

# Materials World Modules

## *A Teacher Sampler*



### Materials World Modules

An NSF Inquiry-based Science & Technology Educational Program  
Northwestern University

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## Introduction

Welcome to the Materials World Modules! The purpose of this sampler is to give you a sense of the types of activities in the Materials World Modules (MWM) program.

In addition to samples taken directly from two modules, we have included a short overview of the approach MWM takes to science education, focusing on the value of materials science as a subject area, as well as the teaching and learning approaches behind the design of the activities.

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### About the Modules

MWM is developing a series of modules that focus on the design, synthesis, and evaluation of materials. The modules introduce advanced, modern scientific techniques rare in high school science, such as enzyme biology. Each module is centered around a *design project*, which encourages students to learn science and math through their application to real world problems.

The module development process brings together high school teachers, scientists, engineers, and educational researchers in a collaborative effort to create activities that fill an important gap in available science curricula.

## Module Descriptions

### Biodegradable Materials

Students make, test, and evaluate biodegradable films and gels. They use their knowledge to design devices that release a dye in a controlled manner as they degrade.

### Biosensors

Students investigate the use of biological molecules as materials and use enzymes as chemical sensors in the design of diagnostic tests for peroxide, cholesterol, and glucose.

### Ceramics

Students learn about the functions and properties of ceramic materials. They design and build a low-threshold-voltage varistor.

### Composites

Students find out what composite materials are and test them to learn their advantages over pure materials. They design a new composite material to make a strong, lightweight fishing pole.

### Concrete: An Infrastructure Material

Students learn how the components of concrete can be modified to alter the properties of concrete. They use their knowledge to make concrete roofing tiles that meet specific design and performance criteria.

### Food Packaging

Students learn about the many functions of food packaging and how these materials affect the environment. Then they design their own environmentally friendly package for delivering a hot baked potato and its topping.

### Polymers

Students examine properties of polymers. They design and test a humidity sensor made of a polymer film.

### Smart Sensors

Students investigate the behavior of piezoelectric films. They use these materials to make a coin-counting device.

### Sports Materials

Students test and analyze a wide variety of materials used in athletic equipment and improve the design of materials for peak performance.



## Why Study Materials Science?

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### Materials Science

Materials are the building blocks of civilizations. Materials such as stone, bronze, iron, gold, and silver were used to make tools and vessels for thousands of years, and naturally, they were used to give names to the major epoch of civilization. Today, metal alloys are used in the construction of bridges, buildings, and transportation vehicles. Newer materials such as synthetic polymers are widely used to make kitchenware, sports equipment, and even the clothing we wear.

During the past 20 years, materials research has produced semiconductors and optical fibers to revolutionize the communications industry and usher in the information superhighway. The field has also spawned growth in industries such as aerospace, energy, automobiles, chemical, biomaterials, metals, and electronics.

### The Science of Materials

Materials science is an interdisciplinary approach to science that brings together tools in science, technology, and mathematics to bear toward the solution of critical societal needs. The study of materials covers all materials, both natural and synthetic. In a quest to uncover nature's design secrets, the materials scientists are gaining spectacular insights into the cross-sections of plant leaves, the microstructure of seashells and corals, and the "superglue" used by mussels as they study how material properties are related to composition and structure at all levels. Material scientists are also focusing on a better understanding of how we can control the basic building blocks of materials, the materials' atomic and electronic configurations, in order to develop new and improved products, such as more energy efficient and environmentally friendly materials.

### Real-World Applications

Since the world of materials touches every aspect of our lives, the study of materials provides opportunities for students to learn science and math in the context of real-world applications. The modules have flexible formats, allowing them to supplement existing science and math curricula.

The activities in each module are designed to provide the necessary background and motivation for the students to successfully complete the design project presented. Each module activity builds on preceding ones and ultimately provides students with the principles, ideas, and techniques that they will use in the design challenge.

Over 9,000 students in more than 450 schools have used the modules. Teachers noted that students are highly motivated through the competitive challenges of the design projects. They observed students engaging in hands-on investigation, asking researchable questions, developing an understanding of scientific variables, and collaborating on designs and the iterative design process. Teachers were excited about how these modules can open the doors of science and math to *all* students.

## MWM Learning Goals

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The science education goals that guided the design of MWM are consistent with the National Education Standards. Using these materials will help teachers meet these standards in their own teaching.

- **Developing the abilities necessary to do scientific inquiry.** Including the ability to generate questions, design and conduct scientific investigations, formulate models, analyze alternative models, and communicate and defend explanations.
- **Understanding scientific inquiry.** Understanding that scientific inquiry is focused on logically consistent explanations, grounded in current knowledge, and augmented by mathematics and technology.
- **Becoming familiar with materials science.** Developing an understanding of materials science by applying knowledge from the physical, life, and earth sciences to create materials for specific purposes.
- **Taking part in iterative design.** Providing opportunities to identify technological problems, propose designs, choose between alternative solutions, implement and evaluate a solution, redesign the product, and communicate the problem, process, and solution.
- **Understanding the relationship between science and technology.** Understanding the differences between the purposes and nature of scientific and technological studies and the interrelationships between these fields.
- **Understanding contemporary problems.** Appreciating the use of science and technology to meet local, national, and global challenges, including problems of personal and community health, natural resources, environmental quality, human-induced hazards.
- **Presenting a historical perspective.** Viewing the history and nature of science as a human endeavor, producing new knowledge, supported by developing technology.



## **Inquiry through Design**

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One of the central ideas embodied in the Materials World Modules is the notion of *inquiry through design*. This phrase captures two main ideas that are important to the learning of science: participation in the process of scientific inquiry and the hands-on application of scientific principles through engineering design.

Inquiry and design work together to help students better understand science. By engaging in inquiry, students identify important scientific principles that they can apply to their design. Conversely, by engaging in design, students discover what scientific principles they need to know to improve their design. Inquiry through design captures the flavor of this intertwined relationship between two important scientific processes.

### **Learning Through Inquiry**

To understand science as an ongoing search for better and better explanations, rather than a collection of sanctioned facts, students need to participate in the process of finding explanations for phenomena that they find interesting. Engaging in scientific inquiry means finding a question for which one wants to know the answer. The process through which one tries to answer the question usually involves some experimentation or research; in either case, the student is responsible for designing the investigation.

Many students who engage in inquiry need support to help them make sense of their investigations. MWM provides structured journals to help students organize their ideas and understand the relationship between their original question and the results of their investigations.

Students engaging in scientific inquiry must also be able to evaluate the answers that they produce. An often over-looked aspect of scientific investigation is the process by which scientists convince others that the results of their investigations provide the best explanation. MWM design projects culminate in class presentations where students argue for the merits of their own designs, while critically examining others' designs.

### **Learning Through Design**

Allowing students to participate in hands-on design has two main benefits. First, the students will be highly motivated because their design ideas may be drawn from real-world experience, not just from science class. Second, these designs allow students to see and appreciate the applications of science to their lives.

The design approach that we advocate consists of a series of design cycles, a process called *iterative design*. In the real world, few engineers and scientists get something right the first time. Rather, they design a product, test it, and then redesign the product based on what they learned from the previous design. In this manner, engineers attempt to create improved designs each time they iterate through the design cycle.

In the classroom, iterative design allows students to learn something about their design, and then apply that knowledge in order to make the design better. This is an extremely important process that is worth the extra time that additional design iterations require, because it allows students to continually build on what they have learned to produce tangible results.



## Components of the Student’s Edition

In addition to a short introduction to the module, the student’s edition (or pupil’s edition, PE) of each module is structured into three main parts:

- A compelling **introductory activity** (Activity 1), or interest grabber, invites students to hypothesize about cause and effect.
- Four to five hands-on, **exploratory activities** (or staging activities) acquaint students with particular aspects and properties of the material under study.
- One or two **design projects** prompt students to apply what they have learned by creating a functional prototype product from the materials at hand.

### Activity Features in the PE

This section is the main focus of the PE. Each activity feature is designed to motivate students to engage in the activity. The main activity features include the following:

- A **connection to the previous activity** reminds students of the main point of the previous activity.
- The **Concepts behind...** box summarizes the key concepts students will learn about in the activity.
- **Think about these questions** essentially presents the learning objectives for the activity.
- The **Predictions** section prepares students to analyze and explain what they see.
- **Procedure and Observations** describe the steps involved in doing the activity.
- In **Interpretations**, students look for patterns among the data they collect.
- In **Reflections**, students compare the results with their original predictions and reflect on how their understanding of key concepts has changed.
- **Putting It All Together** prompts students to summarize what they have learned in their own words and to reconsider the questions they asked at the beginning of the activity.
- **Design Connection** encourages students to begin thinking about how to connect concepts learned to design issues.
- **Design Challenge**, which appears in the one or two design projects, allows students to apply what they have learned in the previous exploratory activities to meet a real-world design problem.

### Other Features of the PE

Though the PE focuses primarily on the activities and design projects, it also includes features that provide additional enhancement, such as:

- Helpful **background information** that appears before each of the exploratory activities and connects the activity to the real world.
- Thought-provoking **quotations** from scientists and other notable figures.
- A **glossary** of terms
- An **Expanding on the Concepts** article that delves into the activity concepts and explicitly prompts students to relate their experience to information in the article.

## Components of the Teacher’s Edition

Each module contains a teacher’s edition (TE) that accompanies the PE. The PE is embedded within the TE, allowing you to follow your students through the module while benefiting from the troubleshooting and teaching tips that surround the pages from the student book.

The TE of each module is divided into three major sections: introductory, planning, and appendix.

### TE Introductory Section

Pages T1 to T32 contain the following sections to introduce teachers to the topic of the module and to suggest ways to incorporate and conduct the module in the classroom.

- The **Background** includes information on the innovative material that is the subject of the module, as well as a selected bibliography of recent books, articles, and Internet links on the subject.
- **Connecting to Your Curriculum** links concepts presented in that particular activity of the module with those taught in traditional science courses.
- **Module At-A-Glance** maps out learning objectives, materials needed, and estimated times for all activities.
- **Adapting the Modules** allows you to tailor the module to fit the time you have and the teaching style you prefer (guided or open-ended) for full flexibility of use.
- **Inquiry and Design in the Classroom** helps you to use the modules to the fullest potential in the classroom.
- **Assessment Options** outlines a variety of assessment options for the module, including the inquiry-based assessments, traditional assessments, self-assessments, and portfolio assessments.



- **A Note About Safety** provides module-specific as well as general recommendation of safe practices to help conduct the module successfully and safely.

### TE Planning Section

Each PE page is included in this section as a reduced page having the same page number. The planning section begins with a two-page planning guide insert (pages #A and #B) and continues as the text that surrounds the reduced PE pages. It features components such as the following:

- **Multicultural Links** relate how people from different cultures use or make different materials or objects from the materials that are the topic of the module.
- **Procedure, Data, and Observations** explain what will happen during the activity and provides various kinds of teaching tips to make the procedure go more smoothly.
- **Interpretation of the Data** suggests possible answers to the questions posed under this heading in the PE and tips you can use to help students make or assess their interpretations.
- **Leading In to the Activity** suggests ways to introduce the activity to the students, motivate them, and help them begin the process of questioning and inquiry that will direct their focus on what they will learn.
- **Estimated Time** gives a time range for each of the parts or steps of an activity.
- **Discussing the Quote** relates the quote appearing in the side margin of the PE with some aspect of the activity and stimulates students' thoughts on the subject.
- **Note on...** is a brief, informational note on a particular item or concept covered in or implied in the activity.
- **Connection to...** provides short, simple teaching tips that help you relate or adapt the activity or some aspect of the activity to your own discipline.
- **Extended Thinking** gives you discussion questions that you can assign for homework after students read the Expanding on the Concept article.
- **Tips from the Trenches** are quotes from teachers who have field tested the module that include specific tips or simple recommendations on how to use the specific activity or project.

### TE Appendix Section

The appendix of the TE, which starts on page A1, may include one or more of the following sections:

- The **Minipedia** is used for student research or background reading.
- **Extension Activities** are used to enhance students' understanding of the featured material and of the science and math concepts presented in the module.
- **Black-Line Masters** which can be photocopied provide data tables and other formats for students to record predictions, observations, data, and other information as they do the activities and design projects.
- The **Index** allows you to have at your fingertips the many fascinating facts about all areas of science that are packed into each module.



## Sports Materials Module Overview

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In this module, students learn about the attributes and advantages of various sports materials in preparation for the Design Projects, in which they are challenged to make a mini-golf ball or to invent a new sports product.

### Activities

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#### Exploring Ball Design and Materials

By examining the construction of different balls used in sports, students recognize that the design of balls varies according to how the balls are used in their sport. They hypothesize why specific materials were chosen for each ball.

#### Measuring the Rebound of Sports Balls

Students use a drop test to compare a variety of sports balls for their ability to rebound. They draw conclusions relating rebound to the materials in each ball and to drop height.

#### Investigating Energy Absorption of Materials

As they measure how high a ball bounces from a number of surfaces, students investigate how materials absorb or return energy. They recognize that energy is absorbed through the deformation of materials.

#### Comparing Rolling Friction on Different Surfaces

Students test how different surfaces impede a ball's ability to roll. They also analyze class data to compare how far different balls rolled across the same surface.

#### Researching Sports Materials

Students research and write a formal report about the sports equipment of their choice-how the equipment was developed, what materials are commonly used and why, and how the equipment might be improved in the future. They learn about the connections between science, technology, and society.

## Design Projects

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#### Designing a Mini-Golf Game

Drawing on what they learned about rebound, energy absorption, and rolling friction, students design a ball to be used in a new kind of mini-golf game. They will design, test, evaluate, and redesign a set of prototypes that must meet a number of specific criteria, including landing in the target area 75% of the time.

#### Designing New Sports Equipment

Students consider their research project as well as the properties they tested throughout the Activities as they propose a new type of sports equipment or an improvement on an existing product. They will design, test, evaluate, and redesign a set of prototypes to meet a list of criteria that they themselves establish for their product.

### Sample Pages

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The following seven pages come from the TE of the Sports Materials Module. They are the complete pages of the Planning Guide to Design Project 1, in which students are challenged to design, construct, test, and redesign a set of prototype mini-golf balls to be used on a specified court. Corresponding pages from the PE are embedded in the TE, with troubleshooting and teaching tips in the surrounding wrap-around notes.



## 1

DESIGN PROJECT

# PLANNING GUIDE Designing a Mini-Golf Game

## Summary of the Project

Students will design, construct, test, and redesign a set of prototype mini-golf balls to be used on a specified court. Students will select materials with which to modify a given ball so that their prototypes meet a number of criteria. For each set of prototypes, students manipulate one variable in a systematic way.

## Possible Materials for Modifying Ball

masking tape	yarn
electrical tape	whole rubber bands
duct tape	rubber band pieces
balloons	felt
cotton balls	fabric scraps
twine	aluminum foil
kite string	plastic wrap
cork	wax paper
velcro	glue
fishing line	rubber cement

## Safety

Discuss safety issues students should be aware of, including:

- handling adhesives carefully and wiping up any spills immediately
- using cutting implements safely
- using caution when handling rubber bands
- not throwing balls in the classroom
- controlling all rolling objects
- not eating or tasting any of the materials
- safety issues that may be of particular concern in your classroom

## Design-Log Sheets

Design-Log Sheets 1–9 are available to help students work through the steps in this project. Using the sheets as a guide, students can formulate a design proposal, record and interpret data, and evaluate the strengths and weaknesses of their designs. The questions on the sheets lead students to think about how to design a device that performs well and how to explain, based on their results, why the device performs as well as it does.

## Advance Preparation

Each group of students will need:

- six to ten hollow plastic practice golf balls, such as golf-sized Wiffle® balls

You will also need to gather a variety of materials, such as those listed at the left, with which students can modify the ball. You could ask students to bring materials from home.

Each group will need a court set-up. To make the court challenging, choose the material you used in Activity 4 that allowed the balls to travel farthest. For the target area, you might provide strips of linoleum, 30-50 cm wide.

To test the prototypes, each group will need:

- cardboard mailing tube or piece of PVC pipe, approx. 6.5 cm in diameter, cut to 30 cm length

Your school may have sturdy mailing tubes, such as the ones maps are shipped in. PVC pipe (2.5" in diameter) is available at hardware or home improvement stores.

## Cooperative Roles

To help students focus their energy, you may wish to suggest that each group assign cooperative roles to the different members over the course of the project. For example, one student might be the record-keeper, taking notes on all design steps and data, another can be the facilitator who encourages discussion of design concepts, test results, and redesign ideas. Two other students might be the implementers, who construct and test the prototypes. Students can switch roles at agreed-upon points in the project.

## Open Alternatives

You may choose to allow students to select their own court materials in addition to designing the ball. In this case, they will be designing two separate elements that must work together. Before they begin creating their designs, allow them time to develop a strategy. Ask them to consider whether to design both parts simultaneously or one at a time, and if one at a time, which element to design first. If students will be designing both elements, you might want to give each group two sets of Design-Log Sheets.

For another alternative approach, you might allow students to select the type of ball they wish to modify for their prototypes. They could choose hollow practice golf balls, table tennis balls, or superballs.

Students could create their own targets by applying masking tape to the target area, with different sectors scoring different points.

## Curriculum Connections

Connecting to Your Curriculum on page T14 suggests ways you can fit the Sports Materials module into your general curriculum.



# Designing a Mini-Golf Game



Mini-Golf World hopes to cash in on the new popularity of golf among young people. Their marketing team has proposed a new game that will be a variation of mini-golf. The object of the game is to use a putter to tee off from a platform so that the ball bounces over an obstacle, then rolls across a "green," and onto a target area. The ball must come to rest within the specified target area for the player to score points.

Mini-Golf World has developed a basic court and a testing method, but they are stumped over what materials to use for the ball. They have heard of your extensive experience with sports materials. Now they have hired you and your team to design a ball to be used on this court. Your task: to create a game that is challenging, but not impossible.

Design Project 1 Designing a Mini-Golf Game

## 1 DESIGN PROJECT

### Estimated Time

Four to five class periods:

- During the first class period, students will design and construct their first set of prototype mini-golf balls.
- During the second period, each group tests and evaluates its first set of prototypes. Groups interpret and discuss their data.
- During the third period, students present their findings and give critiques. They then begin the redesign process.
- During the fourth period, students finish their redesigned prototypes and test and evaluate them. They may begin compiling their final reports. These reports can be finished as homework.
- During the fifth period, students hear reports, discuss the best designs, and talk about what they learned by participating in the design challenge.

### To Save Time

- Assign the final report as a homework assignment.
- Initiate an informal class discussion about the first round of design and testing, rather than having group presentations.
- Students could discuss how they would modify the class's best prototype to make it better, rather than constructing and testing redesigned prototypes.

### Suggested Grouping

Groups of three or four

### Project Objectives

Students will:

- design, construct, and test a set of prototype mini-golf balls to meet specific design criteria
- evaluate the strengths and weaknesses of their prototypes and then redesign the mini-golf balls based on their evaluations
- work with a team to set and meet goals
- keep useful, accurate records of their design, testing, and evaluation process
- apply the concepts they have learned about sports materials from doing the previous activities in the module
- present their findings and explain their results in a formal report

### Materials (per group)

For details, see the Planning Guide on p. 38.

- six to ten hollow practice golf balls
- materials for modifying balls
- C-stand
- clamp
- mailing tube or PVC pipe, cut to 30 cm length
- court materials
- obstacle, such as two bricks stacked one on top of the other
- meter sticks or tape measures
- protractors

Make materials for modifying the balls available to groups as needed.

## **D** The Design Challenge

Ask a volunteer to read aloud the goal of the Design Project, explained in the box at the top of page 40. Discuss the importance of setting specific design criteria to determine whether designs are successful. On the board, list the design constraints for the ball, as noted on page 41. Leave the list prominently displayed so that students can refer to it throughout the design project.

Think about these questions as you work on your prototypes:

- ? What characteristics does the ball need to have?
- ? What factors do you need to control so that the ball ends up in the target area?
- ? In what ways can the properties of the ball be varied?

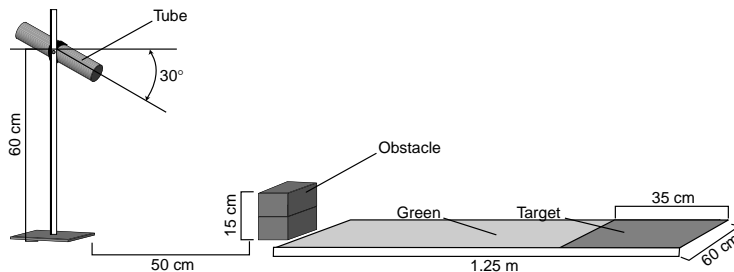
### **D** the Design CHALLENGE

Your goal is to design a ball that can bounce over the court's obstacle, roll across the "green," and stop within the target area. To do so, you will need to control the rebound of the ball, the amount of energy in the ball, and the rolling friction between the ball and the green. You can achieve this by completing the following steps.



### Keeping a Design Log

Each group should keep a log while participating in the design challenge. Your teacher may give you a set of worksheets to fill out as you design, test, and evaluate your prototypes. You can also keep your own design log. Make sure to record all your ideas, even the ones that you decide won't work for some reason. They may come in handy later or give you insight into something you didn't quite understand before.



40 Sports Materials

## Leading In to the Project

Have students read the introduction on page 39. Ask them what factors they might need to consider in order to design a successful game. For example, they will need to consider the ball's rebound, and how the ball interacts with the surface provided. They should also realize that the ball must be relatively round so that it rolls properly, and that its size and weight might be important. To spark discussion, you might ask students to recount the kinds of difficulties they have faced while playing mini-golf.

Tell students that, like researchers in the field of equipment design, they will work in groups during this project. Emphasize the need for cooperation and keeping detailed records. Allow students to make suggestions for ways that they can create a sense of workplace

professionalism, and implement as many of these suggestions as possible.

Ask a volunteer to read aloud the questions in the gray box. Direct students to keep the questions in mind as they work on the project.



### Keeping a Design Log

Design-Log Sheets 1–9 are available for students to record their ideas, procedures, and results during every step of the project. You can photocopy these sheets and distribute them at the beginning of the project, or make them available as students progress through the steps. Alternatively, you can instruct students to plan and keep their own design logs.

Whether students use the sheets provided or create their own, underline the need to keep clear, accurate notes at

each step. Stress that students should write in their logs as they do each part of the project, rather than drawing from memory later. They should also jot down notes during all discussions. These notes may help them later, particularly during the redesign phase. At the end of the project, students can assemble their detailed logs to help them compile their final report.

Students may keep their logs individually, or as a group. If they use a group log, each group member should be given the responsibility of keeping the log for part of the project.

### Propose Prototypes

Before students begin to design their prototypes, go over the design constraints with them. Show them the materials they will be using for the court. You may wish to set up a court and the testing apparatus so that stu-

**Propose Prototypes for a Ball**

Discuss and record different designs for a ball that will meet the needs of this mini-golf game. To help you come up with ideas for different designs, refer back to the information you gathered during the activities about rebound, energy absorption, friction, and the construction of different kinds of balls. Your game needs to meet the following criteria, which have been specified by Mini-Golf World.

1. The game must be played on the court shown in the picture, with dimensions, obstacles, and target as labeled.
2. The ball you design must incorporate the ball provided by your teacher.
3. The ball must not exceed a diameter of 5 cm.
4. The success or failure of the ball and court will be tested by rolling the ball down the tube provided, which must remain fixed at a 30° angle. When rolled down the tube, the ball must bounce once and clear the obstacle.
5. After clearing the obstacle, the ball must roll across the green and stop within the target area at least 75% of the time.

Decide on a set of prototypes for the ball. The set should include three to five prototypes in which a single element is varied. By testing a set of prototypes that differ in a single variable, your group will have a better chance of identifying why certain prototypes in each set work better than others.

**Use a Repeatable Procedure to Construct Your Prototypes**

Write down the amounts of materials you will need and the steps you will follow to construct your prototypes. While constructing the prototypes, be sure to follow safety precautions, such as using rubber bands and cutting implements carefully, cleaning up any spilled liquids, such as adhesives, and controlling any objects that tend to roll so that no one stumbles over them.

Design Project 1 Designing a Mini-Golf Game 41

**Tips from the Trenches**

Allow your students to test and demonstrate their mini-golf prototypes in the same place they worked on them. Some of our teams found that while their prototypes had worked well in one location, they performed very poorly in other locations because the floors weren't always even.

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dents can test an unmodified ball. This may help them formulate ideas about how they need to modify the ball.

1. Explain that for the ball to be successful, it must fit within the context of the game, as other sports balls do, and therefore must interact effectively with this particular court. Point out that, no matter how ingenious, a ball design that does not work within its context is unsuccessful.
2. Tell students that the second constraint gives each group a standard basis on which to build. Students will be better able to compare their results with other groups and incorporate the ideas of other groups if they all are working with the same type of ball.
3. Explain that a limit is set on the size of the ball because 1) the ball must fit easily down the testing tube, and 2) the game is meant to be a varia-

tion of mini-golf and so the ball should not be substantially larger than a golf ball.

4. Ask a volunteer to explain why the ball will be tested by rolling it down a fixed tube, rather than striking it with a putter, the way the game will eventually be played. Be sure students understand that the tube allows them to use an objective testing method that tests the ball, rather than the skill of the player, just as baseballs are tested by firing them from an air cannon.
5. To refresh students on calculating percentages, ask whether hitting the target 3 out of 5 times would satisfy criterion 5. Instruct them to divide 3 by 5, then multiply the answer by 100. (They should arrive at 60%.)

Point out that the ball must have a high success rate when rolled down the tube because the game will be

much more challenging when the tube is replaced with a real player using a putter.

You may wish to define the term *variable* and give an example of ways in which students could change a single variable in their prototype set.

Students can use Design-Log Sheets 1 and 2 to guide them through the planning stages of this project. Encourage them to weigh the pros and cons of each design.

**Constructing Prototypes**

Discuss with students why it is important for them to document their construction techniques and why their procedure must be repeatable. Explain that Mini-Golf World may approve their design and decide to manufacture the ball.

Students can use Design-Log Sheet 4 to guide them through the construction process. Stress the benefit of taking

Design Project 1 Designing a Mini-Golf Game 41



## DISCUSSING THE QUOTE

Ask a volunteer to read the proverb. Then ask the class to suggest how it might relate to the process of design and redesign.

## Knowledge is a treasure, but practice is the key to it.

English proverb

### Predict How Your Prototypes Will Perform

Make a prediction about which of your prototypes will work the best. Consider 1) which ball or balls will rebound high enough to clear the obstacle; 2) which ball or balls will roll straight enough to stay on the course; 3) which ball or balls will have the right amount of energy and friction to stop inside the target. Do you think any of your prototypes will meet criterion 5, stopping within the target area at least 75% of the time? Give reasons you think the prototype or prototypes will be successful.

### Use a Repeatable Procedure to Test Your Prototypes

Record your procedure for testing your prototypes. Make sure your set-up conforms to the specified set-up. Include the number of trials you will run for each ball, making sure that this number allows you to evaluate whether you have met criterion 5. Make one or more data tables to record your results. Then test and record data about your prototypes. Remember to follow necessary safety precautions.

### Interpret the Data

Look for patterns in your data. If one or more prototypes failed, note whether it failed in a consistent way—for example, if it always rolled past the target, rolled unevenly off the green, or did not bounce over the obstacle. If one or more of the prototypes you tested was successful some of the time, calculate the success rate of that prototype, using percentages. Note the prototypes that met criterion 5. Evaluate which prototypes performed the best and which performed the worst. Give reasons for your conclusions.

### Reflect on Your Predictions

Discuss whether your results confirmed or refuted what you predicted would happen. Analyze possible sources of experimental error in your construction and testing procedures.

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clear, accurate, and detailed notes. Tell students to document any obstacles they encountered while building their prototypes, and describe how they overcame those obstacles.

If a group cannot find a solution to a problem they encounter, suggest that they revisit their proposals and modify their designs if necessary. If they do so, they should document the problem and explain why it required redesign because it may help them avoid a similar situation as they continue the Design Project.

### Predictions

Before students test their prototypes, instruct them to predict how they think each will perform. If they think one or more prototypes will succeed some of the time, they should predict whether it will meet criterion 5 by stopping in the target area at least 75% of the time. They should also note any concerns

they have about each prototype. For example, they may predict that an asymmetrical ball will not roll straight enough to reach the target.

Students can use Design-Log Sheet 5 to record their predictions. Direct them to record not only their predictions, but their reasons for making those predictions.

### Testing the Prototypes

As students set up their mini-golf courts, be sure they follow the set-up shown on page 40. The angle of the tube must remain fixed at 30° and the horizontal distance from the end of the tube to the obstacle must be 50 cm, so that students cannot influence the test by manipulating the delivery of the ball onto the court. Suggest that students make periodic measurements to be sure that their set-up remains consistent throughout the trials.

Students should do enough trials with each ball that they are confident with any percentages they calculate. You may want to touch on the subject of experimental error at this time, in terms of which trial results, if any, students might want to exclude. For example, they might want to eliminate results of a trial if the tube was set at the wrong angle or bumped during delivery. However, students should not throw out data simply because a ball did not perform as desired. You may wish to circulate among the groups to check set-ups and to observe the testing procedure.

Students can use Design-Log Sheet 6 to record their data, as well as any notes they wish to make about their testing procedure.

While each group tests its prototypes, or after the actual testing is done, you might want to have each group select a representative or “spy” to visit each of

**Present Your Prototypes and the Results of Your Tests**

Show your prototypes to your class, and describe how you made them. Present your test results, and explain how you interpreted them. Discuss whether any of the prototypes met the criteria set for your product. After your group makes its presentation, ask your classmates to critique your work. The class should evaluate your procedures and discuss whether your results were interpreted correctly. Record the comments and suggestions your classmates give about your work. Then, critique the presentations given by other groups.

**Redesign Your Ball**

Based on what you learned from working on your prototypes and from critiquing the work of other groups, propose improved designs for your ball. Repeat the cycle of design, construction, testing, and evaluation for another round of prototypes.

**Prepare a Report for Mini-Golf World**

Mini-Golf World is eager to know whether you can make its new game work. Write a report for them that describes your design, construction, and testing procedures. Explain how you interpreted your data. Include other ideas you might like to explore to further improve the ball. In your report, suggest ways the ball or court could be altered to make the game easier or more challenging.

**Draw Conclusions About the Design Process**

Explain what you learned about sports materials and about the processes of designing, constructing, testing, and improving mini-golf ball prototypes from participating in this design challenge. If you enjoyed this project, you might consider pursuing a career in materials science or engineering.

**Even if you are  
on the right  
track, you'll get  
run over if you  
just sit there.**

Will Rogers,  
American humorist

**DISCUSSING THE QUOTE**

Ask students whether they agree or disagree with the quote. Ask whether they think it is important for athletes to continue improving themselves and trying to better their best achievements. Then ask them to relate the idea to scientists and their work.

the other groups and try out that team's prototypes. After investigating the designs used by other groups and observing their success or failure, all representatives return to their own groups and share the information. In this way, groups can build on what works best from each set of designs.

Some groups might work to achieve a high success rate by modifying the court in some way, such as raising the target end of the court to slow or stop the ball, or by applying tape with the sticky side up on the target area to snag the ball. You may choose to allow these modifications because they demonstrate ingenuity or to disallow them because they take the burden of performance off the ball. You might also ask whether it's possible for a sports product to work *too* well. That is, if the ball stops in the target 100% of the time, would players be challenged enough to continue playing?

**Interpretations of Data**

Design-Log Sheet 7 is available to help students focus on their interpretations. Encourage them to use charts or graphs to create a visual representation of their results. By analyzing and discussing their data, each group should try to come to a consensus about which of their prototypes performed the best. Ask students to draw conclusions about the overall performance of the prototypes. If none of the prototypes performed well against the criteria, ask whether or not they think it is possible to design a prototype that would meet the criteria. They should explain why or why not.

**Reflections**

Have students read over the predictions they recorded on Design-Log Sheet 5. Students can use Design-Log Sheet 7 to compare their results with the predictions they made. If their results do not

match their predictions, they should offer explanations of why this is so. They should also come up with one or more reasons to explain why one prototype performed better than another.

Lead students to consider possible sources of experimental error, such as mismeasured distances, equipment that may have been bumped, a playing surface that was not level, balls that may have been pushed rather than released down the tube, and so on.

**Presentations**

Point out that by learning about approaches taken by other groups, whether those approaches did or did not work, students can save themselves trouble as they redesign their prototypes.

Students can use Design-Log Sheet 8 to guide them as they prepare for their presentations. You may want to go over the elements each group is to include in its presentation. Design-Log Sheet 8



also gives students some guidelines for critiquing the presentations of other groups.

Set up a court on which students can demonstrate their prototypes during their presentations. Ask students to keep their presentations short—three to five minutes. Encourage them to speak clearly and look directly at their audience. After each presentation, allow time for the rest of the class to critique the presentation. Foster a spirit of respect among students by discussing how to give and receive constructive criticism. Ask students who give criticism that is not constructive to rephrase their ideas in a helpful and positive way.

If you are pressed for time, you can make this step an informal “information swap,” or class discussion wherein students describe what worked for them and what did not.

### Redesign

As students enter the redesign phase of this project, encourage them to consider the results of other groups as well as their own. Challenge students to improve the best design by analyzing the strengths and weaknesses of all prototypes—creating new designs that build on some of the strengths and eliminate some of the weaknesses.

Instruct them to come up with a proposal for a new set of prototypes, again manipulating just one variable. They

can record their redesign strategy on Design-Log Sheet 9. Hand out another set of blank Design-Log Sheets for students to fill out as they work their way through the cycle of building, testing, and evaluating their redesigned prototypes.

If any groups designed a prototype that met all the criteria the first time around, you might provide those groups with different materials from Activity 4 to use as a court, or give them a different type of ball, such as superballs or table tennis balls, to use in their prototypes.

If time is short, you could eliminate the actual construction and testing of the new designs. Instead, ask students to come up with a proposal for a set of new, improved prototypes and let students discuss the various ideas offered by different groups.

For fun, after students complete their redesign, you might bring in a putter and set up a platform to replace the tube apparatus. Students could take turns trying their skill at using the putter to land the ball in the target area.

### Preparing a Report

Before students begin working on the report, review the three main parts of a report—introduction, body, and conclusion. Explain what you expect students to include in each part. Suggest that students include graphic support material, such as pictures, diagrams,

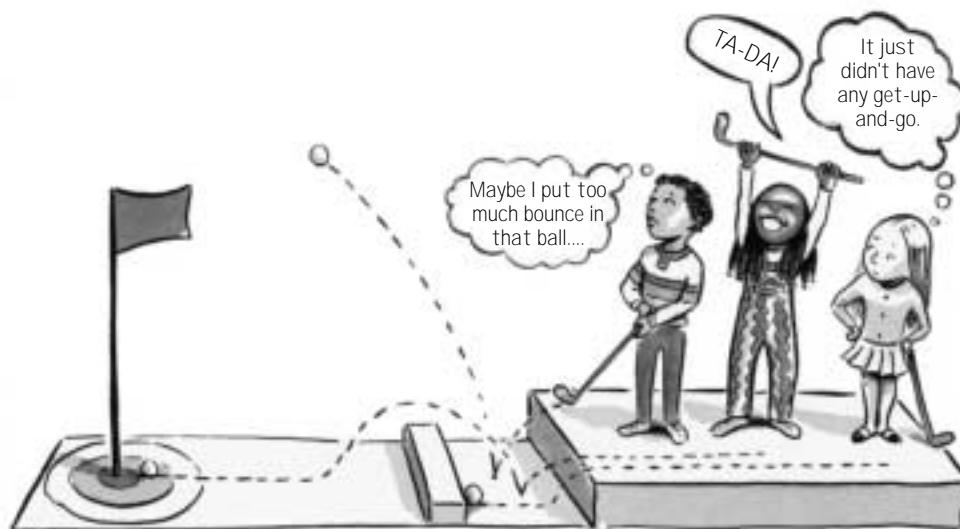
cross-section drawings, graphs, and tables. Direct students to draw on the information they recorded on their Design-Log Sheets as they compile their report. They should also include a section regarding future improvements they might like to pursue, such as how the game itself could be made more fun, more flexible, more challenging, and so on.

You can make this report a cross-curricular assignment, graded jointly by science and English teachers. Students could complete this task as a homework assignment or as an in-class project. Each group member could contribute a different part to complete a group report. They could edit the report together as a group.

### Drawing Conclusions

Prompt students to reflect on the Design Project experience. Ask which parts they liked best and which they liked least. Discuss how doing the activities helped prepare them for the Design Project.

You might take this opportunity to review the sports materials concepts that students explored in this module. As a class, come up with at least one summarizing statement pertaining to each Activity. Write these statements on the board. Ask students to suggest a few more topics relating to sports materials that they might be interested in finding out about.



## Biodegradable Materials Module Overview

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In this module, students learn about the characteristics and uses of biodegradable materials. The Activities prepare them for the Design Project, in which they are challenged to make a medicine-delivery device or to invent a new biodegradable device of their own.

## Activities

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### Comparing Packing Materials

Students discover that a biodegradable packing material can be as effective as a nonbiodegradable packing material in protecting an egg from breaking.

### Hunting for Biodegradable Objects

By searching for common biodegradable objects, students gain an understanding of how biodegradable materials can be used. They draw conclusions about the availability of biodegradable materials today and in the future.

### Processing Biodegradable Materials and Comparing Their Mechanical Properties

Students process gelatin, a biodegradable material, into a gel and into two films that vary in density. They discover how these materials vary in strength and compressibility.

### Measuring the Degradation Rates of Biodegradable Materials

Environmental conditions can affect the rate at which a biodegradable material breaks down. Students test the effect of pH and temperature on the degradation rates of the gel, films, and other materials they worked with in the previous Activity.

### Researching Biodegradable Materials

Students research and write a formal report about a biodegradable material of their choice. The report is to include how the material was developed, how it degrades, and how it is used. From their findings, students should gain an understanding of the close connections among science, technology, and society.

## Design Projects

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### Designing a Medicine-Delivery Device

Students use what they learned about the processing and degradation of biodegradable materials to develop a model of a medicine-delivery device, which they enter in a contest. Students use gelatin to make the device, and a dye is used in place of medicine. During the contest, students' devices will be tested in a warm acid solution, which simulates conditions in the human stomach.

### Designing a New Biodegradable Product

Based on what they learned about the properties of gelatin, students will propose how gelatin can be used to make a new product or improve an existing one. They will make, test, and evaluate gelatin samples to determine whether the product they proposed is feasible.

## Sample Pages

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The following ten pages come from the TE of the Biodegradable Materials Module. They are the complete pages of the Planning Guide to one of the exploratory or staging activities, Activity 4, in which students test the effects of pH and temperature on the degradation of a gelatin capsule, student-made gel and films, and the biodegradable packing material they worked with in the first activity. Corresponding pages from the PE are embedded in the TE, with troubleshooting and teaching tips in the surrounding wrap-around notes.

## 4

ACTIVITY

## PLANNING GUIDE

## Measuring the Degradation

**Purpose**

To give students hands-on experience testing the degradability of different kinds of materials under various environmental conditions.

**Summary of the Activity**

In this activity, students test the effects of pH and temperature on the degradation of a gelatin capsule, the gel and films they made in Activity 3, and the biodegradable packing material they worked with in Activity 1. For each material, students determine its average degradation time and average degradation rate under each condition.

**Advance Preparation**

Materials you may have to obtain in advance (per group):

- 5 pieces of biodegradable packing material (See Advance Preparation on page 1A.)
- 5 gelatin capsules (See Advance Preparation on page 10A.)

Solutions you may have to prepare in advance (per class):

- Prepare 0.0001M HCl (~pH 4) by making a serial dilution, beginning with 0.1M HCl (8.4 mL 12M HCl added to 991.6 mL distilled water). Dilute the 0.1M HCl tenfold to 0.01M by adding 100 mL of the 0.1M acid solution to 900 mL of distilled water. Dilute tenfold two more times to produce 1 L of 0.0001M HCl.
- Prepare 0.0001M NaOH (~pH 10) by making a serial dilution, beginning with 1M NaOH (40 g NaOH in enough distilled water to make 1 L). Dilute the 1M NaOH tenfold to 0.1M by adding 100 mL of the 0.1M base solution to 900 mL of distilled water. Dilute tenfold three more times to produce 1 L of 0.0001M NaOH.

**LINKS**

**TO PREVIOUS ACTIVITIES** Students test materials they worked with in previous activities for their degradability under various environmental conditions.



**TO THE DESIGN PROJECT** Similar environmental conditions will be used to test the degradability of the medicine-delivery device students design in the first Design Project. In the second Design Project, knowing the conditions under which gelatin degrades will help students design a new or improved product.

**Background Information**

In this activity, students will observe that some materials degrade faster in acidic solutions (low pH) while others degrade faster at high temperatures. Positive hydrogen ions in acids react with polymers that have negative charges in their backbone or in their cross-links, causing bonds to break. High temperatures may accelerate certain degradation reactions by increasing the amount of energy available for driving the reactions. In polymers with weak cross-links, such as van der Waals forces, high temperatures can cause the polymer chains to move, thereby breaking the cross-links. As a result, reactants can get in between the chains more easily and degrade them. In contrast, covalently cross-linked polymers do not degrade faster in increased temperature because their strong cross-links hold the chains in place.

**C**urriculum**C**onnections*Relating the*

Connecting to Your Curriculum on page T14 suggests ways you can fit the Biodegradable Materials module into your general curriculum. The chart to the right gives ideas for connecting concepts introduced in this activity with the different disciplines. The page number in the chart refers to a teaching tip in the

margin that you can use to make a connection to the listed subject. The Minipedia at the back of the module includes specific examples of interesting facts about biodegradable materials that you can relate to particular areas of science and technology.

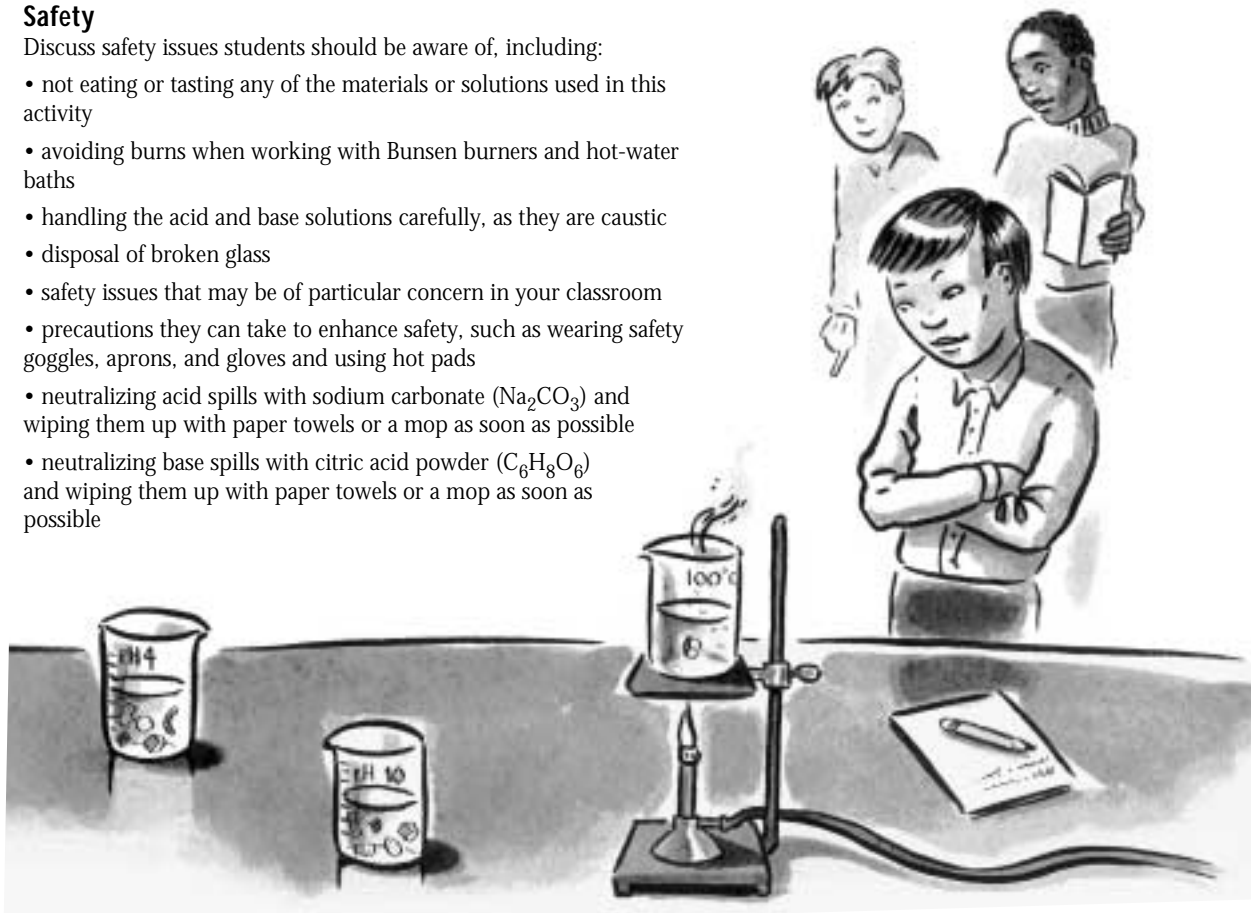


# Rates of Biodegradable Materials

## Safety

Discuss safety issues students should be aware of, including:

- not eating or tasting any of the materials or solutions used in this activity
- avoiding burns when working with Bunsen burners and hot-water baths
- handling the acid and base solutions carefully, as they are caustic
- disposal of broken glass
- safety issues that may be of particular concern in your classroom
- precautions they can take to enhance safety, such as wearing safety goggles, aprons, and gloves and using hot pads
- neutralizing acid spills with sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) and wiping them up with paper towels or a mop as soon as possible
- neutralizing base spills with citric acid powder ( $\text{C}_6\text{H}_8\text{O}_6$ ) and wiping them up with paper towels or a mop as soon as possible



## Degradation Rates Activity to Different Subjects

### Biology

Metabolism  
Protein structure and function  
Enzymes

### Chemistry

Mixtures p. 22  
pH  
Reaction rates  
Intermolecular forces

### Mathematics

Computing averages  
Computing rates  
Making graphs  
Interpreting graphs

### Earth Science

Acid rain

### Tips from the Trenches

*My students were fascinated by the behavior of the gelatin capsules in the acid solution. They wondered whether gelatin capsules behaved in a similar manner in the stomach. A lively and insightful discussion followed.*

**W. James Herget**

**Biology teacher**

**Jacksonville High School**

**Jacksonville, Illinois**

**4**  
INTRODUCTION

In the previous activity, you learned how the design of biodegradable materials affects the materials' mechanical properties.

## Making Biodegradable Materials



Nondegradable plastic wastes

If you were to survey the garbage in a landfill, you would probably find many objects made of nondegradable plastic. Most would be packaging items, such as plastic bags, bottles, and boxes. According to some experts, by the year 2000, plastic wastes will account for about one-third by volume of solid wastes in landfills. Many landfills across the United States are reaching capacity. For this reason, some communities have passed laws that regulate the use of plastic packaging by restaurants and stores.

Researchers are presently developing new materials that will take the place of nondegradable plastics. One development has been the synthesis of a polymer, called E/CO, that begins to degrade when exposed to sunlight for more than six hours. To make E/CO, scientists added carbon monoxide molecules to the nondegradable polymer polyethylene, which is used to make plastic six-pack connector rings. E/CO degrades into smaller, nontoxic pieces of polymer when exposed to sunlight, because the sun's ultraviolet rays break the bonds that hold the carbon monoxide molecules within the polymer. A six-pack ring made of E/CO takes about one week to degrade.



Environmental conditions can affect the degradation rates of some biodegradable materials.

### To Inspire Questioning and Learning

Begin discussion by asking students to list as many objects as possible that are made of plastics. Afterward, you may wish to make photocopies of the chart below and pass them out to students. Students may be surprised to see how many different products are made of

plastics. To emphasize the growing use of plastics, point out that by the year 2000 each person in the United States will produce about 0.5 pounds of plastic wastes per day. In 1960, each person produced less than 0.05 pounds of plastic wastes daily. That's more than a ten-

fold increase. Explain that although most of the wastes we produce each day, such as food and paper products, are biodegradable, nondegradable plastics take up large amounts of space in landfills.

Name of plastic	Uses of plastic
High-density polyethylene (HDPE)	Containers for milk, detergents, and household cleansers; crates; grocery bags
Low-density polyethylene (LDPE)	Food wrap; grocery, trash, and dry cleaner's bags
Polyethylene terephthalate (PET)	Containers for soft drinks, juice, and detergents
Polystyrene (PS)	Disposable cups, plates, and utensils; packing material; egg cartons; meat trays; fast-food packaging
Polyvinyl chloride (PVC)	Containers for bottled water; sporting goods; shrink wrap

Unfortunately, when E/CO is degraded by sunlight, the smaller polymer pieces that are produced cannot be further degraded into simple compounds that can be used by organisms. Thus, E/CO is a degradable material but not a biodegradable one. Any material that can be broken down into smaller parts, by whatever means, is a degradable material. The degradation products of a degradable material may or may not be toxic. However, a degradable material is biodegradable only if it can be broken down by natural processes into smaller, nontoxic parts that can be used by organisms.

Although E/CO has helped the plastic-wastes problem, a better solution has been the development of new kinds of *biodegradable* materials. For example, scientists have developed a biodegradable polymer, called PHBV, that is degraded by water and microbes in the soil. PHBV is used to make a variety of products, including shampoo bottles, disposable razors, and combs. This polymer is made by bacteria when fed a certain chemical. The chemical is a monomer that is chemically bonded within the bacteria, forming a biodegradable polymer (PHBV) that is secreted from the bacteria.

Scientists are also making new biodegradable materials by adding biodegradable fillers, such as starch, to certain nondegradable polymers. When starch-filled polymers are buried in landfills, microbes decompose the starch and cause the polymers to fall apart. The smaller polymer pieces are then further degraded into reusable compounds by chemicals that are released during the decomposition of the starch.



The photo shows the degradation of a cup that was buried in soil for 12 months. The cup is made of a synthetic biodegradable material called caprolactone polyester.

Activity 4 Measuring the Degradation Rates of Biodegradable Materials

19

### Focusing on Study Skills

The Concepts Behind Biodegradable Materials summarizes the main point of the reading on this page and of the activity itself. Write this concept on the board for students to refer to as they read the introduction and do the activity.

### Note About Six-Pack Connector Rings

Nondegradable plastic six-pack rings that litter land and water environments pose a threat to wildlife. Fish, birds, and other animals can become caught in the rings. To help protect marine wildlife, an international treaty was passed in 1988 that prohibits the discharge of all plastic wastes from ships. Environmental groups also urge consumers to cut apart the six-pack rings before disposing of them to avoid entrapment of wildlife.

### Multicultural Links

Japan is one of the most densely populated countries in the world. Its 125 million inhabitants occupy an area about the size of Florida. As a result, the Japanese have struggled to alleviate many environmental problems, including waste disposal. To decrease the volume of garbage disposed of in landfills, the Japanese have developed a garbage-compacting process that can double landfill capacity. The process compacts garbage into three-foot blocks that have no open spaces. Instead of being disposed of, some of these garbage blocks are covered with concrete and are used to build retaining walls, decks, and other types of structures.

### Note About Degradation

Degradable materials take up less space when they break down. However, if a degradable material isn't biodegradable, it still creates waste and can be toxic.

Activity 4 Measuring the Degradation Rates of Biodegradable Materials 19



**Estimated Time**

Two days, 50 minutes each day

- Day 1: students form hypotheses in Part A and test the effects of temperature and pH on degradation in Part B.
- Day 2: students share all their results, make calculations, and graph average degradation rates.

**To Save Time**

Have some groups test the effects of pH on degradation rate while others test the effects of temperature. Groups can then share their results.

**Suggested Grouping**

Part A: pairs

Part B: groups of 3 or 4

**Activity Objectives**

Students will:

- hypothesize about environmental factors that might affect the degradation rates of the gelatin samples they processed in Activity 3
- decide on criteria for concluding whether or not a material has degraded
- test the effects of pH and temperature on the degradation of the biodegradable packing material, gelatin capsule, gel, and films
- calculate the average degradation time of each material tested
- calculate the average degradation rate of each material tested

**4**

ACTIVITY

**Measuring the Degradation Rates of Biodegradable Materials**

Think about these questions as you do the activity:

- ? What happens to a biodegradable material when it degrades?
- ? What environmental factors might affect the manner and rate of degradation of a biodegradable material?
- ? How do the properties of the material and how the material was made affect its degradation rate?

**D**esign Connection How might the environment in which a biodegradable material will be used affect the design of that material?

Biodegradable materials are desirable because they break down into harmless products. But what if a material degraded too soon—before you had a chance to use it? What if a material degraded only under some conditions but not others?

**PART A Hypothesizing About the Degradation of Gelatin**

What are some environmental factors that might affect the rate of degradation of your gelatin films and gel? For example, the polymer PHBV, described in the introduction, is affected by the amount of water to which it is exposed. PHBV would degrade faster in the wet environment of a tropical rain forest than in a desert.

Think about the way your gelatin samples were made. Consider how the type of gelatin you used might break down. As a group, write down all the factors that you think might affect the degradation rates of your samples. Explain how you think each factor will affect your samples. Make a table to use to record your ideas.

**PART B Testing Degradation Rates**

In this part of the activity, you will have the opportunity to measure factors that affect the degradation of different kinds of materials. You will focus on temperature and pH. If you listed other environmental factors in Part A, think about how you could modify the following procedure to test those variables as well.



**Predictions** Consider the effects of temperature and pH on the degradation rates of the materials you worked with in Activity 3. Which material do you predict will degrade fastest under each condition? Slowest? Relate your predictions to the properties of the materials. Record your predictions in a data table.

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**Leading In to the Activity**

- Point out that all the materials used in the activity are fully biodegradable, but students will observe only partial biodegradation of the materials by hydrolysis. More time would be needed for microbes to break down the materials into reusable compounds.
- Have a volunteer read the activity's introductory paragraph aloud. Ask students what they think would be a good time frame for a biodegradable material to degrade. Lead them to recognize that a desirable degradation time depends in part on how the material is used.
- Use the questions in the gray box on page 20 to focus students' thinking about degradation as they do the activity. The Design Connection question links the activity to the Design Projects. You might wish to have students answer the questions after completing the activity.

**Part A**

To stimulate discussion, ask students to think about factors that might cause a gelatin dessert to become gooey or runny. Then, in small groups, have them apply their ideas to the films and gel they made. Encourage students to record all the factors they come up with as well as their hypotheses about how those factors will affect their samples.

**Recording Data**

If you wish to provide a table for students to record their hypotheses about degradation, Activity-Log Sheet 5 is available for photocopying.

► **Make one or more data tables with the following categories:**

- predictions about the materials to be tested
- criteria used to decide if a material has degraded
- mass of each type of sample
- degradation time of each sample under each condition
- average degradation time of each type of material under each condition
- average degradation rate of each type of material under each condition

► **Gather these materials:**

- biodegradable packing material, gelatin capsules, and gel and films from Activity 3
- scissors
- mass balance
- 5 beakers
- distilled water
- dilute HCl solution (pH 4)
- dilute NaOH solution (pH 10)
- Bunsen burner apparatus
- 2 thermometers
- ice chips
- watch with second hand, or stopwatch
- graph paper and colored pencils



### Procedure

1. Discuss with your group the criteria you will use to decide whether a material has degraded. Record the criteria in your data table before you begin testing the materials.
2. **Safety Note:** *Wear goggles. Do not taste or eat any materials.* Cut up the gel and films into five 0.2 g samples each and record the mass. Each sample should be a single piece. Compare the sizes of the samples with their mass. What might cause the samples to vary in size even though they all have the same mass?

**All truths are easy to understand once they are discovered; the point is to discover them.**

Galileo Galilei,  
Italian scientist

### DISCUSSING THE QUOTE

Let students discuss what they think the quote means. You might have them research discoveries made by Galileo, or other scientists, which are now “easy to understand.”

## Part B

### Materials (per group)

The following is a partial list. Refer to page 21 of the Student Edition for other materials needed.

- 5 pieces of biodegradable packing material
- 5 gelatin capsules
- five 250-mL beakers
- 200 mL 0.0001 M HCl (~ pH 4)
- 200 mL 0.0001 M NaOH (~ pH 10)
- Bunsen burner with ring stand, iron ring, and wire gauze (or hot plate)

If students choose to test variables other than temperature and pH, review their procedures and provide them with the materials they will need.



### Predictions

List on the board the materials students worked with in Activity 3 (biodegradable packing material, gelatin capsule, 5% w/v film, 10% w/v film, and gel). Have students recall the properties of each material. Then describe the conditions under which the materials will be tested in this activity. Ask students to predict which material will degrade the fastest and which will degrade the slowest under each condition. Have them relate their predictions to the properties of the materials. Students can record their predictions in their notebooks or on Activity-Log Sheet 5 to refer to after completing the activity.

### Recording Data

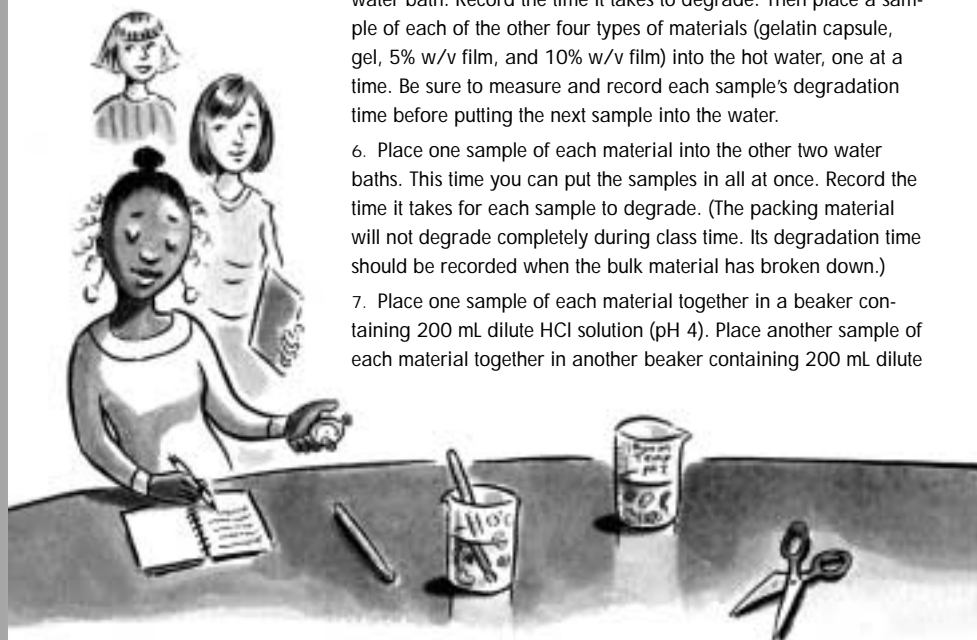
Activity-Log Sheets 5, 6, and 7 can be photocopied to provide students with tables to record their hypotheses, predictions, and data from the degradation tests. Students can graph their data on photocopies of Activity-Log Sheets 8 and 9.



Students can make the acid and base solutions using the given pHs. Have students identify the molarity of each solution and describe the serial dilutions they will need to make. Caution students to handle the concentrated acid and base very carefully.

### Troubleshooting

- Have one person in each group be in charge of maintaining the temperatures of the water baths.
- Have plenty of sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) on hand to clean up acid spills and citric acid ( $\text{C}_6\text{H}_8\text{O}_6$ ) powder to clean up base spills.



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3. Determine the mass of a gelatin capsule and of a piece of biodegradable packing material. Record the masses.
4. Use beakers to prepare three water baths with at least 200 mL of water in each. Heat the first water bath to about  $100^\circ\text{C}$ . Continue heating the water, if necessary, to maintain its temperature. Use ice chips to maintain the temperature of the second water bath at about  $0^\circ\text{C}$ . Keep the third water bath at room temperature.
5. Place a piece of biodegradable packing material into the hot-water bath. Record the time it takes to degrade. Then place a sample of each of the other four types of materials (gelatin capsule, gel, 5% w/v film, and 10% w/v film) into the hot water, one at a time. Be sure to measure and record each sample's degradation time before putting the next sample into the water.
6. Place one sample of each material into the other two water baths. This time you can put the samples in all at once. Record the time it takes for each sample to degrade. (The packing material will not degrade completely during class time. Its degradation time should be recorded when the bulk material has broken down.)
7. Place one sample of each material together in a beaker containing 200 mL dilute HCl solution (pH 4). Place another sample of each material together in another beaker containing 200 mL dilute



### Procedure

- Dispense the gelatin capsules just before students begin the activity. Give each group only as many capsules as they will need.
- It is important to establish criteria for determining whether a material has degraded to ensure that valid comparisons are made. For example, students might agree that a sample has degraded if it 1) completely disappears; 2) reaches a state where it no longer is a solid sample; or 3) breaks into smaller, mushy pieces. If groups have difficulty reaching consensus, you might degrade one of the samples as a demonstration so students can see what the degradation process looks like. Have students record their criteria so they can refer to them as they do the activity.

- Have students decide whether the materials should be stirred or immersed in the solutions or whether they should be allowed to float in the solutions until they degrade.
- To determine how to cut the gel and films into smaller samples, have students weigh each material and then estimate the fraction of the material that would equal 0.2 grams. Students should then cut and weigh each material accordingly. Advise students against using small multiple pieces that add up to 0.2 grams. Using such pieces would make it difficult for students to interpret their data, since the individual pieces of the same material might have different degradation times.
- Ask students to explain any size differences among the gel and film samples. Students should recognize that the sizes

vary because the samples vary in density. You may wish to review the meaning of *density* at this time.

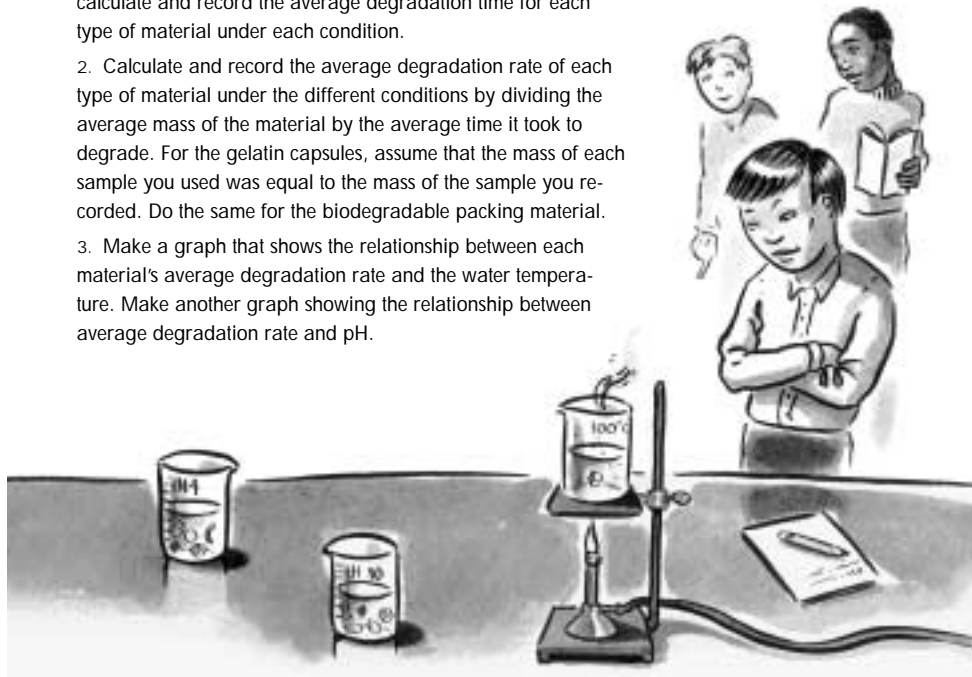
- It is not necessary for students to weigh more than one gelatin capsule and one piece of biodegradable packing material since samples of each kind of material have about the same mass.
- Tell students to label the beakers as shown in the illustration. For each condition, students can test all five types of materials in the same beaker. There is enough solution in the beaker so that the presence of degradation products in the solution will not affect the degradation of the materials. However, if you have enough beakers, you may wish to have students test each type of material under each condition in a separate beaker.

NaOH solution (pH 10). Both solutions should be at room temperature. Record the time it takes for each sample to degrade. Note that the samples placed in water were at neutral pH, i.e., pH 7. Include in your data table the degradation times of the samples at pH 7, room temperature.



### Data and Observations

1. Share your data with other groups. Use the class data to calculate and record the average degradation time for each type of material under each condition.
2. Calculate and record the average degradation rate of each type of material under the different conditions by dividing the average mass of the material by the average time it took to degrade. For the gelatin capsules, assume that the mass of each sample you used was equal to the mass of the sample you recorded. Do the same for the biodegradable packing material.
3. Make a graph that shows the relationship between each material's average degradation rate and the water temperature. Make another graph showing the relationship between average degradation rate and pH.



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## Summary of Experimental Results

Increasing the temperature of the water will increase the degradation rates of the biodegradable material and the gelatin materials. Decreasing the pH of the solutions will increase the degradation rates of the gelatin materials. Samples that are more dense (10% w/v film) will degrade more slowly than those with a lower density (5% w/v film). Samples with a larger surface area (gel and packing material, which have a porous structure) will degrade more quickly than those with a smaller surface area (films and gelatin capsule).

- Students can make a 0°C water bath by melting ice in a beaker. Instruct students to maintain constant water-bath temperatures by adding ice to the water or heating the water as needed.
- It is important that students measure the degradation time of each sample in the hot water before putting in the next sample because the samples will degrade very quickly.
- Students should also use the room-temperature water bath to test the effects of neutral pH on degradation.
- You may wish to have students test the effects of other environmental factors they listed in Part A. Encourage them to write a procedure, including a materials list. Approve students' procedure before they do the tests.

### Data and Observations

- Compile class data on the board for students to compute averages. Discuss with them the difference between average degradation time and average degradation rate.
- Discuss the difference between an independent variable and a dependent variable. Lead students to recognize that average degradation rate is a dependent variable because it depends on pH or temperature, which are independent variables. For example, an increase in temperature may cause an increase in degradation rate.
- Students may need help in graphing their data, particularly in labeling the axes. Direct them to label the environmental conditions (independent vari-

ables) on the x-axis and average degradation rates (dependent variables) on the y-axis. Have groups select appropriate units for the y-axis, based on their data. (Alternately, you may wish to have students use Activity-Log Sheets 8 and 9 to graph their data.)

- Suggest that students use a different colored pencil to plot the data for each type of material. Students might be able to make comparisons more easily if they make bar graphs.

## DISCUSSING THE QUOTE

Discuss the meaning of *serendipity*. Explain that many discoveries in science, such as the discovery of penicillin and radioactivity, were made by chance. Point out that these discoveries may have gone unnoticed if the scientists were not observant, knowledgeable, and well-prepared. Students may be interested in researching these or other serendipitous discoveries in science.

**In the field of observation, chance only favors those minds which have been prepared.**

Louis Pasteur,  
French scientist

**Interpretations of the Data**

1. Study the graphs you made. Which material degraded the fastest under each condition? The slowest?
2. How do pH and temperature affect degradation rate? Is the relationship the same for all the biodegradable materials you tested?

**Reflections**

3. Compare your predictions with the results of the activity. Were you surprised by any of your results? Explain.
4. Explain why it was important to calculate average degradation times.

**Putting It All Together**

5. What environmental factors might affect the degradation of a biodegradable material?
6. How do the properties of biodegradable materials affect their degradation rates?
7. Do all biodegradable materials degrade in the same way? Explain.

**Design Connection** If you were making a biodegradable device out of gelatin, what factors might affect your decision whether to process the gelatin into a gel or film?

**I Wonder**

What new questions do you have about the degradation rates of biodegradable materials? Write down three or more questions to which you would like to learn the answers. Give a reason for asking each question.

**Interpretations of the Data**

1. If students are having difficulty interpreting their graphs, guide them to recognize that the material with the highest average degradation rate degraded the fastest, and vice versa. Students should conclude that under each condition the packing material degraded the fastest and the gelatin capsule degraded the slowest.
2. Students should infer that increased temperature increases the average degradation rates of all the materials tested. A decrease in pH increases the average degradation rates of the gelatin materials.

**Reflections**

3. Encourage students to discuss any unexpected results. Some students might have expected the films, gel, and capsule to degrade at the same rate since they're all made of gelatin. Explain that processing materials by turning them into different products alters their properties and, thus, their degradation rates.
4. If students have difficulty answering this question, have them compare the degradation times of their samples with the average degradation times calculated from the class data. Ask students to explain any differences. Lead them to understand that working with more samples and calculating averages make the data more reliable and allow for more accurate interpretations.

**Putting It All Together**

Encourage students to discuss how their answers to the questions posed at the beginning of the activity have changed as a result of degrading the various materials. Do they have new ideas about how the properties of a material affect its degradation rate? If possible, encourage students to pursue ways of finding the answers to their own questions raised from doing this activity. The notes below address possible answers to the questions posed in Putting It All Together.

5. Students might list the environmental conditions studied in the activity (pH, temperature) as well as some of the other environmental conditions listed in Activity 2 Expanding on the Concepts on page 9 (exposure to water, microbes, ultraviolet light, enzymes).







Read more about how biodegradable materials

break down and how environmental factors can affect their degradation. Does the explanation make sense given your observations of the materials in the activity?

Biodegradable materials break down in different ways, depending on their chemical structure. The figure shows the three types of degradation mechanisms of polymers. In Type I degradation, the unstable cross-linking bonds of a cross-linked polymer are broken. In Type II degradation, the unstable bonds in the backbone of a cross-linked polymer are broken. Type III degradation is similar to that of Type II except that it occurs in linear polymers.

In the activity, the acid broke down the gel by all three degradation mechanisms. First, the gel's cross-links, formed by hydrogen or van der Waals forces, were degraded via the Type I mechanism. As a result, the gel was broken down into smaller gel structures and linear chains. The acid further degrad-

ed the smaller gels via Type II mechanism and the linear chains via Type III mechanism.

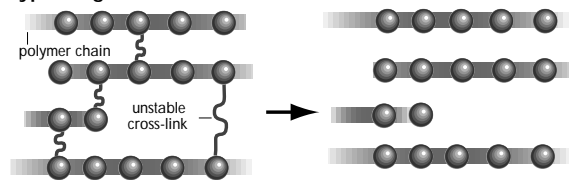
Factors that affect a material's rate of degradation include the material's chemical structure, geometry, and density (in the case of the gelatin solutions, weight percent). Certain environmental factors also play an important role. These factors include the following:

- sunlight
- microbial action (decomposition) by certain bacteria, fungi, and algae
- presence of water (hydrolysis)

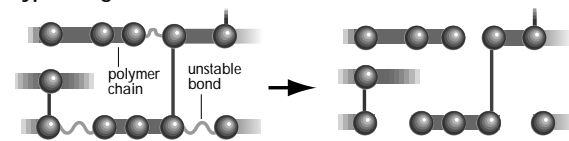
- pH of environment
- temperature
- enzymes

A biodegradable material may be degraded due to one or more of the above factors. For example, the polymer polylactic acid, used as suture material, degrades via hydrolysis in the human body. During hydrolysis, water molecules facilitate the splitting of the polymer's backbone, resulting in monomers of lactic acid. The monomers are then further degraded by enzymes to produce carbon dioxide and water, which are excreted from the body.

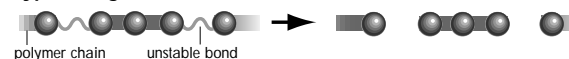
#### Type I Degradation



#### Type II Degradation



#### Type III Degradation



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6. Encourage students to think about how the materials they worked with in this activity varied in shape and density. Based on their data, students should conclude that the denser the material, the lower its degradation rate. Also, materials with a large surface area degrade faster than those with a small surface area. Guide students to realize that the gel and the packing material have a high surface area due to their porous structure.

7. Students should conclude that all biodegradable materials do not degrade in the same way since some environmental factors affect the degradation rate of certain biodegradable materials but not others. For example, pH had no effect on the degradation rate of the packing material, but it did affect the degradation rate of the gelatin materials.

**Design Connection** To help students answer the question, have them think about different environments in which a biodegradable device might be used, such as in a desert, in the ocean, or in the human body. Ask them to identify factors in each environment that might cause the device to degrade, such as sunlight, low pH, presence of microbes, or high temperatures.

#### I Wonder

You may wish to have students work in small groups as they generate their questions. Students may wonder whether the degradation rate of a material can be altered to make it more suitable for a particular application or whether the degradation rate may vary with the age of the material or with prolonged use. Encourage students to give their reasons for asking each of their questions.



This brief article describes the three mechanisms by which biodegradable materials break down and explains how environmental factors can affect the materials' rate of degradation.

#### Introducing the Topic

Display a model of a cross-linked polymer, such as the one shown on page 17. You might show a drawing or a three-dimensional model. Ask students to point to places on the polymer where bonds can be broken. Tell them that the article describes three degradation mechanisms that involve the breaking of a polymer's bonds.

#### Extension Activity

Help students understand that materials made of long polymer chains will degrade more slowly than those made of short polymer chains. Students can observe another effect of polymer-chain length—viscosity—by doing Extension Activity 1 on pages A14-A16.

#### Degradation Rate and Surface Area

The geometry of a surface-degrading material is an important factor in the material's degradation rate. The greater the surface area, the faster the material degrades. Foams and gels, which are surface-degrading materials, have a high surface area due to their porous nature. Thus, these materials degrade faster than films, which are not porous and, although thin and flat, have a smaller surface area. For more information on surface degradation, see page A9 of the Minipedia at the back of the module.