeSoto Avenue, Chatsworth, CA 91311

Science Sleuths (videodisk) by Science Image and Activity Bank/ Videodiscovery, 1700 Westlake Avenue North, Suite 600, Seattle, WA 98109

Notes

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Keep It Cool

About this learning activity

Students will measure the melting rate of ice cubes to explore the effectiveness of various insulators.

Key process skills

- ● Categorizing or classifying
- ● Communicating
- ● Comparing
- ● Controlling variables
- ● Experimenting
- ● Hypothesizing
- ● Inferring
- ● Interpreting data
- ○ Making models
- ● Measuring
- ● Observing
- ○ Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

○ 1 ● 2 ● 3 ● 4 ○ 5 ○ 6 ● 7 ○ 8 ● 9 ○ 10
● 11 ○ 12

6th grade

● 1 ● 2 ● 3 ● 4 ○ 5 ○ 6 ○ 7 ● 8 ● 9 ○ 10

9th grade

● 1 ○ 2 ● 3 ● 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ● 10
○ 11 ● 12 ○ 13 ○ 14 ○ 15 ○ 16 ● 17 ○ 18 ● 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Time estimates

(2 class periods)

Setup	10 minutes
Exploration	90 minutes
Cleanup	10 minutes

Key science principles

- Insulation
- Transfer of heat
- Absorption of heat

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Hint: *Use blue food coloring when freezing so the cubes will be easier to see. Larger cubes may be used, but the activity will require more time to complete.*

Hint: *Ask students to bring in materials that can be used for this learning activity.*

Hints: *The time needed for this activity depends upon the size of ice cubes used. Non-insulated cubes of approximately ½-inch in diameter take about 30 minutes to melt. Cover all tables with newspaper for easier cleanup.*

Materials

- 1 9-ounce, clear plastic cup—with a masking tape label to write the team's name
- Masking tape (cut into strips large enough for students to print their names or their team's name) Attach 1 strip of masking tape to each cup.
- Keep It Cool data sheet
- Cooler of small (½-inch diameter), blue ice cubes
- Clock
- Insulators (Some options are listed below.) Lay them on a table for students to select from.

Styrofoam packing peanuts	Feathers
Aluminum foil	Straw
Fabric scrap	Sawdust
Sawdust	Sand
Plastic bags (any size or type)	Bubble wrap
Newspaper	Cotton socks
Shredded newspaper	Cotton balls
Cardboard	Room temperature liquids such as water, cooking oil, vinegar, and carbonated water
Uncooked rice	
Rubber bands	

Engagement activity

1. Give each student an ice cube in a clear plastic cup.

2. Ask the following questions:

   - What can you tell me about your ice cube? (Possible answers: cold, frozen water, changes back to water, slippery, clear, may have bubbles in it) List students' observations on the chalkboard or on newsprint.
   - What materials do you see on this table that might keep this ice cube from melting? (Possible answers: cardboard, newspaper, sawdust)
   - Where have you seen those materials used? (Possible answers: coolers, cups at fast food restaurants)

3. After the discussion, have students return their ice cubes to the cooler and keep their cups.

4. Assign an insulator definition activity for either a homework lesson or library time. Have students find *insulation* or *insulator* in at least two reference sources (e.g., dictionary, Internet), record definition(s), and list at least five examples of insulators. Discuss students' findings as a class.

Exploration activity

Have students explore how different insulators affect the rate at which an ice cube melts by taking the following steps:

1. Divide the class into teams of 3–5 students each. Instruct the team members to work together to keep their ice from melting.

2. Assign team members to the roles of recorder, reporter, and materials manager(s). All team members are observers.

3. Distribute a Keep It Cool data sheet to each team. Have them complete the top of their data sheets based on the roles assigned.

4. Instruct teams to review the insulator materials located on the table. Explain that teams can choose **1** material for each time they conduct the experiment. Teams may conduct this experiment up to 3 times, using 3 different materials, so have teams decide which they will test first, second and third.

5. Have students complete the insulator materials section of the data sheet.

6. Have students predict which of their selected materials will be the best insulator. They should record their prediction on the data sheet.

7. Distribute 3 cups to each team. Show them the blue ice cubes, explaining that they are blue to make it easier to see them inside the cups.

Safety tips

✚ Puddles from melting ice will make floors slippery. Make sure drips are contained or wiped from the floor immediately.

Note: You may wish to have students conduct this exploration individually.

Note: If no team chooses to put nothing in their cup, the teacher should complete this option so that data will be available for it.

Hint: This exploration can be done more quickly if students experiment with 3 or more insulators at the same time. To do this, each student would choose a different insulator (one each) and all insulators would be tested simultaneously. However, use this method only if your students are experienced enough experimenters, capable of completing multiple observations simultaneously.

Note: *Totals can be rounded to the nearest minute.*

8. Instruct students to print their team name on a cup, put **1** cube in the cup, and cover the cube with the insulator material chosen. Remind them to repeat these 3 steps for each insulator they test.

9. Have students record on their data sheets the time they put the cube in the cup.

10. Warn students to watch their cups and the clock closely, and when the cube melts completely, record that time on the chart.

11. As soon as all cubes are melted and melting times are recorded, have students make the necessary calculations and complete the *total time for ice to melt* column on the data sheet.

Sample Keep It Cool Data Sheet

Insulator	Time ice put in cup	Time ice melted	Total time for ice to melt
carbonated water	3:18	3:20	2 minutes
straw	3:22	4:02	40 minutes
cooking oil	3:22	3:32	10 minutes
feathers	3:40	4:00	20 minutes

12. In the space provided on the data sheet, have teams develop a bar graph of the total melting times for each of their insulators.

13. Instruct teams to draw at least one conclusion from their exploration and record it on the back of the data sheet.

14. When data sheets are complete, have each team present its findings.

15. Facilitate a class discussion about the recorded information. Some questions you could ask include:

- What materials kept the ice from melting quickly?
- Are any materials similar? (e.g., Both Matt and Kathy used liquids, but Matt used water and Kathy used oil. Which cube melted fastest? Answer: the one in water)
- What do you use at home to keep your ice cubes from melting? (Possible answers: freezer, cold pack)
- If you want to take ice from your home to another place, what do you use? (Possible answers: plastic bag, cooler)
- What are coolers made from? (Possible answers: styrofoam, plastic)
- Mike and Sarah used the same materials, but Sarah's cube melted faster. What could have happened? (Possible answers: different sizes of cubes, different amounts of insulation, different density of packing material, different room temperatures)
- What materials made the best insulators?
- How could the heat loss from a building be reduced? from a hot water heater?
- Why might a house built in 1924 need improved insulation more than a house built in 1987.
- If we conduct the same Keep It Cool experiment outside when it's 90°, what would happen? (Answer: The ice will melt quicker, but the insulators will still protect the ice.)

Explanation

All matter is made up of **molecules**. Molecules are in constant motion. Matter that is warm has faster moving molecules than matter that is cool. Furthermore, when faster moving molecules collide with slower moving molecules, **heat energy is transferred** from the faster moving (warm) molecules to the slower moving (cool) molecules—speeding them up. In this way, heat energy is transferred from molecule to molecule until all the molecules in an object are traveling at the same speed and are the same temperature.

Heat travels from warm objects to cooler objects. The process by which heat is transferred through a substance or from one substance to another by the direct contact of molecules is called **conduction**. For example:

- When you hold an ice cube, the heat from your hand transfers to the ice—increasing the cube's temperature. *Note: Your hand feels cold because of the absence of heat; coldness is the absence of heat.*

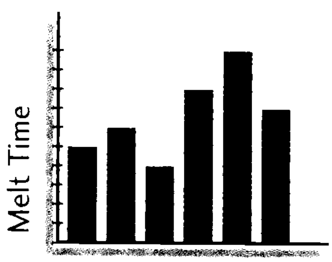
- When you put a container of cold water in a warm room, the heat from the room moves into the water. *Note: The cold does not move out of the water, because heat moves from a hot area to a cold area .*

Insulators help cold things stay cold and hot things stay hot by slowing down the speed at which cold objects absorb heat. All materials absorb heat—but they absorb it at different rates. Materials that are effective insulators reduce the amount of heat that is transferred to a colder surrounding area by conduction—their molecules are farther apart and do not conduct heat energy very easily. Furthermore, because of their molecular structures, poor insulators are good conductors of heat and electricity.

Evaluation

Questions that can be used for a quiz or test
Use all or some of the discussion questions listed in the exploration activity.

Melt Time of Insulators



Insulators

Assessment activity
After the experiment, have students list the insulators in order of effectiveness. Then instruct them to add others that were not used in the experiment. (Perhaps they can use some from the insulator definition activity.) Have students chart the list and corresponding results on a bar graph and present the graph to classmates, along with an explanation of the process of heat dynamics in insulation.

Journal entry
You are a research scientist and your job is to invent a new kind of container to keep things cold. What materials would you use? Explain.

Hint: Consider the chemical make-up of the items in each category; poor insulators are usually metals.

Performance assessment
Collect 10–12 items, ranging from good insulators to poor insulators. Have the students categorize the items into 2 categories (e.g., good insulators, poor insulators) using a graphic organizer (i.e., a chart).

Examples of good insulators: oven mitt, piece of wood, cotton sock, wool hat, piece of heavy plastic, rubber glove, cork, polyester quilt, foam packing peanut, plastic tubing, glass measuring cup, air

Examples of poor insulators: copper wire, silver spoon, lead pipe, iron nail, brass screw, stainless steel pan, water

Extension activities

- ✱ Tell students to imagine that they have been given a cold can of pop on a very hot day. Ask them what they could do to keep the pop can cold longer? Make a list on the chalk board or chart paper. (Possible answers: Keep the can in a freezer between drinks, put the can in foam holder, wrap the can with foil, put the can into a bucket with ice around it, wrap the can in newspaper or cloth, pack sawdust or ice around the can, make a nest for the can from grass or leaves.)

- ✱ Make ice savers. Have each student or team choose up to three materials from the available insulating materials to design a container that will keep a standard-size ice cube from melting. When the container is complete, give everyone an identical ice cube inside a zip-type sandwich bag to be inserted into their ice savers. After 30 minutes, have each student or team remove the plastic bag. Results can be graphed or discussed based on the relative sizes of the ice cubes (or the amount of water found in each plastic bag can be measured).

Note: The World Champion Ice Cube Keeper is David Webster. He kept an ordinary ice cube from melting for sixteen hours in a room at 70°F (from Robert Gardner's Favorite Science Experiments.*)*

- ✱ Study other properties of ice, e.g., water expands when it is frozen, ice floats. (Many of the books listed in the Resource section, Appendix B, contain such activities.)

- ✱ Have students complete these steps:

  1. Fill 2 identical cups with cold water.
  2. Place 2 ice cubes in each cup.
  3. Cover one finger on one hand with ½ inch of vegetable shortening.
  4. Simultaneously, put the shortening-covered finger into one cup of ice water and the same finger (not covered with shortening) from the other hand into the second cup of water.
  5. Observe and record what happened.
  6. Using a thermometer to measure the temperature in both cups, confirm the results.

  Discuss feathers, fur, and fat, and how such things insulate animals in cold temperatures.

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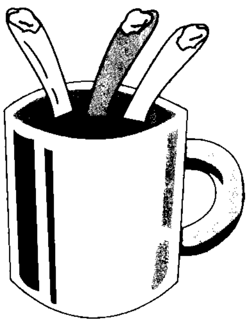
* Guide students through a butter slide experiment, using spoons made of 3 different materials (e.g., stainless steel, wood, plastic). Have students follow these instructions:



1. Put an equal-sized piece of butter on the top part of the handle of each of the 3 spoons.
2. Carefully put all these spoons into a cup of hot water—with the buttered handle end out of the water.
3. Record the time the spoons were placed in the water, then record the time when the butter slides down each spoon. (Use a data sheet similar to the Keep It Cool data sheet.)
4. Calculate how long the butter stayed on the spoon.
5. Make a bar graph that illustrates how long the butter stayed at the top of each spoon.
6. In a class discussion, ask some of the following questions:

Why did the butter slide off the spoon?
Which spoon did the butter slide off of first? Second? Third?
Did the butter slide off of all the spoons?
What hypothesis might explain why the butter slid off of some spoons and not others. Write it down.
What materials are used in your home to keep heat from burning you?
What part of the spoon got hot first?
How did the heat move from the hot water to the spoon?
Did the heat move in the spoon?
How are the spoons the variables in this experiment?

Note: Heat is shown in different colors with warmer temperatures in white, red, and yellow and cooler colors in green, blue, and black.

* Tell students to investigate thermograms of buildings or people that pick up the infrared radiation (heat) given off by all objects. Thermograms are used by insulation companies, engineers, contractors, and similar professions to determine where buildings need insulation. Thermograms are sometimes used with people to determine illness. (These are described in the National Geographic video, *The Invisible World*.)

* Have students analyze their school and/or homes to find places where new or increased insulation could help save heat energy. Identify the consequences of saving heat energy in their homes or school. Correlate the amount of energy saved to the amount of money saved.

* Have students interview local insulation companies to identify the materials used to insulate new buildings, or to improve insulation in existing buildings. They should identify the r-value of these materials and investigate the possibility of inventing a new material to use for insulation.

* Help students compare an insulated house to the layers of the earth's atmosphere. In addition, you can discuss the insulation of the earth's atmosphere by the ozone layer and the effects of chlorofluorocarbon on the atmosphere.

* Instruct students to research present uses of infrared mapping and predict future uses.

Connections to other subjects

Language Arts. Have each team write directions describing how a person would dress to protect their bodies for a 1-day expedition in Antarctica.

Social Studies.
- Have students read about penguins. Discuss some ways animals use insulation to keep warm.
- Help students study Eskimos, focusing on how they retain heat in their bodies, homes, food, and other situations.

Health. Discuss how clothing is used as an insulator. Have students research the symptoms of hypothermia and hyperthermia.

Math. Have students chart the results of all or some of their ice experiments on bar graphs, as described in the evaluation section. Discuss the graphs from a mathematical perspective, e.g., math principles used in practical ways, and other real-world applications for such principles.

Art. Have students draw a picture of themselves and the way they would dress if they were traveling to Antarctica. Begin this activity with a discussion of Antarctica's environment.

Note: Remote sensors (e.g., instruments that gather data using heat, sound, and radio waves—especially from satellites) improve the monitoring of weather and other changes both on earth and in the solar system.

Career pathways

Packaging designer, architect, engineer, chemist, meteorologist, insulation installer, and clothing designer

Resources for teachers and students

Books:

Be a Kid Physicist by William Wellnitz (TAB Books, McGraw-Hill, 1993)

The Little Scientist: An Activity Lab by Jean Stangl (TAB Books, McGraw-Hill, 1993)

Robert Gardner's Favorite Science Experiments by Robert Gardner (Robert Gardner, 1992)

Science Activities for Students by Willard Jacobson and Abby Bergman (Prentice-Hall, 1983)

Wonder Science: Insulation, American Chemical Society/American Institute of Physics (April 1994)

Audiovisuals:

The Invisible World videotape by National Geographic

Keep It Cool

Data Sheet

Recorder ______________________________

Reporter ______________________________

Observer ______________________________

Materials Manager(s) ______________________________

Prediction:

Trial	Insulator	Time ice put in cup	Time ice melted	Total time for ice to melt
1				
2				
3				

Draw a bar graph that illustrates the total melting time for each insulator in the space below:

On the back of this page, write your team's CONCLUSIONS.

Notes

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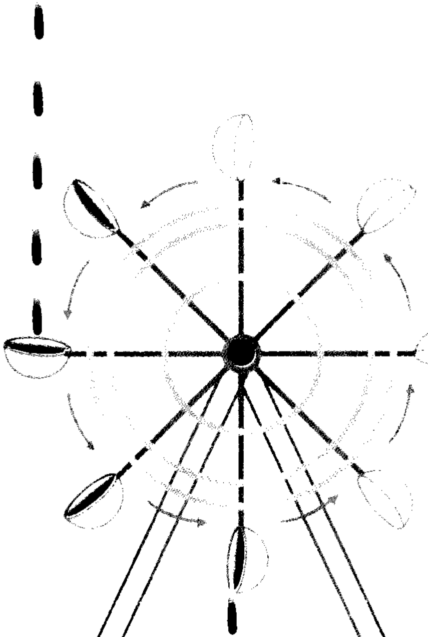
FUN with PHYSICS

Real-Life Problem Solving
for Grades 4–8



Exploring Liquids

Exploring Liquids

Fun with Physics

Real-Life Problem Solving for Grades 4–8

Exploring Liquids

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Liquids Vocabulary

Bernoulli's principle

Capillary action

Drag

Gravity

Lift

Polymer

Pneumatics

Surface tension

Thrust

Notes

Capillary Action

About this learning activity

Students will explore how liquids can defy gravity to travel upward.

Key process skills

Categorizing or classifying	Making models
● Communicating	Measuring
● Comparing	● Observing
● Controlling variables	Ordering
● Experimenting	● Predicting
● Hypothesizing	● Recognizing relationships
● Inferring	● Recording
● Interpreting data	

Ohio science proficiency outcomes

4th grade

1 ● 2 3 4 5 ● 6 7 8 ● 9 10
● 11 ● 12

6th grade

1 2 ● 3 4 ● 5 6 ● 7 ● 8 ● 9 10

9th grade

1 ● 2 3 ● 4 5 6 ● 7 8 ● 9 ● 10
11 12 13 14 15 16 17 18 ● 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

Engagement activity

- 2 3x3-inch pieces of glass
- 1 bowl of water

Exploration activity (for each team)

- 10 paper towels, cut into strips approximately 1 inch x 12 inches
- 1 cup of water
- 1 roll of masking or scotch tape
- Scissors
- Small paper cups (i.e., Dixie™ cups)

Time estimates

(1 class period)

Setup	10 minutes
Exploration	30 minutes
Cleanup	5 minutes

Key science principles

- Osmosis
- Diffusion
- Capillary action, which allows liquids to flow upward

Hint: Put a drop of food coloring in the water to enhance the effect.

Safety tips

- Do not allow students to handle glass pieces during the engagement activity.

Note: They should be able to see that the water level between the glass rises as the 2 pieces get closer together.

Note: Colored water is recommended.

Engagement activity

Conduct the following demonstration to show that water levels can be changed.

1. Place the two pieces of glass into the bowl of water and move them toward each other until they are within ½ inch of each other.

2. Have students describe their observations.

3. Facilitate a class discussion by asking questions such as:

   - Why did the water rise?
   - Can water defy gravity?
   - Why do we use paper towels to clean up liquid spills?
   - What makes Bounty™ the *quicker picker-upper*?
   - What other materials can you use to absorb liquids?
   - Would plastic towels work? Why or why not?

Exploration activity

Help students explore how capillary action enables liquids to travel up and across materials.

1. Have students work in teams of 3–4. Assign roles of materials manager, reporter, and recorder.

2. Instruct each team to tape one end of a paper towel strip to a chair bottom or cabinet bottom—positioned so that the other end rests in the bottom of a cup.

3. Have each team label its cup with a team name or symbol, then fill the cup ¾ full with water.

4. Ask each team to predict how high (i.e., how many inches) they think the water will rise. Have each team record its prediction *before* placing the paper towel strip into the water.

5. Instruct each team to place the end of the paper towel strip in the cup of water.

6. Instruct students to make observations at 2-minute intervals, recording how high the water has traveled up their towels.

7. Facilitate a class discussion by asking the following questions:

- Did your predictions match the results of the experiment? Explain why or why not.
- Why doesn't the water rise all the way to the top of the towel strip?
- Capillary action is used to our advantage in many things. What things at school, at home, or in the community can you think of that use this natural action (scientific principle) to their benefit?
- How can water flow up inside a tree if gravity is supposed to pull things down?
- What are capillaries and what do they do for your body?
- How do nutrients enter and exit cells?
- How can you smell food cooking in the kitchen when you're somewhere else in the house?

Explanation

Paper towels are made from tiny wood fibers; under a microscope you can see tiny pockets or gaps in the material. The wood fibers attract the water, which fills the gaps. Water can climb up a towel because of **capillary action**, which is a combination of adhesive and cohesive forces. An **adhesive force** occurs when one material attracts another and c**ohesive force** is a force that keeps liquids together.

In the exploration activity, water was attracted to the paper towel and the glass—adhesion. Then, through cohesion, more water was attracted to the water that adhered to the towel. Logic might suggest that this process would be continuous; however, the water will only go so high—until the force of gravity overcomes the adhesive force. When these two forces become equal, the water will stop climbing.

For example, industry uses capillary action to its advantage to test for cracks in non-ferrous materials (e.g., aluminum). This test is called a dye penetrate inspection. The first step in the inspection is to apply a coat of red dye to the entire material surface. Any crack or imperfection will absorb the dye through capillary action. Then the excess dye is wiped off and a powder spray is applied to the surface. Since the powder is more absorbent than the crack or imperfection, the dye is drawn away from the crack and absorbed into the powder. Thus, the dye seeps from the cracks, exposing the imperfections.

Note: A dye penetrate inspection is considered non-destructive testing because it causes no permanent damage to the material. Crash tests, like those performed by the automotive industry for safety reasons, are considered destructive testing.

Career pathways

Doctor, medical technician, dental technician, microbiologist, research scientist, textile designer, textile manufacturer, metals manufacturer, quality engineer, agriculturalist, and safety inspectors

Evaluation

Have teams construct a graph that compares time (in 2-minute intervals) with the water heights of a paper towel strip.

Extension activities

- Repeat the experiment using different widths and brands of paper towels and/or varying the types of liquids.
- Place a piece of celery in a jar that contains water and food coloring. Observe it for one week. Discuss the results and/or have students summarize their observations and conclusions in a report.

Connections to other subjects

Math. Have students practice making graphs, taking measurements, and keeping time during scientific explorations.

Earth Science. Have students investigate the process of capillary action in soil.

Social Studies. Disposable diapers and paper towels have made a big impact on our society. Have students investigate the effects of capillary action on our country and others (e.g., third world countries).

Resources for teachers and students

The Science Book of Hot and Cold by Neil Ardley (Harcourt, Brace, and Javonovich, 1991)
Moving Things by Robin Kerrod (Marshall Cavendish Publishing, 1990)
Science Sensations: Easy-to-do Activities that Explore the Science Behind Such Everyday Marvels as Rainbows, Bubbles, and Kaleidoscopes by D. Willow and E. Curran (Addison-Wesley Publishing Company, 1989)
Ideas for Science Projects by Robert Gardner (Franklin Watts, 1986)
Science Experiments with Water by Rosenfeld (Harvey House, 1965)

Pneumatic Flyer

About this learning activity

Students will construct a pneumatic flyer, experiment with its design, and explain how it works.

Key process skills

Skill	Selected	Skill	Selected
Categorizing or classifying		Making models	●
Communicating	●	Measuring	●
Comparing		Observing	●
Controlling variables	●	Ordering	
Experimenting	●	Predicting	●
Hypothesizing		Recognizing relationships	●
Inferring		Recording	●
Interpreting data			

Ohio science proficiency outcomes

4th grade

1 ● 2 3 4 5 ● 6 7 8 ● 9 10
11 ● 12

6th grade

1 2 ● 3 4 5 6 7 8 ● 9 ● 10

9th grade

1 2 ● 3 4 5 6 7 8 ● 9 ● 10
11 12 13 14 15 16 17 18 ● 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

Engagement activity

- 1 2-liter plastic bottle with a lid
- 1 gallon metal can with a lid
- Hot and cold water

Time estimates

(1–2 class periods)

Setup	10 minutes
Exploration	45 minutes
Cleanup	10 minutes

Key science principles

- Pneumatics; compressed air can be used to do work
- Air has pressure; various pressures create energy

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Safety tips

- ✚ Explain and **demonstrate** that air under pressure is very powerful. Then caution students against pointing their pneumatic flyers at another person.

Hint: You may wish to conduct an additional engagement activity focused solely on air pressure safety. Use demonstrations of air pressure power, show video clips, and discuss "what if" scenarios that could actually occur during class experiments.

Exploration activity (for each student or pair of students)

- 1 piece of cardboard
- Thread or fishing line
- 1 dishwashing liquid squeeze bottle
- 1 plastic sandwich bag
- 2 straws—1 small in diameter and 1 larger in diameter
- Tape
- 1 to 2-inch ball of modeling clay
- Pneumatic Flyer instruction and data sheets

Engagement activity

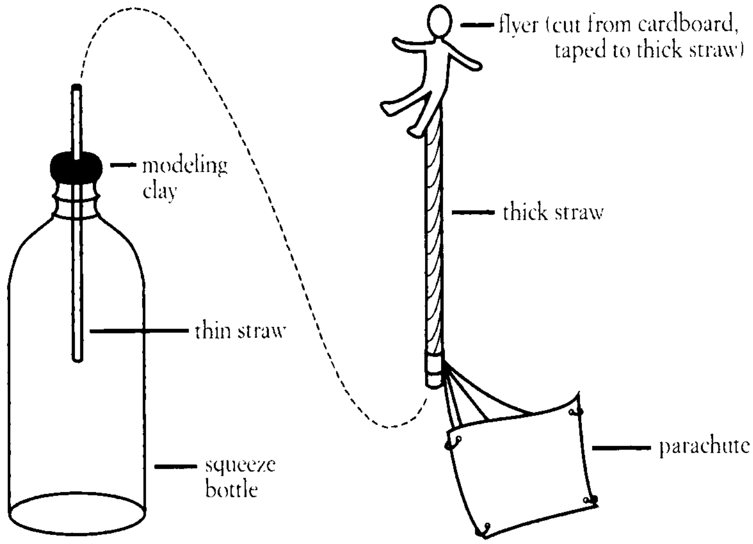
1. Show students that air has pressure by conducting the following demonstrations:

   Demonstration #1
   - Pour hot water into the 2-liter bottle and screw the lid on tightly.
   - Shake the bottle to heat all the air.
   - Unscrew the cap slowly to release the air pressure.
   - Reseal the cap.
   - Ask students to describe what they observed and heard when the cap was unscrewed.
   - Have students record their observations.

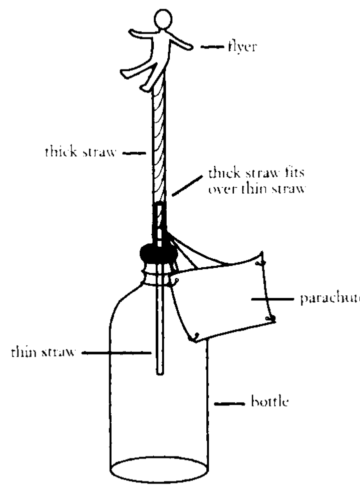
   Demonstration #2
   - Pour boiling water into the metal can and screw the lid on tightly.
   - Shake the can to heat all the air.
   - Unscrew the lid slowly to release air pressure.
   - Reseal the lid.
   - Ask students to describe what they observed and heard when the cap was unscrewed.
   - Have students record their observations.

2. Help students draw conclusions about what they observed in the 2 demonstrations. Conclusions should include the following points:
   - Air in the bottle and can expanded from the heat.
   - When the air cooled, it contracted—there was less pressure inside the bottle and can than outside.
   - Because the air outside had more pressure, it pushed on the bottle and can, causing them to collapse and release air pressure.

Disassembled Flyer



Assembled Flyer



Exploration activity

1. Have each student, or pair of students, make a pneumatic flyer. Instruct students to:

   a. Cut out a figure of a flyer from cardboard.
   b. Attach the flyer to the end of the larger-diameter straw and completely seal that end with tape.
   c. Attach this straw to the smaller-diameter straw by pushing one end of the smaller-diameter straw into the open end of the larger one.
   d. Push the smaller-diameter straw into the opening of the dishwashing liquid bottle. Seal around the opening with modeling clay.
   e. Cut a 6 to 7-inch square sheet from the plastic bag.
   f. Attach a piece of thread or fishing line to each corner of the plastic square (with tape or knots; students can choose their own attachment method). Attach the ends of the thread to the base of the larger-diameter straw with a piece of tape to form a parachute.
   g. Fold the parachute into a strip and lay it alongside the straw.
   h. Launch the flyer by squeezing the bottle sharply.
   i. Experiment by varying the force applied to the bottle.

2. As students experiment, remind them to record their predictions, actions, observations, and conclusions on the Pneumatic Flyer data sheet.

3. Facilitate a discussion that helps students draw conclusions about what they learned during their exploration. Ask questions such as:

   - What happens to the flyer when force is applied to the bottle? What happens to the parachute? (Answer: Compressed air inside the bottle pushes against the sealed end of the larger-diameter straw and pulls it out from the smaller-diameter one. This launches the flyer. Then the open parachute fills with air and slows the flyer's fall.)
   - What other parachute designs could be used?
   - Why can an air mattress hold the weight of a person?
   - How can hollow tires hold the weight of a car?
   - How can hollow tires on a bicycle hold the weight of the rider?

Explanation

Compressed air has tremendous force. When compressed, air can be used to exert enough force to move objects.

In the pneumatic flyer, the force from a student's squeeze compressed the air inside the dishwashing liquid bottle, causing the flyer to pop out of the bottle. Air under the parachute pushed upward to keep the parachute from falling quickly.

Evaluation

Questions for quizzes or tests
Use the questions and conclusions from the engagement and exploration activities, as well as those that follow.

- Explain how you can tell that air has pressure.
- Describe how pneumatic machines are driven by compressed air.
- Explain why air under pressure can be very dangerous.
- Draw a diagram that illustrates how the pneumatic flyer works.

Journal entry
Describe the process you used to design and test your pneumatic flyer.

Extension activities

* ✱ Have students do further exploration using different-sized bottles and measuring the distances the flyers travel.
* ✱ Have students do further exploration using different-sized straws and measuring the distances the flyers travel.

Connections to other subjects

Math.

- Have students measure the height the flyer attained.
- Ask students to graph the distance traveled by each team's or student's flyer.

Language Arts. Have students write a story from the flyer's point of view.

Social Studies. Direct students to research the use of pneumatics by society and report findings to the class.

Resources for teachers and students

1001 Things Everyone Should Know About Science by James Trefil (Doubleday, 1992)

202 Science Investigations by Marjorie Frank (Incentive Publications, Inc., 1990)

Make it Work! Machines by Wendy Baker and Andrew Haslam (Action Publishing, 1993)

Science Made Simple by Margaret Michel, Ed. (The Education Center, Inc., 1994)

Career pathways

Engineer, engineering technician, design engineer, machinist, industrial maintenance technician, automotive technician, nurse, doctor, medical technician, dentist, dental technician

Pneumatic Flyer

Student Instruction Sheet

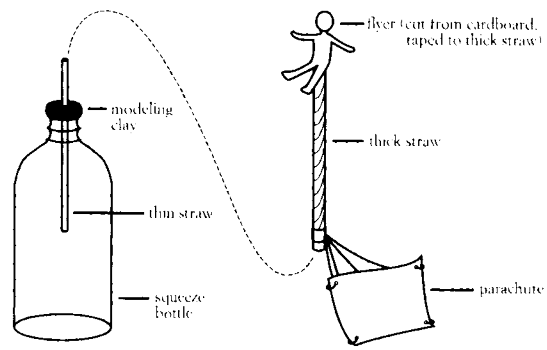
Purpose: Students will work individually or in pairs to construct a pneumatic flyer, experiment with its design, and explain how it works.

Materials:

- 1 piece of cardboard
- Thread or fishing line
- 1 dishwashing liquid squeeze bottle
- 1 plastic sandwich bag
- 2 straws—1 small in diameter and 1 larger in diameter
- Tape
- 1- to 2-inch ball of modeling clay
- Pneumatic Flyer instruction and data sheets

Procedure:

Disassembled Flyer



1. Cut out a figure of a flyer from cardboard.
2. Attach the flyer to the end of the larger-diameter straw and seal that end with tape.
3. Attach the this straw to the smaller-diameter straw by pushing one end of the smaller-diameter straw into the open end of the larger one.
4. Push the smaller-diameter straw into the opening of the dishwashing liquid bottle. Seal around the opening with modeling clay.
5. Cut a 6- to 7-inch square sheet from the plastic bag.
6. Attach a piece of thread or fishing line to each corner of the plastic square (with tape or knots—choose your own attachment method). Attach the ends of thread to the base of the larger-diameter straw with a piece of tape to form a parachute.
7. Fold the parachute into a strip and lay it alongside the straw.
8. Launch the flyer by squeezing the bottle sharply.
9. Experiment by varying the force you apply to the bottle.

Reminder: As you experiment, record your predictions, actions, observations, and conclusions on this data sheet.

Pneumatic Flyer

Data Sheet

Name(s) ___

Trial	Action (What I did.)	Prediction (What I think will happen.)	Result (What happened.)	Conclusion(s) (Why I think it happened.)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Conclusions:

Notes

Flights of Fancy

About this learning activity

Students will identify and control the forces of flight by designing and modifying 5 aircrafts.

Key process skills

- ● Categorizing or classifying
- ● Communicating
- Comparing
- ● Controlling variables
- Experimenting
- ● Hypothesizing
- Inferring
- ● Interpreting data
- ● Making models
- ● Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

1 2 ● 3 4 5 ● 6 7 8 ● 9 10
11 ● 12

6th grade

1 ● 2 3 4 5 6 7 8 9 ● 10

9th grade

1 2 ● 3 ● 4 5 6 7 8 9 10
11 12 13 14 15 16 17 18 ● 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

Engagement activities

- 1 sheet of 8½ x 11-inch paper (approximate)
- 1 drinking straw for each student
- 1 paper cup or similar container filled with water per team
- Paper towels
- 1 ruler
- 1 single-edged razor blade or hobby knife

Time Estimates

(5 class periods)

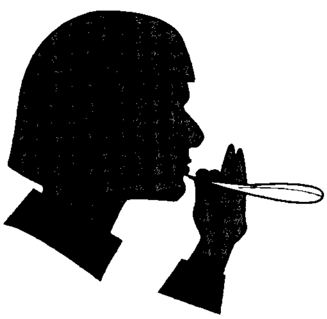
Setup	5 minutes
Exploration	30 minutes
Cleanup	5 minutes

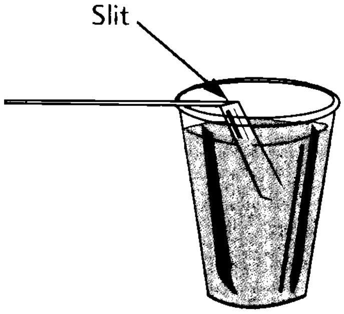
Key science principles

- Bernoulli's principle
- Thrust
- Lift
- Gravity
- Drag

Safety tips

- ✚ Caution must be used when handling razor blades. Teachers who do not want students to use them can slit the straws prior to the class session.





Exploration Activity (for each team)

- Tape
- Paper clips
- Drinking straws
- $8\frac{1}{2}$ x 11-inch paper
- Rulers
- Scissors
- Stopwatch or a clock with a second hand
- Items that students can use to create their own flying machines, such as: wrapping paper or paper towel tubes, paper, aluminum cans, napkins, thread, and pencils or dowel rods
- Student instruction sheets for each paper flyer

Engagement activities

1. Use the following demonstration to help students understand how air pressure affects flight (i.e., Bernoulli's principle).

   a. *Roll* a sheet of paper in half vertically. Do not fold it! Hold the paper just below your lower lip, with the rounded end away from you (see illustration).
   b. Ask students to predict what will happen if you blow over the paper.
   c. Record the predictions on newsprint or a chalkboard.
   d. Gently blow down over the paper. *Note: The paper will lift.*
   e. Compare this result with the students' predictions.
   f. Discuss the actual outcome.

2. Guide students through the following activity to help them gain a deeper understanding of how air pressure affects flight (i.e., Bernoulli's principle).

   a. Measure about 2 inches from one end of the straw and cut a small, horizontal slit. Be careful not to cut all the way through the straw!
   b. Flatten the longer side of the straw and bend it at the cut.
   c. Put the short end of the straw in the container of water, so that the cut is just above the surface of the water.
   d. Blow briskly through the straw. *Note: A mist of water will spray from the opening in the bend.*

e. Facilitate a class discussion that includes the following questions:

- What happened when you blew through the straw?
- Where did the water come from?
- Why do you think this happened?

Note: Daniel Bernoulli discovered that as the speed *of a fluid is increased, the pressure* lowers. *In this example of Bernoulli's principle, the jet of air through the cut in the straw opening lowers the pressure. The pressure caused by blowing into the straw presses down on the surface of the water, forcing water up through the straw, where it is blown out in a mist.*

Exploration activity

In this activity, students learn how to make a flying machine that will stay aloft and travel the farthest distance possible. After making several flying machines in class, students will design their own craft. Directions and patterns for 4 types of flying machines are provided. It is recommended that teachers focus on 1 design each day—with the original student designs being tested on the fifth day of this exploration activity. Students can work individually or in pairs.

Important: Instruct students to maintain a journal of their design activities. Each day's journal entry should include a description of what was done (including 1 or more diagrams), what design-related decisions were made, and what was learned.

Day 1—Continuous Wing Flyer

1. Ask students to make a continuous wing flyer per the instructions on the student instruction sheet, p. 271.

2. Facilitate a discussion during which you might ask the following questions:

   - What is the best way to fly this craft?
   - What is the farthest distance your continuous wing flyer traveled?
   - What adjustments did you make to cause this craft to perform better?
   - Could you make further adjustments to improve its performance? If yes, what?
   - Do you think it would fly better with rudders or wings? Why?
   - Why can this craft fly?

3. Have students list in their journals the positive qualities of this craft.

Note: Have students test their helicopters from 2 meters, if necessary.

Note: After their predictions are made, have students test this design adjustment.

Day 2—Helicopter

1. Ask students to build a helicopter per the instructions on the student instruction sheet, p. 272.

2. Facilitate a discussion during which you might ask the following questions:

   - How long does your helicopter stay aloft when dropped from a height of 2 meters?
   - Do you think it would fly longer if you added another paper clip?
   - To get the best performance, how many paper clips should you use on your helicopter?
   - Why can the helicopter fly?

3. Have students list in their journals the positive qualities of their helicopters. Then have them compare their helicopters to their continuous wing flyers, e.g., was this craft superior to the previous one you built? Explain.

Day 3—Glider

1. Ask students to construct gliders per the instructions on the student instruction sheet, p. 273.

2. Facilitate a discussion during which you might ask the following questions:

   - How far can your glider travel?
   - What adjustments did you make to cause the glider to fly farther?
   - What additional adjustments could you make to further improve its performance?
   - What happens when you fly the glider backwards, with the large ring in front?
   - Why can the glider fly?

3. Have students list in their journals the positive qualities of their gliders. Then have them compare their gliders to their continuous wing flyers and helicopters, e.g., was this craft superior to the previous ones you built? Explain.

Day 4—Plane

1. Ask students to construct an airplane per the instructions on the student instruction sheet, p. 274.

2. Facilitate a discussion during which you might ask the following questions:

   - How far can your plane travel?
   - What adjustments did you make to increase the distance?
   - What additional adjustments could you make to further improve its performance?
   - Does constructing this plane from a heavier or lighter paper improve the flying? Explain.
   - Why can the plane fly?

3. Have students list in their journals the positive qualities of their airplanes. Then have them compare their airplanes to their continuous wing flyers, helicopters, and gliders, e.g., was this craft superior to the previous ones you built? Explain.

Day 5—Student Designs

1. Begin this session with a discussion about aerodynamics. Because the students have had some experience with the 4 forces of flight during the previous classes, they should be able to draw conclusions about design factors that result in high-performance flying machines. Encourage students to make use of the information they gathered from their previous work with aircraft (i.e., journal entries and experiential knowledge) as they develop an original design for a flying machine.

2. Have students design and construct their own, unique flying machines.

3. When the flying machines are constructed, hold a derby to determine which craft flies the farthest and which can stay aloft the longest. Record the derby data on a class data sheet.

Note: Students can bring materials from home and/or use materials available in the classroom.

Explanation

There are four basic forces that work together to enable flight thrust, lift, gravity and drag. Each force is described below:

- **Thrust** is the force that moves something forward.
- **Lift** keeps the object in the air. When an object is moving forward, the air flowing over and under it creates lift. Lift relates to Bernoulli's principle.
- **Gravity** is the force that attracts all objects to the earth.
- **Drag** is the force of the air that the object is flying through—pulling on the object, or slowing it down. If you have ever tried to run through a swimming pool or lake, you have felt drag.

In successfully-designed flying machines, lift and thrust are balanced and they are stronger than gravity and drag.

Scientists classify both liquids and air as fluids. In 1738, a Swiss scientist named Daniel Bernoulli discovered that there was a relationship between moving fluids and pressure. The faster a fluid is moving, the less pressure it exerts. This explains why the shower curtain flies into your legs in the shower. The fast moving stream of water exerts less pressure on the inside of the curtain than the still air is exerting on the outside of the curtain. The still air pushes in on the curtain and it brushes your legs.

Bernoulli's principle also explains how planes and birds can achieve lift and fly. A wing is flat on the bottom and curved on top. The wing splits the air, i.e., half goes over the wing and half goes under, creating 2 air streams. Both air streams meet on the backside of the wing at the same time. Since the air going over the wing must travel a longer distance over the curve, it goes faster. The faster air has less pressure. The air going under the wing is traveling slower—and has more pressure. The pressure pushes up on the bottom of the wing, creating lift and enabling flight.

Evaluation

Suggestions for evaluating students during and after the design activities

- Evaluate students' responses during each day's class discussions.
- Grade students' project journals.
- Have students give a brief oral description of their original designs—including the design characteristics that promote flight.

Questions for quizzes or tests
See the discussion questions that are included with each day's design activity.

Journal entry
Describe what process you used to design your flying machine.

Extension activities

* Assign student research projects about the Wright brothers or other famous aircraft designers.
* Have students visit an Air Force museum.
* Have students study a toy (e.g., Puddle Jumper®, Frisbee®) and identify the properties that enable it to fly.
* Have students analyze the design of a commercial airliner to identify its flight qualities and ways to improve upon the design.
* Instruct students to research the space shuttle design (i.e., its large fuselage and small wings, and the flight theories behind the design).
* Have students study the bone structure and other body design elements of indigenous birds to determine why they can fly.

Connections to other subjects

Math. Have students calculate the distance flown and time aloft for each test flight of their original flying machines. Then, graph the data. Have the class compare the 2 pieces of data for each plane (i.e., distance and time aloft) and decide which plane achieved the best overall results.

Social Studies.
- Tell students to investigate the impact of the airline industry on society.
- Have students research famous flying machine designers (e.g., Charles Lindbergh, the Wright brothers).
- Instruct students to work in pairs to make a time line of the development of flying machines.

Career pathways

Pilot, industrial maintenance technician, automotive technician, airplane technician, design engineer

Language Arts.

- Have students write an advertisement for the aircraft they designed.
- Help students write a *Flights of Fancy* newspaper, with stories related to the craft designs and the derby.

Resources for teachers and students

Science Arts: Discovering Science Through Art Experiences by M. A. Kohl and J. Potter (Bright Ring Publishing, 1993)

The World's Greatest Paper Airplane and Toy Book by K. Laux (McGraw-Hill, 1997)

Notes

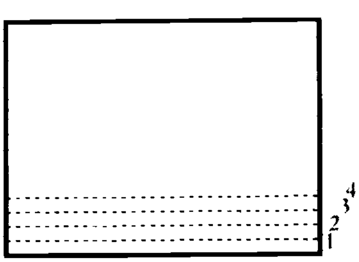
Continuous Wing Flyer

Student Instruction Sheet

Make a continuous wing flyer:

1. Fold a piece of $8\frac{1}{2}$ x 11-inch paper in half vertically and crease.
2. Cut carefully along the crease.
3. On 1 of the 2 resulting sheets, measure in 1 cm in from the long edge.
4. Draw a line at this point parallel to the long side of the paper. Label this line 1.
5. Draw additional lines at 2, 3, and 4 centimeters. Number these lines 2, 3, and 4, respectively.
6. Fold and crease the paper along line 1, bringing the edge of the paper even with line 2.
7. Fold the creased edge so it is even with line 3.
8. Make one more fold so that the creased edge is even with line 4.
9. Next, roll (don't fold) the paper to make a loop, bringing the short ends together and interlocking the folded edges. Secure the overlapped edge with a piece of tape.
10. Fly the aircraft.
11. Modify the design to improve the flyer's performance.

A.



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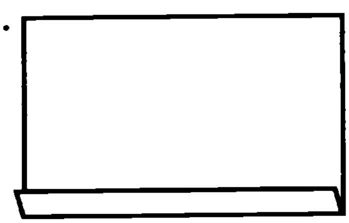

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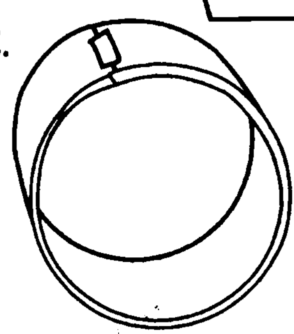


Be sure to maintain a journal of your design activities. Each day's journal entry should include a description of what you did (including 1 or more diagrams), what design-related decisions you made, and what you learned about aircraft design. You should also list the positive qualities of your flyer.

Note: Throw this craft with the heavy side in front. As you throw it, let it roll off your fingers like a quarterback throwing a football. Now try an underhand throw.

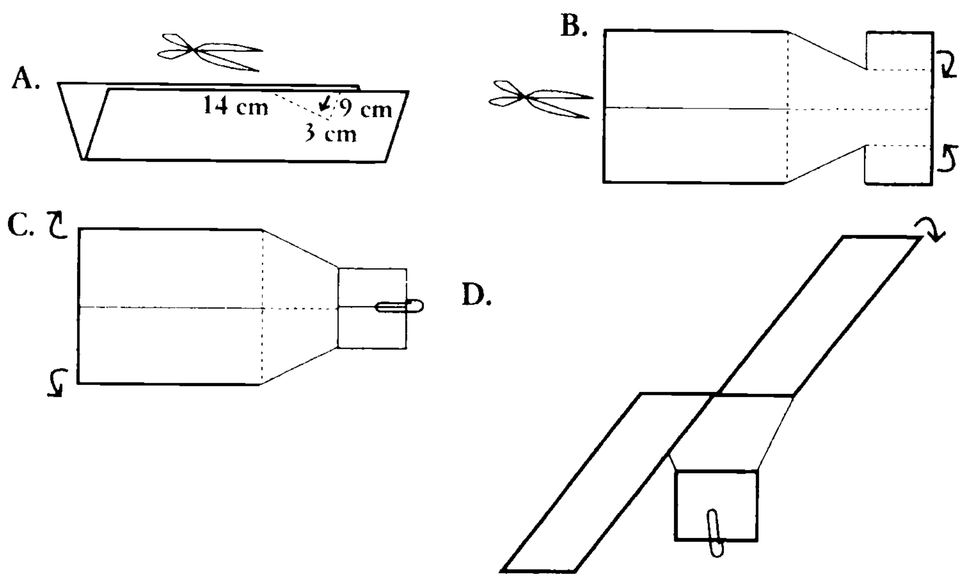
Helicopter

Student Instruction Sheet

Be sure to maintain a journal of your design activities. Each day's journal entry should include a description of what you did (including 1 or more diagrams), what design-related decisions you made, and what you learned about aircraft design. You should also list the positive qualities of your helicopter, then compare it to your continuous wing flyer, e.g., was this craft superior to the previous one you built? Explain.

Build a helicopter:

1. Fold an 8 ½ x 11-inch piece of paper in half vertically and crease.
2. Cut carefully along the crease.
3. Fold 1 of the resulting 2 sheets in half vertically.
4. Using a ruler, measure along the open side of the paper and make a mark at the 9-cm point and the 14-cm point.
5. At the 9-cm point, measure across the paper 3 cm and make a mark at that point.
6. Connect these points with straight lines to form a triangle.
7. Cut out the triangle. Be sure to cut through both layers of paper.
8. Open the paper. Draw a line across the paper where the sides jut in.
9. Cut up the center fold to this line. The two wings are now formed.
10. Fold the tabs toward the center and secure with a paper clip.
11. Fold the wings in opposite directions.
12. Fly the helicopter by holding it above your head and dropping it.
13. Modify the design to improve the helicopter's performance.



Glider

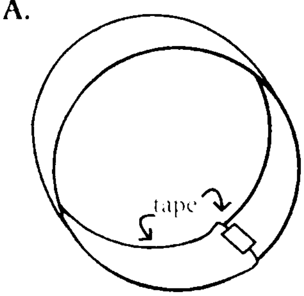
Student Instruction Sheet

Construct a glider:

1. Cut a soda straw to 21 cm long.
2. Cut two strips of paper—one 2 cm x 16 cm and the other 1.5 cm x 14 cm.
3. Bend the large strip of paper so it makes a ring and overlap the edges by about 2 cm.
4. Tape the inside and the outside of the overlapped pieces, forming a small pocket that the straw can fit in.
5. Pry open the pocket and slip one end of the straw into it.
6. Bend the smaller piece of paper in the same way, forming a small pocket. Slip it over the other end of the straw.
7. Move the two paper circles until they are both positioned above the straw. Tape them in place.
8. Looking down on the glider, make sure that the wings are at right angles to the straw. If they're not, loosen the tape and re-tape them so they are straight.
9. Fly the glider by holding it by the straw (with the smaller wing in front) and tossing it forward gently.
10. Modify the design to improve the glider's performance.

Be sure to maintain a journal of your design activities. Each day's journal entry should include a description of what you did (including 1 or more diagrams), what design-related decisions you made, and what you learned about aircraft design. You should also list the positive qualities of your glider, then compare it to your continuous wing flyer and helicopter, e.g., was this craft superior to the previous ones you built? Explain.

A.



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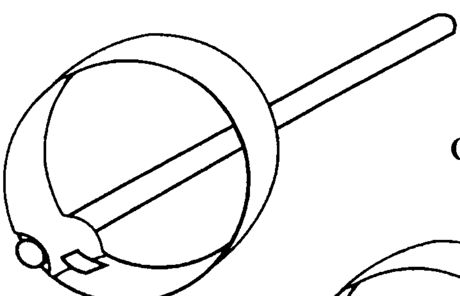

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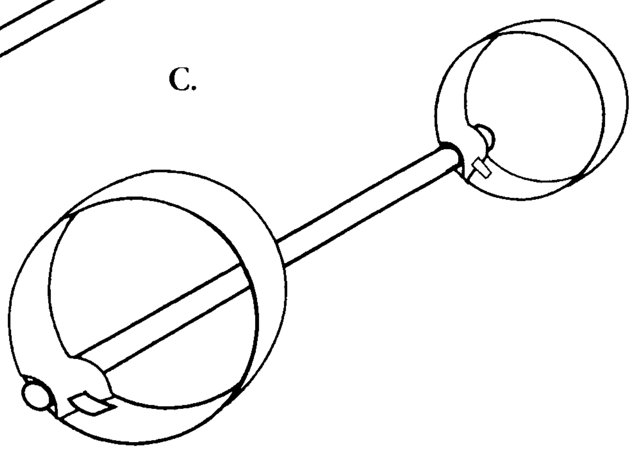


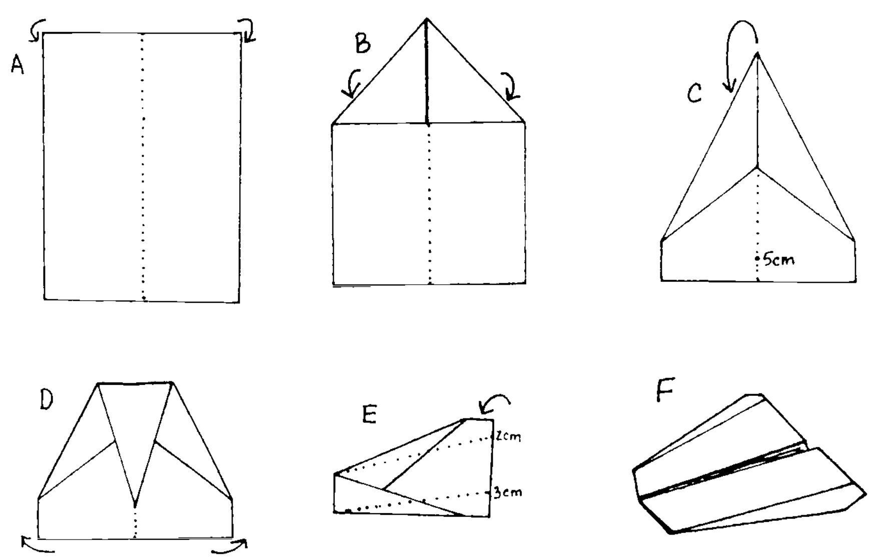
Plane

Student Instruction Sheet

Be sure to maintain a journal of your design activities. Each day's journal entry should include a description of what you did (including 1 or more diagrams), what design-related decisions you made, and what you learned about aircraft design. You should also list the positive qualities of your plane, then compare it to your continuous wing flyer, helicopter, and glider. e.g., was this craft superior to the previous ones you built? Explain.

Make an airplane:

1. Fold an 8½ x 11-inch piece of paper in half vertically and crease.
2. Open the paper flat again and fold the top corners down to the center crease.
3. Fold the diagonal folds to the center crease.
4. Measure 5 cm from the bottom and make a small mark on the center crease.
5. Fold the point down to this mark.
6. Fold the paper in half along the original center crease, unfolded sides together. Press hard to be sure to ensure a strong fold.
7. Measure along the straight edge at the back and make a mark 3 cm from the bottom and 2 cm from the top. If you draw lines from these marks to the two corners in front you will form a pair of parallel lines.
8. Fold each side down along these parallel lines and crease. Unfold these again to form the wings.
9. Fly the plane by gently tossing it forward into the air.
10. Modify the design to improve the plane's performance. *Note: The plane may or may not require a paper clip to weight the nose.*



Clusters of Bubbles

About this learning activity

Students will use bubbles to create patterns and identify structures and shapes.

Key process skills

Skill		Skill	
	Categorizing or classifying		Making models
●	Communicating	●	Measuring
●	Comparing	●	Observing
	Controlling variables		Ordering
●	Experimenting	●	Predicting
●	Hypothesizing	●	Recognizing relationships
●	Inferring	●	Recording
●	Interpreting data		

Ohio science proficiency outcomes

4th grade

● 1 ● 2 ● 3 4 5 6 7 8 ● 9 10
● 11 12

6th grade

● 1 ● 2 3 4 5 6 7 8 ● 9 ● 10

9th grade

● 1 2 ● 3 4 5 6 7 8 ● 9 10
11 12 13 14 15 16 17 18 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

Engagement activity (for each team)

- Newspaper
- Paper towels
- 1 penny
- 1 plastic medicine dropper
- 1 cup of water

Time estimates

(1–2 class periods)

Setup (advanced preparation)	30 minutes
Exploration	45 minutes
Cleanup	10 minutes

Key science principles

- Surface tension
- Law of conservation of energy
- Patterns in nature
- Systems

Bubble Solution Recipe

In a bucket, mix 2 cups of Joy® or Dawn® dishwashing liquid with 2 gallons of cold or lukewarm water. If possible, add 1/4 cup of glycerin, which is inexpensive and available from drug stores.

Safety tips

- Bubble solution can make the floor very slippery. Be diligent about putting thick sections of newspaper on all tables where bubble solution will be present to collect spills.
- Remind students to avoid slopping bubble solution on the floor, and to clean up spills immediately.
- Remind students not to put soap or materials with soap on them in eyes or mouths.
- Encourage students not to put their mouths directly on their bubble-blowing tools. Have them blow from a few inches away from the object or wave it through the air.

Exploration activity

- Bubble solution
- Pitcher (to pour bubble solution into students' plates)
- Newspaper (to cover tables)
- Dinner-size plastic plates (1 per student)
- Plastic drinking straws (1 per student)
- Vinegar solution (half water, half vinegar) in a spray bottle
- Paper towels
- Squeegie (for clean-up)
- Overhead projector (optional)
- Blank transparency sheets (optional)

Engagement activity

1. Have students work in teams of 2–4.
2. Provide each team with plenty of newspaper (to cover their table), a penny, a cup of water, and a medicine dropper.
3. Have students predict how many drops of water the penny will hold.
4. Provide plenty of time for students to experiment, dropping one drop at a time on the penny surface while it lays flat on the table.
5. After experimentation, facilitate a discussion that includes 1 or more of these questions:

   - Are you surprised by how many drops the penny will hold?
   - Do shiny new pennies or older pennies hold more drops?
   - Which side of the penny holds more, heads or tails?
   - What shape is the water as it lays on the penny?
   - Why do you think the water takes this shape?

Note: Water is sticky. Water molecules stick together forming droplets or, in the case of the drops on the penny, a dome. This stickiness is called cohesion and it occurs between like molecules. Cohesion causes the water to have a strong surface, known as high surface tension.

Clean-up suggestions:

- Sponges and rags leave a filmy residue that remains slippery. A squeegie works best to clear soapy solution from surfaces.
- If using metal items as bubble-blowing tools, rinse and dry them promptly or they'll rust.
- A vinegar and water solution applied by spray bottle makes clean-up quick and easy.

Exploration activity

Because this activity is wet and soapy, we have not provided a data sheet for students to complete during the activity. Conclusions will be discussed at the end of the exploration. Remember to cover tables with heavy thicknesses of newspaper.

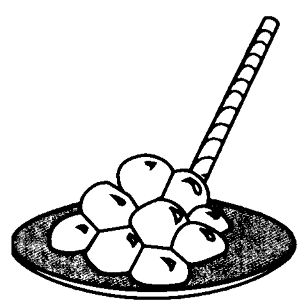
1. Give each student a plastic plate and a straw. Using a pitcher, pour bubble solution in each plate about 1/4- to 1/2-inch deep.

2. Challenge students to learn whatever they can about bubbles and bubble patterns by doing some or all of the following:

   - Use your straw to blow bubbles of different sizes on your plate.
   - Make as many bubbles as you can on your plate.
   - Make the biggest bubble you can on your plate.
   - Make a bubble within a bubble on your plate.
   - Blow a cluster of bubbles on your plate. Are there honeycomb-shaped (i.e., hexagonal) bubbles? What else is shaped like a honeycomb?
   - Observe your bubbles. What do they look like? Does their appearance change over time? What color are they? Does the color of your plate change the color of your bubbles?
   - Touch a bubble with a dry finger. What happened? Now touch it with a wet finger. What happened?
   - Blow just one bubble on your plate. Watch it. Do you see different colors and patterns? Can you tell how old a bubble is by its colors? Can you predict when the bubble will pop based on the colors and patterns on its surface?

Hint: You can have students blow bubble clusters on blank transparency pages. The unique and interesting clusters can then be placed on the overhead projector for the whole class to see. This is also a good way to enable students to measure the angles between bubbles without touching or breaking the bubbles.

Hint: Students can also blow bubbles directly on tables.



3. Help students draw conclusions about what they learned and record their conclusions on newsprint or the chalkboard. Use some or all of the following questions:

   - What shape do bubbles in a large cluster most often take?
   - Can you blow a cluster in which the middle bubble is shaped like a cube? How many bubbles do you think must be in the cluster before a cube bubble appears?
   - What shape does a single bubble surrounded by air take? Is this always true? Why do you think so?
   - Can you make a bubble with 4 sides? 5 sides? Explain.
   - Can you make a bubble with straight sides? Explain.
   - What shapes do you see?
   - What angles do you see?
   - Can you blow a bubble inside a bubble?
   - What is the maximum number of bubbles that touch each other at any one time?
   - What other things can you use to blow bubbles? What shapes make the best bubbles?

Explanation

A bubble is a thin skin of liquid that surrounds a gas. This thin skin (i.e., soap film) has elastic qualities—it can stretch. The soap film is composed of molecules of water and soap. The gas that fills bubbles is carbon dioxide and other gases that are exhaled by the bubble-blowing person. The liquid and gas are separated by a **surface**—the soap film. A bubble encloses the largest volume of air with the smallest surface area, giving it the spherical shape.

Water has very strong **surface tension**, as was demonstrated in the engagement activity. Bubbles occur in part due to the strong bonds between water molecules or high surface tension of water. The addition of soap causes these bonds to weaken (i.e., molecules are pushed farther apart) enough to lessen the surface tension. This makes the formula a little more stretchy, so the soap bubbles can be formed. In addition, soap and glycerin help to slow down the process of evaporation, which allows the bubbles to last longer.

A **system** tends to seek the state of lowest energy at which it can still function as a system. This is shown when students blow bubbles in clusters. When two bubbles touch, a **flat surface** separates them. If three bubbles come together, the lines that form to separate the bubbles are always at **120-degree angles**. The array of **hexagons** that form when many bubbles are touching exemplifies a system with the least amount of surface area for the greatest volume.

Bubbles have been studied by scientists and mathematicians for centuries. The spherical shape of a single bubble is an example of a system functioning with the lowest possible energy. It has the smallest amount of surface area combined with the largest enclosed volume. The bubble is truly a marvel.

Bubbles can be blown with just about any tool—anything that has a hole in it. The size of the hole will generally predict the size of the bubble. However, the size of the bubble can be influenced by whether the bubble is blown slowly and gently or quickly. In addition, the shape of the bubble can be affected by the shape of the bubble-blowing tool.

Evaluation

Questions for quizzes or tests

What patterns and structures did you find in your bubbles?
What geometric shapes did you find in your bubble clusters?
How does the concept of conservation of energy relate to bubble clusters?
What stops bubbles from popping as soon as they're blown?
What common factors exist among the tools that make bubbles? that make big bubbles? that make small bubbles?
What is surface tension and how does it affect bubbles?
Why do soap bubbles last longer than water bubbles?

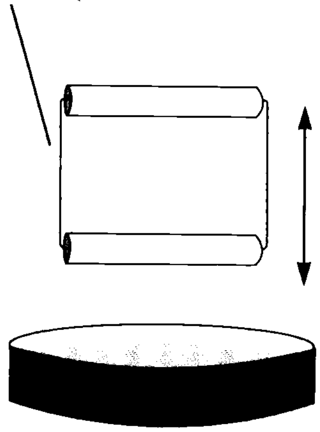
Observation

During the engagement and exploration activities, observe students as they hypothesize, predict, and draw conclusions about bubbles. Ask them questions about their process as they explore.

Journal entry

- Pretend you are a bubble. Write a story about what it feels like to be a bubble.
- Draw from memory the bubble shapes you observed. Name as many different polygons as you can.

String tied through drinking straws



Note: Explain that students can use their hands as tools too.

Hint: This is a good opportunity to point out the steps involved in the scientific process.

Extension activities

✱ Have students make bubbles from objects of different shapes and experiment with ways in which bubbles can change shapes.

✱ Show students how to make a bubble window from 2 straws and a string that is 3–4 times the length of a drinking straw. Have them tie the string through the straws. When they hold the straws parallel to each other and pull them apart, they create a collapsible bubble loop. Have each student put their bubble window into the bubble solution, then carefully lift it up and pull it back toward them. The trick is in flipping the frame up or down to break off a bubble.

✱ Let students experiment with other bubble-blowing devices. Here are some ideas:

- On a newspaper-covered table, give each team of 4 students a pan containing ½-inch or more of bubble solution and a variety of tools with which to blow bubbles (e.g., protractors, large paper clips, plastic six-pack holders, berry containers, toilet paper rolls, paper towel rolls, string, rubber bands, spools, paper cups, metal washers, springs, flower pots, food strainers and colanders, pieces of window screen, twist ties, slotted spoons, plastic tubing of different lengths and sizes, strips of heavy paper, small zip-type bags, small paper plates, medicine droppers, meat basters, aluminum foil).

- Have students choose a tool and predict whether it will blow a big bubble, a small bubble, or no bubble at all. Then have them test their prediction. They should test each of the tools at their table in this way. Once students have had enough time to explore, hold a class discussion. On chart paper, list the tools that were tested, students' predictions, and the results (i.e., whether the tools made big bubbles, small bubbles, or no bubbles at all). Help students draw conclusions about bubbles and the tools that can create them.

- Have the class examine the non-bubble blowing tools. Ask them to consider how they could be made into bubble-blowing tools. If possible, have them take the actions that they suggest, then test their modified bubble-blowing tools.

Connections to other subjects

Math. Have students blow large bubbles with a straw on a table top, then complete some or all of the following activities:

- Measure the height and width of the bubbles with rulers or plastic unifix cubes.
- Chart or graph their measurements.
- Identify the geometric shapes of classmates' bubbles.
- Measure angles where bubbles meet.
- Measure the diameter of their bubbles.
- Make graphs of the class's data.

Art. Ask each student to make bubble prints by placing a plastic cup on top of white paper and then **gently** blowing bubbles into plastic cups that contain bubble solution and a small amount of food coloring. The bubbles will flow over the rim of the cup and fall onto the paper. Keep blowing until there is a big pile of bubbles on the paper! Then lift the cup. Within 30 minutes, the bubbles will have burst and a beautiful bubble print will remain on the paper. (Alternative: Omit the food coloring from the cup. Instead, quickly place a few drops of food coloring or poster paint on the middle of the mound of bubbles with an eye dropper. The colors will be brighter and multiple colors can be used.)

Math and Art. Have students make bubble prints, as described in the previous art section. Then have them use rulers to measure the size of their bubbles and make a chart or graph of their measurements and those of classmates.

Language Arts.
- Tell students to imagine they are interviewing a bubble. Have them record both the questions and responses, as well as location, bubble appearance, body language cues, and similar observations.
- Have students write directions for making the biggest bubble, tallest cluster, and/or the most colorful bubble.

Social Studies and Science. Instruct students to investigate places that the hexagon can be found in nature and in industry. Why is this such a stable shape?

Career pathways

Scientist, biologist, microbiologist, pharmacist

Social Studies. Challenge students to answer one or more of the following questions:

Who is the most famous *bubbleologist*?
Who invented the carbonated soda?
Do children of other cultures play with bubbles?

Resources for teachers and students

Bubbles by Bernie Zubrowski, A Children's Museum Activity Book. (Little Brown & Co., 1979)
Bubble Festival, A GEMS Teacher's Guide for Presenting Bubble Activities in a Learning Station Format (Lawrence Hall of Science, 1994)
Liquid Magic by Philip Watson

Notes

Polymer Putty

About this learning activity

Students will explore properties of solids and liquids by experimenting with cornstarch and polymer solutions.

Key process skills

- Categorizing or classifying
- ● Communicating
- ● Comparing
- Controlling variables
- ● Experimenting
- ● Hypothesizing
- ● Inferring
- ● Interpreting data
- Making models
- ● Measuring
- ● Observing
- Ordering
- ● Predicting
- ● Recognizing relationships
- ● Recording

Ohio science proficiency outcomes

4th grade

1 2 3 4 5 6 7 8 ● 9 10
● 11 12

6th grade

1 ● 2 ● 3 ● 4 ● 5 6 ● 7 ● 8 ● 9 ● 10

9th grade

1 ● 2 ● 3 ● 4 5 6 7 8 ● 9 10
11 ● 12 13 14 15 16 ● 17 18 ● 19

Refer to Appendix D, pp. 327–329, for a description of outcomes.

Materials

Materials for exploration activity #1 (for each student)

- 1 plastic spoon or craft stick (for stirring)
- 1 aluminum pie pan (If needed, substitute disposable plastic plates.)
- ½ cup cornstarch
- Water in a container (e.g., beaker, paper cup)
- 1 piece of aluminum foil (approximately 3 x 3-inches)
- 1 plastic knife
- Measuring cups (1 cup, ½ cup, and/or ¼ cup)
- Bucket with water (for rinsing)
- Cornstarch Putty student instruction sheet
- Cornstarch Putty data sheet

Time estimates

(1–2 class periods)

Setup	10 minutes
Exploration	20 minutes
Cleanup	10 minutes

Key science principles

- Phases of matter
- Mixtures
- Viscosity

Hint: To help students gather and return materials, provide a tray for each team.

Safety tips

- Some people are allergic to borax, so teachers should take care when handling it. Be sure to use it in a well-ventilated area. In addition, teachers should wash their hands after contact with the solid. *Note: Generally, there is little danger with diluted borax solution. However, as a precaution, students and teachers should wash their hands after this activity.*
- Dispose of cornstarch putty and glue putty in the trash can not down sinks or toilets.

Hint: If the mixture is too runny, add a little more cornstarch. If the mixture does not flow off the spoon, add a little more water.

Materials for exploration activity #2 (for each student)

- 40 paper clips
- 1 craft stick
- 2 paper towels
- 1 ball bearing or marble
- 1 small bathroom cup containing 1 tablespoon of glue-water solution
- 1 small bathroom cup containing 2 tablespoons of borax solution
- Measuring cups (1 cup, ½ cup, and/or ¼ cup)
- Bucket with water (for rinsing)
- Polymer Putty student instruction sheet
- Polymer Putty data sheet

Materials for making glue-water solution and borax solution for exploration activity #2

- 2 8-ounce bottles of Elmer's® white glue
- 2 tablespoons of borax laundry powder (Borax can be found in some grocery stores.)
- Measuring teaspoons
- 2 spoons (for mixing glue solution and borax solution)
- 2 wide-mouth containers (for mixing glue solution and borax solution)
- Food coloring (optional)

Engagement activity

There is no engagement activity.

Exploration activity

Activity #1: Cornstarch Putty

1. Have students work individually to mix and experiment with cornstarch putty.

   a. Put ½ cup of cornstarch into the aluminum pie pan. Observe the properties of the cornstarch. Record them on the data sheet.
   b. Observe the properties of the water. Record them.
   c. Slowly add some water (¼ cup or less) into the cornstarch. (Optional: Add a drop or two of food coloring.)
   d. Stir the mixture with a plastic spoon or craft stick. The putty should flow slowly from your spoon and should crack if you push on it in the pan.
   e. Spoon some putty into your hand and squeeze it or roll it into a ball. Observe what happens to the putty.

f. Let your hand relax. Observe what happens to the putty.
g. Spoon some putty onto a small piece of aluminum foil. Push on it with your finger, then cut it with the plastic knife. Observe what happens to the putty.

2. Facilitate a class discussion by asking these questions:

   What happened to the putty when you squeezed it or when you made it into a ball?
   What happened to the putty when you let it sit in your hand?
   What happened when you tried to cut it?
   Is cornstarch putty a liquid or a solid?
   What are the properties of a liquid? of a solid?
   What other matter behaves like cornstarch putty?

Activity #2: Glue Putty

1. **Prepare a borax solution** by pouring 2 tablespoons of borax laundry powder into 2 cups of water in a wide-mouth container; stir until the solid is dissolved. Each student will need about 1 tablespoon of borax solution in a bathroom cup. This recipe makes enough solution for 30 students.

2. **Prepare a glue-water solution** by pouring 2 8-ounce bottles of glue into 2 cups of water in a wide-mouth container. Stir until the solution is mixed thoroughly. Each student will need about 2 tablespoons of glue-water in a bathroom cup. This recipe makes enough solution for 30 students.

3. Instruct students to **explore the properties** of a new substance (i.e., glue or polymer putty).

   a. Work individually, in pairs, or in teams of 4—depending on your teacher's instructions. If working in teams, choose the roles of recorder, materials manager, artist, and observer.

      - *Recorder:* Write down the predictions, actual results, and the activity conclusion
      - *Materials Manager:* Get and return all materials and organize clean-up of team's area
      - *Artist:* Draw sketches of ongoing activity (usually 2–3 sketches)
      - *Observer:* Watch how long it takes for the liquids to become a new substance and give the recorder accurate measurements of the proportions used to make the *best* putty

Hint: If the solution is too watery, stir in a little more borax solution.

Hint: If you don't have enough putty yourself, combine your putty with one or more classmates.

Note: If enough force is applied to the cross-link bonds they will break apart and reconnect in the same or another place.

b. Throughout this learning activity, record your predictions, research notes, sketches, and conclusion(s) on your data sheets.
c. Take 1 cup of glue–water solution and 1 cup of borax solution for each student.
d. Observe both liquids and predict what will happen when the 2 solutions are mixed together. In other words, what properties do you think the new substance will have?
e. Pour the borax solution into the glue-water and stir with a craft stick until a putty mass forms. The mixture will form a glue putty. Make observations and record the properties of this new substance.
f. Remove the putty from the cup. Deposit the cup in a trash can immediately.
g. Experiment with the putty:
   - knead it
   - roll it into a ball
   - bounce it
   - snap it
   - tear it
   - stretch it
   - create more ideas for experimentation

   Record the reaction of the putty as you experiment.
h. Roll 2 putty balls.
   - Observe one putty ball to see how long it takes for the putty to become flat.
   - Place a ball bearing or marble on top of one putty ball and observe what happens to the ball bearing.
   - Record your observations.
i. Continue experimenting to gain an understanding of the chemical changes that occur when putty is made.

4. **Build a polymer model** by doing the following:

a. Create 4 paper clip chains with 10 paper clips in each chain. Each clip represents a monomer or a team of atoms. Each *link* in the chain represents a chemical bond, through which a chain of monomers creates a polymer.
b. Wiggle the chains around on the table or in the air. Describe on your data sheet how the chains move.
c. Put the 4 chains into a small paper bathroom cup. With a hand over the opening of the cup, shake up the chains. Then, try to pull the chains out of the cup one at a time. Record what happened to the chains. Notice that the chains are caught on each other. This is similar to the connections that hold polymers together.

5. **Draw conclusions** by discussing the following:

   a. Discuss with your teammates the elastic properties of rubber and some plastics. Consider how some plastics become rigid. Record your ideas and conclusions on your data sheet.
   b. Discuss with your teammates the relationship between the cross-linked paper clip chains and the (polymer) glue putty. Record your ideas and conclusions on your data sheet.

6. Facilitate a **class discussion** by asking some or all of the following questions:

   How did your predictions compare to the properties of the glue putty you created?
   What happened as you mixed the two liquids together?
   What are some characteristics of this substance?
   What happened as you pulled the putty quickly? slowly?
   What happened to the putty ball that you watched flatten?
   What happened to the marble when you placed it on top of the putty ball?
   Now that you know what glue putty is, how could you change the recipe to make it different?
   How could this substance be used around your home? your school? in the community?
   Can you name 2 or 3 of the many cross-linked substances in our world?
   What are the similarities and differences between glue putty and rubber?
   Polymers are made of carbon atoms. Where do carbon atoms usually come from? In other words, what natural resource do we use to create polymers?

Important: Remind students to wash their hands; some people are allergic to borax.

Have materials managers facilitate clean-up activities, as follows:

- Dispose of solutions in trash cans—not sinks or toilets.
- Rinse tools, work areas, and hands.
- Return materials to proper location(s).

Explanation

Monomers are small molecules. Molecules are groups of atoms formed by sharing electrons. An atom has an electron, proton, and a neutron, and is the smallest part of an element. Monomers can *link* to other monomers to form a **polymer**. A polymer is a very large molecule created by a chain of repeating monomers linked together by chemical bonds. A **chemical bond** is a force that holds the atoms together in a compound. A **compound** is a substance formed when two or more elements combine chemically. Molecules are the building blocks of compounds. The linking of different compounds in a polymer gives the polymer different characteristics. The polymer might be elastic (like glue putty) or hard (like the plastic in a comb) or resistant to heat (like a handle on a pan) or slick (like Teflon™). In physics, polymers are called non-Newtonian fluids because they do not follow the laws that Sir Isaac Newton (1642–1727) observed and recorded.

In today's society, we use many polymer products, yet we know very little about them. Rubber is an example of a natural polymer. Some examples of man-made polymers are nylon, super glue, polyester, foam, Teflon™, plastic toys, plastic kitchen utensils, transparent tape, and plastic wrap (i.e., polyethylene).

Fluids flow because their molecules roll over each other. As the molecules roll over each other, friction is created. The slower a liquid flows the more friction exists between the molecules. This friction is called **viscosity**. As an example, honey is an ordinary fluid that has high friction or viscosity between its molecules and flows slowly. Water is an example of a liquid that has low friction or viscosity between its molecules and flows quickly. Ordinary fluids change viscosity when their *temperature* is changed, e.g., honey flows quickly when it is hot and very slowly when it is cold. Non-Newtonian fluids change their viscosity by applying *force*. When a fluid polymer ball is allowed to sit, it becomes flat because of the pressure (or force) of *gravity* pushing down on it. When pulled slowly, a fluid polymer ball will stretch. However, when a polymer ball is pulled sharply, the viscosity increases so much that the ball won't flow at all and the polymer breaks. Similarly, when cornstarch putty is pulled, it becomes hard; when it is left in a person's hand, it drips between the fingers. In other words, the polymers have properties of both liquids and solids.

Hint: Think about the paper clip chains.

Cross-linked polymers, like the cornstarch and glue putties, are created by assembling monomers into chains that are linked together. When the glue-water and the borax solutions are mixed, the molecules in each substance rearrange themselves into *different molecules* or monomers. These monomers form links or chemical bonds between themselves, creating long **polymer chains**. The polymer chains are linked together with monomers and chemical bonds.

Evaluation

- Grade students' notes from their exploration activities.
- Have each team write a lab report in scientific format, including: question, hypotheses (predictions), experiment, research, and conclusion. The team should use the information gathered during the exploration activities to complete the lab report.

Journal entry

Write a short description of life before polymers were discovered and invented. Describe what materials were used then to produce the various items which are now made of polymers. For example, what materials were used for buildings, clothing, toys, and kitchen equipment? Consider whether some of these materials are still being used today, and discuss why and how they are used. An example is the continued use of cotton in clothing, with the addition of polyester to increase the life of the clothing, keep the color brighter, and reduce wrinkling.

Extension activities

- Have students experiment with various putty solutions, including these:
  - Increase the amount of water from 1 cup to 1 ½ cups for each 1 cup of glue, which will make a thinner consistency of putty.
  - Create a similar type of putty using equal amounts of white glue and liquid starch. For each student, use ¼ cup of glue and ¼ cup of liquid starch in separate cups. Mix the starch into the glue with a craft stick. After the substance forms putty, remove the putty from the cup and rinse it under running water. Compare the properties of the cross-linked polymers in the new putty with the original glue putty.
- Have students let the putty dry out and record the changes in its properties.
- Have students mix a dime-sized piece of glue putty with 10–20 drops of vinegar, stir with a stick, and observe what happens. (The putty will slowly dissolve again.)
- Have students design an experiment to measure the flow of a polymer (e.g., glue putty or cornstarch putty). They could hypothesize several methods for measuring the flow, including how long it will take for the putty to flow out of a circle, or flow down a ramp. Give them time to test several methods of measuring flow. Have them describe their flow-rate methods and record the different rates. The students or the class can assess each method's performance as a measurement tool.
- Have the students use the flow-rate techniques to distinguish polymers from non-polymer fluids.

* Polymer products are creating environmental problems; they are non-biodegradable, affecting disposal. Have students investigate the current problems, past problems, and solutions.

Career pathways

Organic chemist, engineer, waste manager, packaging designer, product designer, and product manufacturer

Connections to other subjects

Math. Discuss the concept that different things travel at different rates of speed. Have students consider the speeds of sound, light, an automobile, and/or water and measure the speed rates of some objects.

Language Arts. Instruct students to create a sales campaign (e.g., a newspaper advertisement, a slogan, a logo, a sales pitch, and/or an article about the inventor and the invention) to sell the putty products created in exploration activities #1 and #2.

Health. Investigate the topic of allergies. Use students' knowledge that some people are allergic to borax (i.e., the students were asked to wash their hands after working with the glue putty) to discuss practicing preventative behaviors to maintain good health.

Social Studies. Ask students to conduct research concerning the uses of polymers around the world. Have them consider whether polymers are available to all cultures and whether the use of polymers has created an environmental problem in those cultures. Students should explain their findings.

Resources for teachers and students

Chemical Investigations for Changing Times by John Hill, Lawrence Scott. and Peter Muto (Macmillan Publishing Co., 1988)

Physics for Every Kid by Janice VanCleave (John Wiley & Sons, Inc., 1991)

Project Science: Water & Floating by Alan Ward (Franklin Watts, 1992)

Cornstarch Putty

Student Instruction Sheet

1. Work individually to mix and experiment with cornstarch putty.

   a. Put 1/2 cup of cornstarch into the aluminum pie pan. Observe the properties of the corn starch. Record them on the data sheet.

   b. Observe the properties of the water. Record them.

   c. Slowly add some water (1/4 cup or less) into the cornstarch. (Optional: Add a drop or two of food coloring.)

   d. Stir the mixture with a plastic spoon or craft stick. The putty should flow slowly from your spoon and should crack if you push on it in the pan.

   Hint: If the mixture is too runny, add a little more cornstarch. If the mixture does not flow off the spoon, add a **little** *more water.*

   e. Spoon some putty into your hand and squeeze it or roll it into a ball. Observe what happens to the putty.

   f. Let your hand relax. Observe what happens to the putty.

   g. Spoon some putty onto a small piece of aluminum foil. Push on it with your finger, then cut it with the plastic knife. Observe what happens to the putty.

2. Draw conclusions and record them on your data sheet.

Reminder: When recording your observations, include diagrams as appropriate.

Cornstarch Putty

Data Sheet

Name(s) ______________________________

Action (What we did.)	Observations (What happened.)

Conclusions:

Polymer Putty

Student Instruction Sheet

1. Explore the properties of a new substance (i.e., glue or polymer putty).

   a. Work individually, in pairs, or in teams of 4 depending on your teacher's instructions. If working in teams, choose the roles of recorder, materials manager, artist, and observer.
      - *Recorder:* Write down the predictions, actual results, and the activity conclusion
      - *Materials Manager:* Get and return all materials and organize clean-up of team's area
      - *Artist:* Draw sketches of ongoing activity (usually 2–3 sketches)
      - *Observer:* Watch how long it takes for the liquids to become a new substance and give the recorder accurate measurements of the proportions used to make the *best* putty

   b. Throughout this learning activity, record your predictions, research notes, sketches, and conclusion(s) on your data sheets.

   c. Take 1 cup of glue-water solution and 1 cup of borax solution for each student.

   d. Observe both liquids and predict what will happen when the 2 solutions are mixed together. In other words, what properties do you think the new substance will have?

   e. Pour the borax solution into the glue-water and stir with a craft stick until a putty mass forms. The mixture will form a glue putty. *Hint: If the solution is too watery, stir in a little more borax solution.* Make observations and record the properties of this new substance.

   f. Remove the putty from the cup. Deposit the cup in a trash can immediately.

   g. Experiment with the putty:
      - knead it
      - roll it into a ball
      - bounce it
      - snap it
      - tear it
      - stretch it
      - create more ideas for experimentation

      Record the reaction of the putty as you experiment.

   h. Roll 2 putty balls. *Hint: If you don't have enough putty yourself, combine your putty with one or more classmates.*
      - Observe one putty ball to see how long it takes for the putty to become flat.
      - Place a ball bearing or marble on top of one putty ball and observe what happens to the ball bearing.

      Record your observations.

   i. Continue experimenting to gain an understanding of the chemical changes that occur when putty is made.

2. Build a polymer model by doing the following:

   a. Create 4 paper clip chains with 10 paper clips in each chain. Each clip represents a monomer or a team of atoms. Each *link* in the chain represents a chemical bond, through which a chain of monomers creates a polymer.

   b. Wiggle the chains around on the table or in the air. Describe on your data sheet how the chains move.

   c. Put the 4 chains into a small paper bathroom cup. With a hand over the opening of the cup, shake up the chains. Then, try to pull the chains out of the cup one at a time. Record what happened to the chains. Notice that the chains are caught on each other. This is similar to the connections that hold polymers together. *Note: If enough force is applied to the cross-link bonds they will break apart and reconnect in the same or another place.*

3. Draw conclusions by discussing the following with your teammates:

   a. What are the elastic properties of rubber and some plastics? Consider how some plastics become rigid. Record your ideas and conclusions on your data sheet.

   b. What is the relationship between the cross-linked paper clip chains and the (polymer) glue putty? Record your ideas and conclusions on your data sheet.

Reminder: Wash your hands after these experiments; some people are allergic to borax.

Materials managers should facilitate clean-up activities, as follows:

- Dispose of solutions in trash cans, not sinks or toilets.
- Rinse tools, work areas, and hands.
- Return materials to proper location(s).

Glue Putty

Data Sheet

Name(s) ______________________________

Action (What we did.)	Observations (What happened.)

Conclusions:

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Notes

FUN with PHYSICS

Real-Life Problem Solving
for Grades 4–8

Appendices

Appendices

Real-Life Problem Solving for Grades 4–8

Appendices

Appendix A: References

Adkinson, S., M. Fleer, eds. (1995). *Science With Reason.* London: Hodder and Stoughton Educational.

American Association for the Advancement of Science (1993). *Benchmarks for Science Literacy: A Project 2061 Report.* New York: Oxford University Press.

American Association for the Advancement of Science (1990). *Science for All Americans: A Project 2061 Report on Literacy Goals in Science, Mathematics, and Technology.* New York: Oxford University Press.

Ohio Department of Education (1994). *Ohio's Competency-Based Science Model: Scientific Literacy for the 21st Century.* Columbus, OH: State Board of Education.

National Council of Teachers of Mathematics (1993). *Curriculum and Evaluation Standards for School Mathematics.* Reston, VA: NCTM.

National Research Council (1996). *National Science Educational Standards.* Washington, DC: National Academy Press.

Sadker, M. and D. Sadker (1994). *Failing at Fairness: How America's Schools Cheat Girls.* NY: Charles Scribner's Sons.

The Secretary's Commission on Achieving Necessary Skills (1992). *Learning a Living: A Blueprint for High Performance: A SCANS Report for America 2000.* Washington, DC: U.S. Department of Labor.

Appendix B: Resources

Appendix B contains resources for gathering background information about scientific principles that relate to simple machines, electricity, heat, and liquids. In addition, this appendix contains valuable information about learning activities that teachers, parents, and students can use to expand upon the material presented in *Fun with Physics*. Appendix B is divided into the following sections:

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Resources

Guidebooks About Science Resources

The following guidebooks help educators locate high-quality, age-appropriate science materials.

Association for Supervision and Curriculum Development, Education and Technology Resource Center (1995). *Only the Best: The Annual Guide to the Highest-Rated Educational Software and Multimedia.* Alexandria, VA: ASCD.

The Education and Technology Resource Center compiles an annual list of the highest-rated materials for many subject areas, including science. Judges are leading national software and multimedia evaluators.

National Science Resources Center (1996). *Resources for Teaching Elementary School Science.* Washington, DC: National Academy Press.

This wide range of curriculum materials and references reflect the content and process skills identified in the National Science Education Standards. Reviews of each resource are thorough. Many free or low-cost materials are included.

"Outstanding Science Trade Books for Children for 1995." *Science & Children*, Vol. 32, No. 6 (March 1995).

A panel of educators appointed by the National Science Teachers Association and the Children's Book Council selected this list of 50 science trade books for preschool through 8th grade.

Richter, B. and P. Nelson, eds. (1994). *Every Teacher's Science Booklist.* NY: Scholastic Professional Books.

Scholastic presents short reviews of 890 science book titles published since 1990. It is designed to serve as an aid in selecting quality children's science books, planning classroom activities, and conducting science project research.

U.S. Department of Energy (1995). *Educators Guide to Free Science Materials*, 36th ed. Randolph, WI: Educators Press Services.

Physics Reference Books

The following books provide teachers and parents with detailed, user-friendly information about the physics principles addressed in *Fun with Physics*.

Freeman, Ira (1990). *Physics Made Simple.* Doubleday Made Simple Books. Bantam Doubleday Dell Publishing Group.

This book describes just about every scientific principle you can think of in a clear, uncomplicated manner. It is a "must" for teachers who need an easy-to-understand reference about physics.

Gnock, Larry and Art Huffman (1990). *The Cartoon Guide to Physics.* New York: Harper Perennial.

Trefil, James (1992). *1001 Things Everyone Should Know About Science.* New York: Doubleday.

Trinklein, F. E. (1992). *Modern Physics.* New York: Holt, Rinehart and Winston.

Support Materials for Teachers and Parents

The following comprehensive list of high-quality support materials can help teachers and parents gather information about scientific principles and inquiry-based learning. Many exemplary activities that can be used as extensions to those in *Fun with Physics* are included, as well. Note: Additional resources are listed at the end of each *Fun with Physics* learning activity.

Activities Integrating Mathematics and Science (AIMS)

AIMS is an educational foundation formed to enrich the education of K–9 students through hands-on activities that integrate math, science, technology, and other disciplines. AIMS publishes a newsletter, does teacher training, and publishes many teacher-developed and tested books that are full of practical, easy-to-use learning activities. AIMS can be reached toll free at 888/733–2467. An AIMS catalog can be downloaded from http://www.AIMSedu.org . Selected book titles and their designated grade levels follow:

- *Mostly Magnets* (2–8)
- *Primary Physics* (K–3)
- *Under Construction* (K–2)
- *Water Precious Water* (2–6)
- *Popping with Power* (3–5)
- *Electrical Connection* (4–9)
- *Soap Films and Bubble* (4–9)
- *Math + Science, A Solution* (5–9)
- *Floaters and Sinkers* (5–9)
- *Fun with Food* (5–9)
- *Machine Shop* (5–9)
- *Brick Layers: Creative Engineering with LEGO® Constructions* (4–9)
- *Teaching Science with Everyday Things* (K–9)

American Chemical Society (1996). *Packaging.* Dubuque, IA: Kendall/Hunt Publishing Co.

A well-planned unit helps students understand what packaging does by leading them through investigations of packaging materials, math in packaging, packaging nets, and uses of packaging. Teacher's guide and student workbooks are available. Developed for students in grade 6, it can be used in grades 4–7, too. An example is available at the Eisenhower National Clearinghouse, which is listed in the Suppliers of Science Resources and Materials section of this appendix.

Bath, J. (1995). *Science Process Skills: Grades 2–5.* Greensboro, NY: Carson-Dellosa Publishing.

This resource provides teachers with background and learning activities for helping students develop skills in observing, collecting information, communicating, measuring, classifying, inferring, predicting, controlling variables, representing data, hypothesizing, and experimenting.

Bredthauer, V. (1995). *Hands-On Thinking Activities: Centers Through the Year.* Monterey, CA: Evan-Moor Corp.

Bredthauer has designed thoroughly-planned learning centers that focus on scientific and mathematical processing skills such as predicting, estimating, interpreting, sorting, classifying,

organizing, and designing. He includes options for independent centers and/or seasonal carnivals, as well.

Butel, M. et al. (1994). *Problem Solving: Making a Difference.* Wichita, KS: Wichita State University.
This teacher-developed unit was designed for grades 8–10, and can be adapted for students of other ages. Eight activities require students to probe a mystery box; design a packaging container from the fewest materials; design two down-hill racers with different performances; and construct a system that travels a certain distance, reverses direction, and returns the same difference. Activity books are distributed by Wichita State University, 316/689–3322. Also available at the Eisenhower National Clearinghouse, which is listed in the Suppliers of Science Resources and Materials section of this appendix.

Carin, A. (1993). *Guided Discovery Activities for Elementary School Science,* 3d ed. NY: Macmillan Publishing Company.

Center for Mathematics, Science, and Technology Education (1995). *Manufacturing.* Normal, IL: Illinois State University.
This grade 7 curriculum follows the National Science Standards. It contains six sequential modules that progressively increase the integration of math, science, and technology through hands-on activities. *Manufacturing* is the fifth module and focuses on the importance of manufacturing to society. Activities involve making a book cover and learning the operations necessary to manufacture a marketable product. Materials can be ordered from CeMAST at 309/438–3089; fax 309/438–3592. A commercial edition is under development and may be available by publication of *Fun with Physics.* Also, an example is available at the Eisenhower National Clearinghouse, which is listed in the Suppliers of Science Resources and Materials section of this appendix.

Center for Occupational Research and Development, in cooperation with the Agency for Instructional Technology (1996). *Principles of Technology: A Contextual Approach to Workplace Physics.* Waco, TX: CORD.
Principles of Technology is a series of books that comprises a course in applied physics for high school students and adults who plan to pursue careers as technicians or who simply want to keep pace with advances in technology. It combines an understanding of basic principles with hands-on practical applications to give students a firm foundation for understanding technology. Fourteen separate units (books) are available, covering topics like force, work, rate, resistance, energy, power and more. Materials can be purchased from CORD by calling 800/231-3015.

Consell, C. (1990). *Science EQUALS Success.* Newton, MA: WEEA Publishing Center.
Middle- and early secondary-school science teachers can use this book to motivate all students, because it builds upon the fun of science. It is an especially important book for retaining the enthusiasm of girls and other students who traditionally lose interest in science and math during the middle and secondary years. Consell includes over 30 hands-on, discovery-oriented, field-tested activities that are designed to supplement the existing curriculum; however, each can stand

alone. In addition to basic scientific principles, EQUALS teaches problem solving, cooperative learning, and spatial skills, and provides career awareness. Can be ordered from the WEEA Equity Resource Center by calling 800/793–5076. *NOTE: Even though these materials specify grade levels, most can be adapted to meet the needs of younger and older students.*

Diehn, G. and T. Krautwurst (1994). *Science Crafts for Kids: 50 Fantastic Things to Invent & Create.* NY: Sterling Publishing Co.

This resource gives teachers and parents a wide variety of activities that combine principles of science and art. Middle- and high school students can use this book independently.

Dunn, S. and R. Larson (1990). *Design Technology: Children's Engineering.* NY: The Falmer Press.

Fraser, S. (1982). *SPACES: Solving Problems of Access to Careers in Engineering and Science.* Palo Alto, CA: Dale Seymour Publications.

SPACES integrates the principles of math and science that are required for creating structures. Designed for grades 4–10, it also incorporates the skills of logical thinking, spatial visualization, estimation, and research, and enhances career awareness. Developed through The Lawrence Hall of Science at the University of California, Berkeley with a National Science Foundation grant, educators may copy and use this material for noncommercial purposes.

Gertz, S., D. Portman, and M. Sarquis (1997). *Teaching Physical Science through Children's Literature.* NY: Terrific Science Press/Learning Triangle Press, an imprint of McGraw-Hill, Inc.

The 20 complete lessons in this resource provide a truly integrated approach to teaching hands-on science in the elementary grades.

Girls, Inc. (1990). *The Power Project: Operation SMART Activity Guide.* Girls, Inc. (formerly Girls Clubs of America)

This guide comprises a program to encourage every female student in science, math, and technology. It provides a foundation from which non-science teachers can facilitate inquiry-based learning about the use of power and the environment. Developed for middle- and high school girls, this practical, easy-to-use guide is a solid program for *all* students—in and out of the formal classroom—and can be adapted for adults. Available from Girls, Inc. Resource Center at 317/634–7546.

Girls, Inc. (1990). *Spinnerets and Know-How: Operation SMART Planning Guide.* Girls, Inc.

Developed for middle- and high school girls, this practical guide helps educators and others develop an effective, inquiry-based program. It also lays the foundation for developing an out-of-the-classroom program to encourage every girl in science, math, and technology, but can be used in mixed-gender groups, too. Available from Girls, Inc. Resource Center at 317/634–7546.

Haggart, M. (1994). *Mystery Lab.* Dubuque, IA: Kendall/Hunt Publishing Co.
The Reading is Fundamental program has created a series of books for a science and reading motivation program that supplements existing science curricula in the upper elementary grades. Each unit in the program explores a topic in the natural and physical sciences, as well as children's literature. The program also integrates science and technology into a series of laboratory investigations. *Mystery Lab* helps students use the scientific method to solve a mystery. Teacher and mentor guides are available. Examples of these program materials are available at the Eisenhower National Clearinghouse, which is listed in the Suppliers of Science Resources and Materials section of this appendix.

Hockett, A. (1996). *Red Herrings Science Mysteries: Solving Mysteries Through Critical Questioning,* Level A, Books 1 and 2. Pacific Grove, CA: Critical Thinking Books & Software.
These books, developed for grades 4–6, teach students to develop questioning strategies used in the scientific method and build reading comprehension and vocabulary skills. By analyzing short mysteries designed around scientific principles, generating hypotheses, and testing possibilities, students learn that things are not always as they appear. The book seeks to motivate students by providing a springboard for further investigation of scientific principles. Examples are available at the Eisenhower National Clearinghouse, which is listed in the Suppliers of Science Resources and Materials section of this appendix.

Holley, D. (1996). *Science Wise: Discovering Scientific Process Through Problem Solving,* Books 1, 2, and 3. Pacific Grove, CA: Critical Thinking Books & Software, Inc.
Each book is structured around a wide variety of Dynamic Demos and Creative Challenges, which include detailed instructions and discussion questions. Dynamic Demos are teacher-led experiments that carefully guide students through specific steps in order to develop their understanding of scientific process and methodology. (Demonstrations can be modified to become hands-on activities.) Creative Challenges are student-centered tasks that actively engage students' creativity, and critical thinking and problem solving skills. The books were designed for non-science teachers and activities require low-cost materials. Thinking Books & Software can be reached directly at 800/459–4849. These books are also available from the Eisenhower National Clearinghouse and William Sheridan & Associates, which are listed in the Suppliers of Science Resources and Materials section of this appendix.

Jorgensen, M. (1993). *Assessing Habits of the Mind: Performance-based Assessment in Science and Math.* Columbus, OH: ERIC Clearinghouse.

Kaufman, Allan and Jim Flowers (1996). *Technology Projects for the Classroom.* Ann Arbor, MI: Tech Directions Books.
This book presents 20 inexpensive project for middle- and high-school technology education students. Projects reinforce principles taught in production, communication, transportation, and R & D areas. Projects include a small-scale hot-air balloon, a fiber-optic communicator, a hydraulic robot arm, an electronic sound amplifier, and a miniature solar-powered race boat. A very inexpensive teacher's guide is also available. Books can be ordered directly from Tech Directions Books at 800/530–9673, ext. 200.

Korchin, F. (1995). *Science in the Marketplace.* Red Bank, NJ: Tiger Publications.

Teachers or students will find over 60 lab activities based on everyday consumer topics, including making cottage cheese, making soap, comparing bleaches, treating hard water, dying textiles, sugars and sweeteners, and testing antacids. Suitable for grades 7–adult. Available from Tiger Publications at 32 Friendship Court, Red Bank, NJ 07701; 908/747–9042. Sample labs are provided on Tiger's web site at http://www.monmouth.com/ rosin/tiger.

Lawrence Hall of Science. Great Explorations in Math and Science (GEMS) Series. Berkeley, CA: University of California.

Each GEMS guide comprises a comprehensive, ready-to-use unit on a given topic. Developed for use by non-science teachers, each involves students in hands-on, inquiry-based learning. Science titles are listed below. Other GEMS titles, including those pertaining to biology, ecology, and math, are also available. New titles are developed each year. GEMS materials are available through many suppliers, including William Sheridan Associates, which is listed in the Suppliers of Science Resources and Materials section of this appendix. GEMS staff can be reached directly at 510/642–7771; fax; 510/643–0309. *Note: Grade levels are listed after each title; however, most can be adapted for younger or older students.*

Acid Rain (6–10)
Bubble Festival (K–6)
Bubble-ology (5–9)
Build It! Festival (K–6)
Chemical Reactions (6–10)
Color Analyzers (5–9)
Convection: A Current Event (6–9)
Crime Lab Chemistry (4–8)
Discovering Density (6–10)
Experimenting with Model Rockets (6–10)
Fingerprinting (4–8)
Height-O-Meters (6–10)
Investigating Artifacts (K–6)
Learning about Learning (5–10)
Mystery Festival (2–9)
Of Cabbages and Chemistry (4–8)
Paper Towel Testing (5–9)
Secret Formulas (K–4)
Vitamin C Testing (4–8)

Pedagogical handbooks in the GEMS series:
GEMS Teacher's Handbook
GEMS Leader's Handbook
Once Upon a GEMS Guide: Literature Connections
Insights and Outcomes: Assessment for GEMS Activities
A Parent's Guide to GEMS
To Build a House: A Thematic Approach to Teaching Science

Levenson, E. (1994). *Teaching Children about Physical Science: Ideas and Activities Every Teacher and Parent Can Use.* NY: McGraw-Hill, Inc.

This resource not only provides information about basic physical science principles, but also suggests a wide variety of activities that demonstrate those principles.

Main, J. and P. Eggen (1991). *Developing Critical Thinking Through Science*, Books 1 and 2. Pacific Grove, CA: Critical Thinking Books and Software, Inc.

Book 1 targets grades 1–4 and Book 2 targets grades 4–6. Both were developed for non-science teachers, involve students in hands-on discovery, and require low-cost materials. Contact Thinking Books & Software directly at 800/459–4849. They are also available from William Sheridan & Associates, which is listed in the Suppliers of Science Resources and Materials section of this appendix.

McCormack, A. (1981). *Inventors Workshop. NY: Fearon Teacher Aids*, Simon & Schuster Supplementary Education Group.

This resource provides teachers and/or students with ideas for a wide variety of inventions, including inside-the-box inventions, candle-powered inventions, electrical inventions, and Rube Goldberg contraptions.

Rezba, R., R. Sprague et al. (1995). *Learning and Assessing Science Process Skills*, 3rd ed. Debuque, IA: Kendall/Hunt Publishing.

The wide variety of activities in this book target process skills; each activity is linked to specific competencies.

Sadker, M. and D. Sadker (1994). *Failing at Fairness: How America's Schools Cheat Girls*. NY: Charles Scribner's Sons.

This book provides a comprehensive report on the results of a national research study into educational equity in the classroom. Concrete, easy-to-implement suggestions for improving equity are also provided and can be used by both educators and parents.

Salvadori, Mario (1990). *The Art of Construction: Principles and Projects for Beginning Engineers and Architects*.

This book includes the principles involved in building bridges, sky scrapers, and other buildings and structures. Classroom projects that demonstrate these principles are provided.

Salvadori, Mario (1983). *Why Buildings Stand Up: The Strength of Architecture*. Thornton, IL: Vocational Marketing Services. Teacher's manual is also available, which includes 70 activities divided into 10 units.

Sarquis, J. et al. (1997). *Investigating Solids, Liquids, and Gases With TOYS*. NY: Terrific Science Press/Learning Triangle Press, an imprint of McGraw-Hill, Inc.

This resource provides complete, hands-on activities for students in the middle school grades. Activities can be adapted for older students.

Sarquis, M. et al. (1995). *Teaching Chemistry with TOYS*. NY: Terrific Science Press/Learning Triangle Press, an imprint of McGraw-Hill, Inc.

A wide variety of practical, well-planned, teacher-tested activities teach process skills and principles of chemistry through discovery and critical thinking. Designed for grades K–9 and adaptable for high school and adult students.

Stenmark, J., V. Thompson, and R. Cossey (1986). *Family Math.* Berkeley, CA: Lawrence Hall of Science.
Family Math gives educators, parents, and students a wide variety of activities that target math and problem-solving skills.

Taylor, B. et al. (1995). *Teaching Physics with TOYS.* NY: Terrific Science Press/Learning Triangle Press, an imprint of McGraw-Hill, Inc.
This resource provides a wide variety of practical, well-planned, teacher-tested activities for teaching process skills and principles of physics through discovery and critical thinking. Designed for grades K–9 and adaptable for high school and adult students.

Taylor, B. (1997). *Teaching Energy with TOYS.* NY: Terrific Science Press/Learning Triangle Press, an imprint of McGraw-Hill, Inc.
This book supplies a wide variety of practical, well-planned, teacher-tested activities to teach process skills and principles of energy through discovery and critical thinking. Designed for grades K–9.

TOPS Learning Systems. Candy, OR: TOPS.
The TOPS Open-Ended Task Card and Structured Activity Sheet series provide thoughtfully-sequenced activities for teaching and reinforcing specific science principles and process skills through hands-on, guided discovery. TOPS' non-profit status helps them to offer these books for $8–$16 each. Most activities require low-cost, everyday materials. TOPS materials can be purchased from many suppliers, including William Sheridan Associates, which is listed in the Suppliers of Science Resources and Materials section of this book, or directly from TOPS at 10970 Mulino Road, Canby, OR 97013; 888/722–9755; fax 503/266–5200; e-mail tops@canby.com .

Open-Ended Task Card Series: Designed for the grades noted beside each title, each series includes 16–36 lessons and teaching notes.

Analysis (grades 5–10)
Balancing (grades 3–7 and 6–11)
Cohesion Adhesion (grades 6–10)
Electricity (grades 3–8 and 8–12)
Floating and Sinking (grades 7–12)
Graphing (grades 5–10)
Heat (grades 8–12)
Kinetic Model for Problem Solving (grades 7–2)
Light (grades 6–11)
Machines (grades 7–12)
Magnetism (grades 3–8 and 8–12)
Measuring Length (grades 5–10)
Metric Measure (grades 5–9 and 8–12)
Motion (grades 7–12)
Oxidation (grades 6–10)
Pendulums (grades 4–9 and 8–12)
Pressure (grades 7–12)
Solutions (basic)
Weighing (grades 5–10)

Structured Activity Sheet Series: Designed for grades 3–10, each book includes 20 ready-to-copy lessons. Skill levels are indicated beside each title.

Balancing (basic)
Electricity (basic)
Focus Pocus (light and lenses) (moderate)
Lentil Science (primary)
Magnetism (basic)
Metric Measuring (moderate)
Pendulums (moderate)

Wright, Russell G. (1998). *Thrill Ride! From the Event-Based Science Project Series, Force and Motion Module.* NY: Dale Seymour Publications.

Developed for grades 5–9, *Thrill Ride!* uses the opening of a new ride at an amusement park as the focus of a five-week study of Newton's laws of motion. Each module includes a videotape, a teacher's guide, and a student text. Students watch television news coverage of a real science-related event and read newspaper reports about it. Teams of students design a thrill ride that illustrates Newton's laws.

Hands-On Science Activity Books

These resources contain learning activities that students can complete independently. They also provide teachers and parents with great ideas for facilitating science-related activities. Information about basic scientific principles can be found in many of these books. Note: Additional books are listed at the end of each *Fun With Physics* learning activity.

American Chemical Society. *Wonder Science: Fun Physical Science Activities for Children and Adults to Do Together.*

Since 1989, children and adults have been reading about science and doing the well-planned activities described in the *Wonder Science* newsletter. For under $10 per year, children receive 8 newsletters on topics such as insulation, playground physics, inventions, heat/convection, plastics, forces, aerodynamics, and food chemistry.

Ardley, Neil (1991). The Science Book Series includes the following books, which are published by Harcourt, Brace, and Javonovich.

The Science Book of Air
The Science Book of Electricity
The Science Book of Hot and Cold
The Science Book of Water

Ardley, Neil (1993). *101 Great Science Experiments: a Step-by-Step Guide.* London: Dorling Kindersley Limited.

This guide provides background information and activities that demonstrate physical science principles about topics such as air and gases, water and liquids, hot and cold, color, magnets, electricity, and motion and machines.

Ardley, Neil et al. (1984). *How Things Work.* NY: Simon and Schuster, Inc.

This book provides simple explanations about how things work, including flashlights, magnets, car batteries, electric motors, transformers, electromagnets, fire extinguishers.

Barber, N. And T. Keegan (1990). *175 More Science Experiments.* NY: Random House.

Caney, S. (1980). *Steven Caney's Invention Book*. NY: Workman Publishing.
Caney offers many examples of inventions that have been and/or can be created. Also available on CD-ROM.

Carow, R. (1996). *Put a Fan in Your Hat!: Inventions, Contraptions, and Gadgets Kids Can Build*. NY: Learning Triangle Press, an imprint of McGraw-Hill, Inc.

Gardner, R. (1990). *Investigate and Discover Forces and Machines*. NY: Franklin Institute Science Museum.

Gateway's Simple Machines Series includes the following titles:
Inclined Planes
Levers
Pulleys
Electricity

Hann, J. (1991). *How Science Works*. Pleasantville, NY: Reader's Digest.
Helpful for students, teachers, and parents, this well-illustrated book of activities and information is organized around basic science topics.

Iovine, J. (1991). *Homemade Holograms: The Complete Guide to Inexpensive, Do-it-Yourself Holography*. NY: Learning Triangle Press, an imprint of McGraw-Hill, Inc.

Kerrod, R. (1990). *How Things Work*. NY: Marshall Cavendish Publishing.
The functioning of common machines (e.g., clocks, automated teller machines, satellites) is explained. Kerrod includes an illustrated glossary and a section that outlines the scientific principles at work in many machines.

Kohl, M. A. and J. Potter (1993). *Science Arts: Discovering Science Through Art Experiences*. Bellingham, WA: Bright Ring Publishing.
This resource helps students from age 5–14 experience many scientific principles related to air and water, light and sound, motion and energy, and reaction and matter.

Laux, K. (1997). *The World's Greatest Paper Airplane and Toy Book*. NY: Learning Triangle Press, an imprint of McGraw-Hill, Inc.

Macaulay, D. (1990). *The Way Things Work: From Levers to Lasers, Cars to Computers A Visual Guide to the World of Machines*. London: Dorling Kindersley Publishers.
Macaulay provides a history of the development of machines. Detailed illustrations show how several everyday machines work. Also available on interactive CD-ROM.

Ontario Science Center (1986). *Sportsworks: More than 50 Fun Activities that Explore the Science of Sports*. Reading, MA: Addison Wesley Publishing Company.

Ontario Science Center (1986). *Scienceworks.* Reading, MA: Addison Wesley Publishing Company.

Parrotore, Phil M. (1996). *Electricity and Magnetism.* Cypress, CA: Creative Teaching Press, Inc.
Parrotore provides fairly detailed information and hands-on learning experiences on 4 units: electric charges, electric flow, magnetism, and electric and magnetic energy. Process skills are identified and a performance assessment are provided. This book was designed for students to use independently. It makes an excellent resource for teachers, parents, and students.

Sobey, E. (1996). *Wrapper Rockets and Trombone Straws: Science at Every Meal.* NY: Learning Triangle Press, an imprint of McGraw-Hill, Inc.

Taylor, B. Steps into Science Series. NY: Random House. Titles include:
Get It In Gear: The Science of Movement
Over the Rainbow: The Science of Color and Light
Up, Up & Away!: The Science of Flight

VanCleave, J., author of many science books published by John Wiley & Sons, Inc., including:
Chemistry for Every Kid: 101 Easy Experiments that Really Work
Gravity: Mind-boggling Experiments You Can Turn into Science Fair Projects
Machines: Mind-boggling Experiments You Can Turn into Science Fair Projects
Magnets: Mind-boggling Experiments You Can Turn into Science Fair Projects
Physics for Every Kid: 101 Easy Experiments in Motion, Heat, Light, Machines, and Sound
200 Gooey, Slippery, Slimy, Weird & Fun Experiments
200 More Gooey, Slippery, Slimy, Weird & Fun Experiments

Walpole, B. (1988). *175 Science Experiments.* NY: Random House.

Willow, D. and E. Curran (1989). *Science Sensations: Easy-to-do Activities that Explore the Science Behind Such Everyday Marvels as Rainbows, Bubbles. and Kaleidoscopes.* Boston, MA: Addison-Wesley Publishing Company in cooperation with The Children's Museum and Reading.

Wood, R. (1996). *Mechanics FUNdamentals: FUNtastic Science Activities for Kids.* NY: Terrific Science Press/Learning Triangle Press, an imprint of McGraw-Hill.

Wellnitz, W. (1993). *Homemade Slime and Rubber Bones!: Awesome Science Activities.* NY: Learning Triangle Press, an imprint of McGraw-Hill, Inc.

Wellnitz, W. (1993). *Be a Kid Physicist.* NY: Learning Triangle Press, an imprint of McGraw-Hill, Inc.

Zubrowski, B. Boston Children's Museum Activity Book Series. Beech Tree Paperback Books, Inc.
Zubrowski has written many science books for this series. Titles include:
Bubbles
Balloons: Building and Experimenting with Inflatable Toys

Blinkers and Buzzers: Building and Experimenting with Electricity and Magnetism
Inks, Food Colors, and Papers
Messing Around with Baking Chemistry
Messing Around with Drinking Straw Construction
Raceways: Having Fun with Balls and Tracks
Tops: Building and Experimenting with Spinning Toys
Wheels at Work: Building and Experimenting with Models of Machines

Learning Kits

These kits contain all of the information, and some or all of the materials, needed to teach a unit. Suppliers such as Delta Educational sell additional kits on a wide variety of topics and William Sheridan & Associates develops custom-made kits upon request. Information about these retailers is provided in the Suppliers of Science Resources and Materials section of this appendix.

Roller Coaster Physics, K'NEX in the Classroom Series (1997). Hatfield, PA: K'NEX Industries, Inc., Education Division.

Developed for grades 8–12, this kit helps students explore the physics concepts in simple systems first, and then apply those concepts to build a complex roller coaster system. Also, an example is available at the Eisenhower National Clearinghouse, which is listed in the Suppliers of Science Resources and Materials section of this appendix.

Scholastic Science Place, Sampler Edition (1995). NY: Scholastic, Inc.

The Science Place series was developed through a collaboration between Scholastic and the nation's leading science museums. It is a hands-on, thematic, core K–6 program comprising six complete kits for each grade. Each kit includes books, teacher's map to exploration, reusable exploration materials, sciencemats, assessment collection, recording board, home connection collection, videotape, and a bag. All units can be adapted for younger or older students. These kits can be purchased from Scholastic at 800/724-6527; fax 314/653-5881; http://www.scholastic.com. Also, an example is available at the Eisenhower National Clearinghouse, which is listed in the Suppliers of Science Resources and Materials section of this appendix.

How Buildings Work: How People Use Materials to Build Structures (grade 3)
How People Use Electricity: How Electric Energy Works (grade 4)
Motion: How Moving Objects Interact (grade 4)
How People Invent: How Problems and Solutions Change Over Time (grade 5)

Society of Automotive Engineers. (1996). *A World in Motion II: The Design Experience.* Warrendale, PA: SAE.

This multidisciplinary unit is one of three engineering design challenges. Developed for seventh graders, it can be easily adapted for younger or older students. Each real-world design scenario focuses student design teams, teachers, and volunteers from the professional community on the math, science, and technology concepts required to solve a design problem. The curriculum covers an 8-week period. In Unit II, students develop a motorized, gear-driven toy. Through such hands-on activities, students learn about energy, force, friction, simple machines, levers, gears, and torque. Kits contain a teachers manual, teacher concept video, CD-ROM, two posters, and a video set. Available for $85 each from the SAE at 800/456-2946; fax 412/776-2103; http://www.sae.com. Also, an example is available at the Eisenhower National Clearinghouse, which is listed in the Suppliers of Science Resources and Materials section of this appendix.

Computer Software, Laser Disks, and Video Tapes

Many of the software programs on the market are not much more than a workbook of drills designed to reinforce basic skills. Educators and parents are encouraged to select software that targets students' *critical thinking* and *problem-solving* skills. The following software titles meet this criteria.

Gryphon Bricks

This interactive software, sold through Gryphon Publishing, provides users, age 6 and up, with more than 200 styles of bricks to build whatever their imagination can dream up.

The Incredible Machine

This interactive CD-ROM, developed and distributed by Sierra Software, allows students ages 9 and up to analyze how machines work and create their own machines and contraptions.

Introduction to Simple Machines

This live-action video presents both the theory and applications of topics including levers, pulley systems, wheel and axles, inclined planes, and screws. Developed for middle- and high-school students. Teacher manual and student handbooks are available. Sold by Vocational Marketing Services at 800/343-6430.

The Learning Company, Inc. provides several titles that help students build basic mathematical or science principles. In addition, students are given many opportunities to practice hands-on experimentation, deductive reasoning, and real-world problem solving. The following programs are available from The Learning Company, One Anthenaeum Street, Cambridge, MA 02142; 800/227-5609.

Math/Science Problem Solving

Super Solvers OutNumbered! (ages 8-10)
Super Solvers Gizmos & Gadgets! (ages 8-10)
Operation Neptune (ages 10 and up)
Logic Quest (ages 10 and up)

Museum Madness

Developed for students in grades 5–8, this software provides students with opportunities to build higher order thinking skills, increase reading comprehension, and develop an interest in the covered topics. Set in a local museum, students must employ logic and problem solving skills as they experience strange happenings at the museum. They also experience history and interact with historical figures. Distributed by Minnesota Educational Computing Corporation, 6160 Summit Drive North, Minneapolis, MN 55430; 800/685-6322; fax 612/569-1551; http://www.mecc.com. Also, an example is available at the Eisenhower National Clearinghouse, which is listed in the Suppliers of Science Resources and Materials section of this appendix.

Paper Planes

This software tutorial teaches students to build and pilot their own paper airplane squadron. Patterns for dozens of simple and complex planes that can be made quickly are included. Sold by Vocational Marketing Services at 800/343-6430.

Science Sleuths

Science Sleuths invites students to solve science mysteries that introduce them to problem solving, critical thinking, the scientific method, and specific scientific concepts and terms. An automated student notebook and teacher assessment are included. Science Sleuths was developed for grades 3–6. However, each interactive mystery has 6 progressively more challenging levels to play, each with a different solution, so they can be customized to virtually any grade level. This series is available on CD-ROM (volumes I and II, with 4 mysteries) and video disk (with 24 mysteries). Teachers guides are available. Developed in collaboration with Scholastic, Inc., the materials are sold through Videodiscovery, Inc., 1700 Westlake Avenue North, Suite 6000, Seattle, WA 98109-3012; 800/548-3472; fax 206/285-9245; http://www.videodiscovery.com/vdyweb. Also, an example is available at the Eisenhower National Clearinghouse, which is listed in the Suppliers of Science Resources and Materials section of this appendix.

Strategy Challenges, Collections 1 and 2

This software program, which is appropriate for grades 4–12, encourages strategic planning and problem solving, although it does not target any one specific discipline. Through a wide variety of games and activities, students use the problem solving process to confront real-life situations that require critical thinking. The software was field tested and given very high ratings by teachers participating in the Ohio SchoolNet Plus Software Review Project. Distributed by Edmark Corporation, P.O. Box 97012, Redmond, WA 98073; 800/362-2890; fax 206/556-8430; edmarkteam@edmark.com. Also, an example is available at the Eisenhower National Clearinghouse, which is listed in the Suppliers of Science Resources and Materials section of this appendix.

Thinking Like a Scientist: Process Skills and Critical Thinking

Developed for students in grades 4–6, this software uses colorful graphics and animations that allow students to discover how to use science to work and think critically. Topics include correcting faulty problem statements, designing experiments, interpreting graphs, and making predictions based on patterns, probability, and sample information. Distributed by Educational

Activities, Inc., P.O. Box 329, Freeport, NY 11520; 800/645-3739; fax 516/623-9282. Also, an example is available at the Eisenhower National Clearinghouse, which is listed in the Suppliers of Science Resources and Materials section of this appendix.

The Way Science Works

This software, developed for grades 3 and up, involves students in creative game play by challenging them to repair three pinball "worlds" and rescue their missing inventor. It was designed by highly respected author David Macaulay.

The Way Things Work: A Unique Guide to A Magical World of Machines, Inventions, and Technology

This software mirrors the book of the same title, which was designed by David Macaulay and Dorling Kindersley Publishing for students in grades 5 and up. Use this interactive CD-ROM to learn about inventors, inventions, scientific principles, and history. Topics range from light bulbs to lasers.

Widget Workshop: The Mad Scientist's Laboratory

This software package, designed for grades 4 and above, is a science construction kit that enables students to design and build mechanical inventions (e.g., puzzles, machines) using simulated parts. The package is distributed by Maris Multimedia, Ltd., 2 Theatre Square, Suite 2302, Orinda, CA 94563-3346; 800/336-2947; fax 510/253-3736. Also, an example is available at the Eisenhower National Clearinghouse, which is listed in the Suppliers of Science Resources and Materials section of this appendix.

Suppliers of Science Resources and Materials

Burt Harrison & Company

Burt Harrison is a favorite supplier of "batteries and bulbs activities" among Fun with Physics contributors. In addition to basic electricity-related supplies, the company sells activity cards, motor kits, and similar materials developed by Burt Harrison. Contact the company at P.O. Box 732, Weston, MA 02193; 617/647-0674

Center for Occupational Research and Development (CORD)

CORD develops and distributes applied math and applied science materials, as described in the Support Materials for Teachers and Parents section of this appendix. Contact CORD at P.O. Box 21206, Waco, TX 76702-1206; 800/231-3015.

Delta Education

Delta provides a wide variety of science materials that can be used in hands-on science activities. In addition, they carry many kits on topics such as electricity, bubble science, color and light, electromagnetism, lenses and mirrors, and simple machines. Contact Delta at P.O. Box 3000, Nashua, NH 03061; 800/442-5444.

Eisenhower National Clearinghouse for Mathematics and Science Education (ENC)

The ENC was established to help K–12 teachers locate useful teaching materials. The clearinghouse collects all types of materials at its repository in Columbus at The Ohio State University. The ENC reference desk is located at 1929 Kenny Road, Columbus, Ohio 43210–1079; 800/621–5785; 614/292–7784; fax 614/292–2066; e-mail info@enc.org.

Great Explorations in Math and Science (GEMS)

GEMS develops materials and provides in-service training to educators on topics related to inquiry-based science and math. Much of their work is done through regional support centers/network sites. The GEMS materials which is listed in Appendix B can be obtained from William Sheridan and Associates (listed below) or directly from GEMS. GEMS staff can be reached at Lawrence Hall of Science, University of California, Berkeley, CA 94720–5200; 510/642–7771; fax 510/643–0309.

National Science Foundation (NSF)

NSF provides a toll-free service that answers questions about science. NSF also distributes learning materials and awards grants to educators. The foundation can be reached at 800/682–2716 or through its home page at http://www.nsf.gov/od/lpa/nstw/quests/start.htm.

Vocational Marketing Services

VMS publishes and supplies books, videos, and software for technology education (as well as many vocational programs, Tech Prep, and school-to-work). They can be reached at 17600 South Williams Street, #6, Thornton, IL 60476; 800/343–6430.

William Sheridan & Associates

Sheridan & Associates provides a wide variety of science, math, and language arts materials. The company carries an amazing inventory of written resources as well—including most of those listed on the previous pages. They also create custom-designed learning kits on a wide variety of science topics. Bill Sheridan and his staff have a reputation for friendly, personal service and locating almost anything a customer needs. They have several catalogs of their own, and supply the materials found in the Basic Science, Flinn Scientific, Connecticut Valley Biological catalogs, too. Their Discovery Store is open to the public, and located at 8311 Green Meadows Drive N., Lewis Center, Ohio 43035 (just north of Columbus). Call them at 800/433–6259; fax 740/548–0485.

Women's Educational Equity Act (WEEA) Program Publishing Center

WEEA distributes a wide variety of materials on topics related to educational equity, including disabilities, gender equity, careers, history, math, science, and technology. Materials and catalogs are available from WEEA at 55 Chapel Street, Suite 224, Newton, MA 02158–1060; 800/793–5076; e-mail WEEApub@EDC.org. Their web site can be found at http://www.edc.org/CEEC/WEEA.

Internet Sites*

Resource	Internet Address
Active Learning with Hands-On Resources (an ENC site)	http://enc.org/classroom/focus/ENC2868/2868.htm
Ask ERIC Lesson Plans	gopher://ericir.syr.edu:70/11/Lessons/Science
Bill Nye, The Science Guy	http://www.nyelabs.kcts.org/
Clearinghouse for Mathematics and Science Education	http://www.nsta.org
The Exploratorium Science Snackbook	http://www.exploratorium.edu/publications/Snackbook/Snackbook.html
Federal Resources for Educational Excellence	www.ed.gov/free
Implementing Science Education Standards	http://cedar/cic/net/ncrel/sdrs/areas/issues/content/cntareas/science/sc300.htm
Improving Math & Science Education	http://www.learner.org/content/k12
Integrating Math and Science (an ENC site)	http://enc.org/classroom/focus/107941/7941.htm
Issues in Science and Technology	http://www.utdallas.edu/research/issues/
Lawrence Hall of Science	http://www.lhs.berkeley.edu/
McGraw-Hill Publishers	http://www.mcgraw-hill.com
NASA	http://quest.arc.nasa.gov/women/teachingtips.html
National Science Foundation	http://www.nsf.gov
National Science Education Standards	http://www.nap.edu/readingroom/
National Science Teachers Association	http://www.nsta.org
Newton's Apple Educational Materials	http://ericir.syr.edu/Newton/welcome.html
NPR Science Friday Kids Connection	http://www.npr.org/sfkids/index.html

*Internet addresses were correct upon *Fun with Physics* publication. They are subject to change.

Resource	Internet Address
Professional Development for Math and Science (an ENC site)	http://enc.org/classroom/focus/pd/index.htm
Roller Coaster Physics	http://www.pen.k12.va.us/anthology/Pav/Science/Physics/book/home.html
The Science Club	http://www.halcyon.com/sciclub/
Science Education Resources	http://www.edu/intec/science.html
Science, Technology, and Society Links	http://gpu2.srv.ualberta.ca/ slis/guides/scitech/kmc.htm/
U.S. Department of Energy	http://www.doe.gov
Using Children's Literature in Math and Science (an ENC site)	http://enc.org/classroom/focus/childlit/index.htm
The World Wide Guide to Coasters, Parks, and Rides	http://www.demon.co.uk/arvus/wwg/

APPENDIX C: Basic Scientific Principles

Fun with Physics focuses on simple machines, electricity, heat, and liquids. Each of these topics involves energy sources, flow, pressure, and resistance. Appendix C provides scientific background knowledge relative to these topics. It may be especially helpful for non-science teachers. The background information is organized as follows:

APPENDIX C: Basic Scientific Principles

Scientific Principles and Laws

Bernoulli's principle: The faster the flow of air or fluid, the lower the pressure.

Boyle's law: Pressure is affected by the force exerted on a unit of the surface—the smaller the surface, the greater the pressure (given the same force and a constant temperature).

Charles's law: If a gas's temperature is raised, its volume also increases by the same ratio (providing its pressure remains constant). Or, if a gas's temperature is raised, its pressure increases by the same ratio (providing its volume remains constant).

Hooke's law: The greater the force exerted on an object, the more it will be moved. In other words, the force applied to a spring is directly proportionate to the distance the spring is stretched. So, the heavier the weight pulling on a spring, the farther the spring stretches.

Newton's laws of motion:

- An object will remain at rest or in uniform motion unless acted upon by an outside force.
- When a force acts upon an object, it changes the momentum of that object, and this change is proportionate to the applied force and to the time that it acts upon the object.
- Every action (i.e., force) is followed by an equal and opposite reaction (i.e., force).

Laws of thermodynamics:

- Energy cannot be created or destroyed.
- Heat energy always flows spontaneously from hot to cold.

Ohm's law: Current is directly proportionate to the voltage and inversely proportionate to the resistance.

Pascal's law: Pressure added to a confined fluid at any point instantly appears equally at all other points, and is always at right angles to the containing surfaces.

Generalizations About *Simple Machines*

A **machine** is something that performs work.

Work is done when a force causes an object to move.

Simple machines, which are described below, make up compound (or complex) machines.

Examples of **compound machines** include a bicycle, a rod and reel, a typewriter, a can opener, a scissors, a hand drill, a car, a weight machine, and a treadmill.

Gears

- The force that is applied to a driver gear is transferred to a driven gear.

- When two gears of different sizes are meshed together, the smaller gear turns faster (more rotations per minute) than the larger gear.

- Gears that are side-by-side and meshed together move in opposite directions.

- The direction and speed of the driver gear determines the speed and direction of gears that are meshed with it.

Pulleys

- A pulley is a wheel with a rope, belt, or chain around it.

- Pulleys change the direction of movement and make work easier.

- Fixed pulleys change the direction that an object is moved; they do not make work easier.

- Moveable pulleys change the direction that something is moved and make work easier.

- The more pulleys in the system, the easier it is to do work (e.g., pulling or lifting an object).

- The more pulleys involved in a system, the greater distance to be pulled, but the easier it is to do work.

- The thinner the windlass, the easier it is to turn.

- Two different sets of pulleys will turn at the same speed, if the wheels are connected by a shaft and both pairs of pulley wheels are the same size.

- Common pulleys include crankshafts, sailboats, and window blinds.

Inclined planes

- An inclined plane is a slanted surface that is used to raise or lower heavy objects from one position to another.
- Inclined planes help reduce the amount of force needed to complete a given amount of work, but require greater distance.
- The steeper the plane, the more difficult the work.
- Wedges are two back-to-back inclined planes.
- Common inclined planes are a screw, a bolt, a drill bit, a clamp, a car jack, and a bottle top.

Levers

- A lever is a bar or rod that is free to move or turn on a fulcrum.
- A lever multiplies force, but some distance must be given up.
- The shorter the effort arm, the less force is attained and the greater distance is attained.
- The longer the effort arm, the more force is attained and the less distance is attained.
- Examples of levers include scissors, a broom, a claw hammer, a nutcracker, a mop, tongs, a crowbar, a can opener, tweezers, a baseball bat, boat oars, and a car jack handle.

Wheel and axle

- A wheel and axle is like a spinning lever (e.g., an ice cream machine crank).
- The center of the axle is the fulcrum.
- The wheel is larger than the axle; the wheel turns a greater distance than the axle turns. Work is done at the wheel and is multiplied at the axle.
- Common wheel and axle combinations include a screwdriver, roller skates, a water faucet handle, a bicycle pedal, a can opener, a car steering wheel, and a clock.

Overview of *Electricity*

Electricity is the continuous flow of electrons, or **current**, from one atom to another. No electron flow will occur unless there is a pathway over which the electrons can move. This flow is similar to a water system, where pipes or hoses move water from storage tanks to the delivery point. In electrical wiring, the pathway through which electrical current flows is called a **circuit**. A simple circuit consists of a power source, conductors, load, and a device for controlling current. Each is described below.

- In buildings, the **power source** could be considered the electrical generating stations that pump electricity into residential and commercial buildings. However, primary sources of electrical power also include small generators and batteries.

- **Conductors** (e.g., wiring) provide a path for the current so that it can travel from one point to another.

- A **load** is a device through which electricity produces work. For example, a lamp is a load that, when plugged in and turned on, produces light. Other examples of loads include heaters, electric motors, and televisions.

- **Switches** (e.g., on-off switches) control when the electrical current flows through circuits.

- **Fuses** and **circuit breakers** are protective devices that control current by preventing too much current from flowing into the circuit, which would damage equipment. When an excessive amount of electricity passes through them, fuses and circuit breakers "blow" (shut down) to stop the flow of electricity through the circuit.

In a circuit, **resistance** lowers the amount of electrical energy available to do work. Both wires and load affect resistance. It might be helpful to think of a similar situation with a hose that is connected to two sprinklers. As water passes through a hose, turns or kinks in the pathway cause friction (which is resistance) that results in a slower flow. In addition, when some of the water is diverted to the first sprinkler (which is a load), less water is available for use in the second sprinkler.

There are two types of current flow. Current is either **direct** (flowing in one direction) or **alternating** (flowing in one direction, then reversing to the other direction approximately 60 times per second). In most cases, direct current is provided to equipment by batteries (e.g., flashlights, portable radios, and cars). Alternating current is provided to equipment through electrical systems in buildings.

Measurement of electric current

The *rate* at which electricity flows is called **amperage**. It is measured in **amperes**. A 100-watt bulb requires a current of approximately 1 ampere to make it light up completely. Current flow is measured with an **ammeter**. Most heating and power equipment indicates the amount of current needed for proper operation.

Measurement of electrical pressure

Pressure is applied to electrons to force them to move through a conductor and around a circuit. This pressure is measured in **volts**. The pressure, or **voltage**, is available in wiring circuits all of the time—whether or not electrical equipment is being used. Voltage is measured with a **voltmeter**.

Calculation of power

The amount of *power* derived from an electrical device or system is called **wattage**. Wattage is the product obtained from electrical energy; it is the power that we put to use for lights, heating, cooking, hot water and other everyday needs. For example, the electric company sells electrical energy. Electrical energy or power is measured in **watts** and can be calculated as follows:

For direct-current circuits: volts x amperes = watts

For alternating-current circuits: volts x amperes x power factor = watts

NOTE: Power factors range from 0–1. Large equipment (e.g., an electric heater) may have a power factor as high as 1; small equipment (e.g., a small engine) may have a power factor as low as .25.

Ohm's law

Ohm's law is a simple formula used to describe the *relationship* between current (flow), voltage (pressure), and resistance of an electrical circuit. Each component interacts to affect the operation of a circuit. In other words, because voltage pushes current through a resistance, a change in any of these components will result in a change in the others. The following three equations are Ohm's law rearranged to solve for each of the quantities:

Current = Voltage ÷ Resistance $I = \frac{E}{R}$

amps = volts ÷ ohms

An increase in voltage causes an increase in electrical current flow. An increase in circuit resistance causes a decrease in electrical current flow.

Voltage = Current x Resistance $E = I \times R$

volts = amps x ohms

An increase in current causes an increase in voltage. An increase in resistance causes an increase in voltage.

Resistance = Voltage ÷ Current $R = \frac{E}{I}$

ohms = volts ÷ amps

An increase in voltage causes an increase in resistance. An increase in current causes a decrease in resistance.

Overview of Magnetism

Magnets are objects that attract materials or things that contain iron. All metals are not iron-like, and therefore, all metals are not magnetic. There are basically two types of metals:

- **Ferrous metals**, which contain iron or iron-like material (e.g., steel, cast iron). Magnetite, often called lodestone, is a naturally magnetic material.
- **Non-ferrous metals**, which do not contain any iron (e.g., aluminum, lead, stainless steel, copper, brass, titanium, magnesium)

Magnetism is caused by the flow of electric charges through an object. The directional property of magnets (e.g., used in compasses) comes from the polar quality of magnets, which we call **north and south poles**. The magnetic forces are strongest at the poles (or ends) of magnets. Magnetic forces **attract** objects (i.e., pull toward themselves) that are of opposite polarity (e.g, north pole of one magnet and south pole of another) or **repel** objects (push away) that are of identical polarity (e.g., north poles of 2 magnets).

Items made from ferrous metals contain **magnetic domains**. When an item made from ferrous metals is magnetic, these domains all point in the same direction. When these domains are going in different directions, the item is not magnetic—but it is still **attracted** to magnets.

Magnetism is used in many places, including junkyards (to pick up cars and other metal items and recycling centers (to separate metal items from the other trash). In addition, magnets are used in motors and generators that produce electricity. Furthermore, magnetism is used in manufacturing to check for cracks in ferrous metal parts (e.g., engine blocks) by using a process called magnaflux. The process begins by magnetizing the engine block and then spraying onto it water that has phosphorescent iron particles in it. If there is a crack in the block, it will form a positive and a negative pole that attract iron particles. When a black light is applied to the surface of the engine block, the particles that are condensed around the crack because of the magnetism become visible.

Overview of How Electricity and Magnetism Can Work Together

The **electric motor** is based on the interaction of magnets and electricity. In 1821, Michael Faraday built the world's first electric motor. It was a very simple motor consisting of a magnet in a tube filled with mercury and a wire with a charge running through it. (Mercury is a very good conductor of electricity, but it is a poisonous substance and is not used for these types of experiments today.)

An electric motor requires three components: a **source of current**, a **magnet**, and one or more **loops of wire** that are free to turn within the magnetic field of a magnet. Commercial motors may run on either direct current or alternating current. In addition, they may use permanent magnets or electromagnets and may contain more than one coil.

In electric motors, when the circuit is closed, the **electrons** from the battery produce a **current** in the copper wire. In other words, when the pole of a magnet is placed beside an electric current, the **lines of force** push the pole of the magnet in a circle around the current. A loop, which is carrying the current in a magnetic field, has forces on it that cause it to turn. If the current flows in one direction without interruption, the force deflects the coil in one direction and it stays in position.

Generalizations About *Electricity*

- The longer the wire, the greater the resistance; the thinner the wire, the greater the resistance.
- An increase in the temperature of a wire causes an increase in resistance.
- An ordinary electrical cord has two wires; one for the flow of current from the power source and the other for the return or ground.
- The voltage (pressure) and current (flow of electricity) directly affect how much power is available to do work. Less energy source or lower flow will result in less electrical power being produced and vice versa.
- A series circuit has only one path for the flow of current. In a series circuit, objects are placed one after another and the current flows through each of them in succession. The current is the same throughout, however, and the voltage is divided among the objects in the circuit.
- In a parallel circuit, there are 2 or more paths, or branches, for the flow of current. The current will divide and flow through each of the paths simultaneously. Every branch has the same voltage—and if the appliances are all the same—will have the same amount of current. The total circuit resistance is less than any one branch.
- When batteries are connected in a series, the current is the same; the total voltage is the sum of the voltage of each battery. The terminals are connected +, – , +, – , and so on.
- When batteries are connected in parallel, the total current is the sum of the currents in each battery; the total voltage is the same as that of one cell. The terminals are connected +, +, +, and – , – , – .

Generalizations About *Heat*

- Heat travels through conductors (e.g., metal) better than through insulators (e.g., wood).
- Dark-colored surfaces absorb more heat than light-colored surfaces.
- Rough or dull surfaces absorb more heat than smooth or shiny surfaces.
- When friction causes heat, the object that is in constant contact gets hotter than the movable object (e.g., the wood being cut gets hotter than the saw blade, car brake shoes get hotter than the wheel).

Generalizations About *Liquids*

Pressure

- The amount of pressure exerted by a fluid depends upon the height and the density of that fluid and is independent of the shape of the container that is holding the fluid.
- The deeper the fluid, the greater the pressure it exerts.
- The denser the fluid, the greater the pressure it exerts (e.g., salt water is denser than fresh water).
- Fluids seek equilibrium—seek their own level; a fluid will flow from a place of high pressure to a place of low pressure.
- A fluid can never rise higher than its source without an external force (e.g., a pump).

Evaporation

- The higher a liquid's temperature, the faster it will evaporate.
- The lower a liquid's pressure, the faster the liquid will evaporate.
- The more surface area of a liquid that is exposed to air, the faster the liquid will evaporate.
- The more circulation of air above a liquid, the faster the liquid will evaporate.

Boiling point

- Increased pressure on a liquid raises the liquid's boiling point.
- Decreased pressure on a liquid lowers the liquid's boiling point.

Buoyancy

- The easier an object floats, the denser the liquid or the lighter the object's weight.

APPENDIX D: Selected Science Proficiency Outcomes

Selected 4th-Grade Science Proficiency Outcomes

(Outcomes That are Relevant to Simple Machines, Electricity, Heat, and Liquids)

Strand I—Nature of Science. Refers to students' abilities and thinking habits in investigating science ideas. Outcomes in this strand overlap with traditional science units and with each other. Therefore, they should be reinforced throughout the science curriculum. That is, they should be taught in context—at every grade level.

1. *Create and/or use categories to organize a set of objects, organisms, or phenomena.*

2. *Select instruments, make observations, and/or organize observations of an event, object, or organism.*

3. *Identify and/or compare the mass, dimensions, and volume of familiar objects in standard and/or nonstandard units.*

4. *Use a simple key to distinguish between objects.*

5. *Analyze a series of events and/or simple daily or seasonal cycles and predict the next likely occurrence in the sequence.*

6. *Evaluate a simple procedure to carry out an exploration.*

7. *Identify and/or discuss the selection of resources and tools used for exploring scientific phenomena.*

8. *Evaluate observations and measurements made by other persons.*

9. *Demonstrate an understanding of safe use of materials and/or devices in science activities.*

Strand II—Physical Science. This strand is limited to physical principles of physics and chemistry that can be observed and explored without complicated instrumentation or theories.

10. *Explain the operation of a simple mechanical device.*

11. *Identify characteristics of a simple physical change.*

12. *Explain and/or predict the motion of objects and/or describe the effects of some objects on other objects.*

Selected 6th-Grade Science Proficiency Outcomes

(Outcomes That are Relevant to Simple Machines, Electricity, Heat and Liquids)

Strand I—Nature of Science. Students' thinking habits in investigating science ideas.

1. *Use a simple key to classify objects, organisms, or phenomena.* Students should be able to classify or identify objects according to shared characteristics or attributes (e.g., structure, function, shape, state of matter) using a simple key (e.g., dichotomous key, flow chart, key in table or chart format).

2. *Identify the potential hazards and/or precautions involved in scientific investigations.*

3. *Make inferences from observations of phenomena and/or events.*

4. *Identify the positive and/or negative impacts of technology on human life.*

5. *Evaluate conclusions based on scientific data.*

Strand II—Physical Science. Physical and chemical principles that can be observed and explored, and the inferences that can be made, based on concrete experiences that are observable without complicated instruments or theories.

6. *Recognize the advantages and/or disadvantages to the user in the operation of simple technological devices.* "Mechanical advantages" refers broadly to a device's mechanical advantage, or the ratio of the output forces produced by a machine to the applied input force (e.g., the use of various ramps to lift boxes).

7. *Predict the influence of the motion of some objects on others.* Students should have a basic understanding of Newton's laws of motion, which are listed in Appendix C.

8. *Propose and/or evaluate an investigation of simple, observable physical or chemical changes.*

9. *Provide examples of transformation and/or conservation of matter and energy in simple physical systems.* Students should be able to identify what type of energy transformation is occurring, describe how energy is conserved, and/or how it can be converted into other matter plus energy (e.g., combustion). Students should have a basic understanding of potential and kinetic energy, the main forms of energy (electrical, mechanical, thermal, chemical, and nuclear), various types of energy conversions (conversion of matter to energy, and energy to matter), and the laws of conservation of matter and energy.

10. *Identify simple patterns in physical phenomena.* Examples include the elasticity and/or compressibility of materials, the reflection and refraction of light and waves, and the production of sounds.

Selected 9th-Grade Science Proficiency Outcomes

(Outcomes That are Relevant to Simple Machines, Electricity, Heat and Liquids)

1. *Devise a classification system for a set of objects or a group of organisms.* In other words, students should use common characteristics in grouping the items.

2. *Given a presentation of a scientific situation, distinguish between "observation" and "inference."* In other words, students should be able to tell the difference between facts and observations, and the assumptions that are made based upon those facts and observations.

3. *Identify and apply science safety procedures.*

4. *Demonstrate an understanding of the use of measuring devices, and report data in appropriate units.*

5–7. (Earth and space science; not included in *Fun with Physics.*)

8. *Apply the use of simple machines to practical situations.* Students should be able to use simple machines, such as levers, pulley systems, and inclined planes, and describe how they can make a task easier.

9. *Apply the concepts of force and mass to predict the motion of objects.* (See description in Sixth-Grade Outcome #7.)

10. *Apply the concepts of energy transformation in electrical and mechanical systems.* Students should be able to distinguish between different forms of energy, such as chemical, electrical, and thermal; potential and kinetic. For example, students should be able to describe how the energy in a flashlight battery is transformed into heat and light.

11. *Apply the concepts of sound and light waves to everyday situations.* For example, students should be able to describe how sound and light travel through different materials.

12. *Describe chemical and/or physical interactions of matter.* For example, students should be able to describe how a cube of sugar dissolves in water, how metal rusts, and how things burn.

13–16. (Life science; not included in *Fun with Physics.*)

17. *Describe the way scientific ideas have changed, using historical events as examples.*

18. (Earth and space science; not included in *Fun with Physics.*)

19. *Describe the relationship between technology and science.* For example, students should be able to discuss how science and inventions affect each other.

20. (Life science; not included in *Fun with Physics.*)

APPENDIX E: Matrices of Learning Activities, Proficiency Outcomes, and Process Skills

Four sets of matrices are included in Appendix E.

The first three sets illustrate the relevant 4th-, 6th- and 9th-grade **proficiency outcomes** for each learning activity included in *Fun with Physics*. There is one matrix for each set of learning activities—simple machines, electricity, heat, and liquids.

The forth set outlines the **process skills** addressed by each learning activity.

4th-Grade Science Proficiency Outcomes for Learning Activities

Proficiency Outcomes ▶ / Learning Activities ▼	1	2	3	4	5	6	7	8	9	10	11	12
Exploring Simple Machines												
All About Simple Machines	✓	✓							✓	✓		✓
Give Me the Advantage!									✓	✓		✓
Faster than a Speeding Bullet									✓	✓		✓
What's a New York Minute?		✓	✓			✓			✓			✓
Gravity & Free-Falling Bodies			✓						✓			✓
For Every Action							✓		✓	✓	✓	✓
On the Incline			✓				✓		✓	✓	✓	✓
Don't Slow Me Down—Friction			✓				✓		✓	✓	✓	✓
Rube Goldberg is the Man			✓				✓		✓	✓	✓	✓
Roller Coasters			✓				✓		✓	✓	✓	✓
Exploring Electricity												
Conductors vs Insulators	✓	✓		✓			✓		✓			✓
Quiz Master	✓	✓		✓			✓		✓			✓
Series & Parallel Circuits	✓	✓		✓			✓		✓			✓
Magnetic Materials	✓	✓		✓			✓		✓			✓
Motors in Motion	✓	✓		✓			✓		✓			✓
Exploring Heat												
Some Like It Hot			✓				✓		✓		✓	
Ice Scream			✓						✓		✓	
Keep It Cool		✓	✓	✓			✓		✓		✓	
Exploring Liquids												
Capillary Action		✓				✓			✓		✓	✓
Pneumatic Flyer		✓				✓			✓			✓
Flights of Fancy			✓			✓			✓			✓
Clusters of Bubbles	✓	✓	✓						✓		✓	
Polymer Putty									✓		✓	

6th-Grade Science Proficiency Outcomes for Learning Activities

Proficiency Outcomes ▶ / Learning Activities ▼	1	2	3	4	5	6	7	8	9	10
All About Simple Machines	✓	✓				✓	✓			
Give Me the Advantage!	✓					✓	✓	✓	✓	✓
Faster than a Speeding Bullet		✓				✓	✓	✓	✓	✓
What's a New York Minute?		✓	✓		✓		✓		✓	✓
Gravity & Free-Falling Bodies		✓					✓	✓	✓	
For Every Action		✓				✓	✓		✓	✓
On the Incline		✓					✓	✓	✓	
Don't Slow Me Down—Friction							✓	✓	✓	
Rube Goldberg is the Man		✓			✓		✓	✓	✓	✓
Roller Coasters		✓			✓		✓	✓	✓	
Exploring Electricity										
Conductors vs Insulators	✓	✓	✓					✓	✓	✓
Quiz Master	✓	✓	✓	✓				✓	✓	✓
Series & Parallel Circuits	✓	✓	✓	✓				✓	✓	✓
Magnetic Materials	✓	✓			✓		✓	✓	✓	
Motors in Motion	✓	✓			✓		✓	✓	✓	
Exploring Heat										
Some Like It Hot					✓			✓	✓	✓
Ice Scream		✓			✓				✓	✓
Keep It Cool	✓	✓	✓	✓				✓	✓	
Exploring Liquids										
Capillary Action			✓		✓		✓	✓	✓	
Pneumatic Flyer		✓							✓	
Flights of Fancy		✓							✓	
Clusters of Bubbles	✓	✓						✓		✓
Polymer Putty		✓	✓	✓	✓		✓	✓	✓	✓

9th-Grade Science Proficiency Outcomes for Learning Activities

Proficiency Outcomes ▶ / Learning Activities ▼	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Exploring Simple Machines																			
All About Simple Machines	✓		✓						✓	✓									
Give Me the Advantage!			✓	✓				✓	✓	✓									
Faster than a Speeding Bullet			✓	✓				✓	✓	✓									
What's a New York Minute?		✓	✓	✓					✓	✓							✓		✓
Gravity & Free-Falling Bodies			✓	✓				✓	✓	✓									
For Every Action			✓					✓	✓	✓							✓		✓
On the Incline			✓	✓				✓	✓	✓									
Don't Slow Me Down—Friction			✓	✓					✓	✓							✓		
Rube Goldberg is the Man			✓	✓				✓	✓	✓							✓		✓
Roller Coasters			✓					✓	✓	✓							✓		✓
Exploring Electricity																			
Conductors vs Insulators	✓		✓							✓									
Quiz Master	✓		✓							✓									✓
Series & Parallel Circuits	✓		✓							✓									✓
Magnetic Materials	✓		✓							✓									✓
Motors in Motion	✓		✓							✓									✓
Exploring Heat																			
Some Like It Hot			✓	✓			✓			✓									
Ice Scream			✓	✓								✓							✓
Keep It Cool	✓		✓	✓						✓		✓					✓		✓
Exploring Liquids																			
Capillary Action		✓		✓			✓		✓	✓									✓
Pneumatic Flyer			✓						✓	✓									✓
Flights of Fancy			✓	✓															✓
Clusters of Bubbles	✓		✓						✓										
Polymer Putty		✓	✓	✓					✓			✓					✓		✓

Fun with Physics for Grades 4–8

Process Skills

Process Skills ▶ / Learning Activities ▼	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Exploring Simple Machines															
All About Simple Machines	✓	✓	✓					✓	✓	✓	✓		✓	✓	✓
Give Me the Advantage!		✓	✓	✓	✓	✓		✓		✓	✓		✓	✓	✓
Faster than a Speeding Bullet			✓	✓	✓	✓		✓		✓	✓		✓	✓	✓
What's a New York Minute?		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
Gravity & Free-Falling Bodies		✓	✓	✓	✓	✓	✓	✓			✓		✓	✓	✓
For Every Action		✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
On the Incline		✓	✓	✓	✓	✓		✓		✓	✓		✓	✓	✓
Don't Slow Me Down—Friction				✓	✓	✓		✓		✓	✓		✓	✓	✓
Rube Goldberg is the Man		✓		✓	✓	✓			✓	✓	✓		✓	✓	✓
Roller Coasters		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
Exploring Electricity															
Conductors vs Insulators	✓	✓	✓	✓	✓		✓				✓		✓	✓	✓
Quiz Master	✓	✓	✓		✓		✓		✓		✓		✓	✓	✓
Series & Parallel Circuits	✓	✓	✓	✓	✓		✓		✓		✓		✓	✓	✓
Magnetic Materials	✓	✓	✓	✓		✓		✓		✓	✓		✓	✓	✓
Motors in Motion		✓		✓	✓		✓		✓	✓	✓			✓	✓
Exploring Heat															
Some Like It Hot	✓	✓	✓	✓	✓		✓	✓		✓	✓		✓	✓	✓
Ice Scream		✓					✓	✓		✓	✓		✓	✓	✓
Keep It Cool	✓	✓	✓	✓	✓	✓		✓		✓	✓		✓	✓	✓
Exploring Liquids															
Capillary Action		✓	✓	✓	✓	✓	✓	✓			✓		✓	✓	✓
Pneumatic Flyer		✓		✓	✓				✓	✓	✓		✓	✓	✓
Flights of Fancy	✓	✓		✓		✓		✓	✓	✓	✓		✓	✓	✓
Clusters of Bubbles		✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓
Polymer Putty		✓	✓		✓	✓	✓	✓		✓	✓		✓	✓	✓

Process Skills Key

1 = Categorizing or classifying
2 = Communicating
3 = Comparing
4 = Controlling variables
5 = Experimenting
6 = Hypothesizing
7 = Inferring
8 = Interpreting data
9 = Making models
10 = Measuring
11 = Observing
12 = Ordering
13 = Predicting
14 = Recognizing relationships
15 = Recording

FUN *with* PHYSICS

Real-Life Problem Solving for Grades 4–8

Teachers and students are talking about *Fun with Physics*:

"I have taught this unit at least three other times BUT this time it was far superior because of the creative, hands-on activities from your book."

Pilot Teacher

"[The activities] were fun to do, and it made learning fun. I especially like taking machines apart. There's a lot of things in a telephone that I didn't know about."

Pilot Student

"Those things I picked were very fun! But they were also very interesting. I learned a lot with them...enjoying myself at the same time. I really hope we do more activities like this."

Pilot Student

In-Service Training

The Vocational Instructional Materials Laboratory (VIML) at The Ohio State University's Center on Education and Training for Employment provides coaching and training that will prepare teachers and trainers to effectively use the *Fun with Physics* books and other VIML publications. Workshops in problem solving with physics and math for grades 9-12 and adults working in industry are also available. For further information about these services, contact the VIML at **800/848-4815 or 614/292-8300;** 1900 Kenny Road, Columbus, OH 43210.

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