Chemicals, the Environment, and You: Explorations in Science and Human Health

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National Institute of Environmental Health Sciences

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Please contact NIH with questions about this supplement at *supplements@science.education.nih.gov*.

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Foreword

This curriculum supplement, from *The NIH Curriculum Supplement Series*, brings cutting-edge medical science and basic research discoveries from the laboratories of the National Institutes of Health (NIH) into classrooms. As the largest medical research institution in the United States, NIH plays a vital role in the health of all Americans and seeks to foster interest in research, science, and medicine-related careers for future generations. NIH's Office of Science Education (OSE) is dedicated to promoting scientific literacy and the knowledge and skills we need to secure a healthy future for all.

We designed this curriculum supplement to complement existing life science curricula at both the state and local levels and to be consistent with the *National Science Education Standards* (released by the National Academy of Sciences in 1996). It was developed and tested by a team of teachers, scientists, medical experts, and other professionals with relevant subject-area expertise from institutes and medical schools across the country, representatives from the National Institute of Environmental Health Sciences, and curriculum design experts from Biological Sciences Curriculum Study (BSCS) and Videodiscovery, Inc. The authors incorporated real scientific data and actual case studies into classroom activities. A three-year development process included geographically dispersed field tests by teachers and students. For the 2012 edition, key sections of the supplement were updated, but the Student Lessons remain basically the same.

The curriculum supplements enable teachers to facilitate learning and stimulate student interest by applying scientific concepts to real-life scenarios. Design elements include a conceptual flow of lessons based on the BSCS 5E Instructional Model, cutting-edge science content, and built-in assessment tools. Activities promote active and collaborative learning and are inquiry-based to help students develop problem-solving strategies and critical-thinking skills.

Each of our curriculum supplements comes with a complete set of materials for teachers and students, including extensive background and resource information, detailed lesson plans, masters for student worksheets, and a Web site with videos, interactive activities, updates, and corrections (as needed). The supplements are distributed at no cost to educators across the United States upon request. They may be copied for classroom use but may not be sold.

We welcome your comments. For a complete list of curriculum supplements and ordering information, or to submit feedback, please visit *http://science.education.nih.gov*.

We appreciate the valuable contributions of the talented staff at BSCS and Videodiscovery, Inc. We are also grateful to the NIH scientists, advisors, and all other participating professionals for their work and dedication. Finally, we thank the teachers and students who participated in focus groups and field tests to ensure that these materials are both engaging and effective.

I hope you find our series a valuable addition to your classroom and wish you a productive school year.

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About the National Institutes of Health

Founded in 1887, NIH is the federal focal point for health research in the United States. Today, NIH is one of the agencies within the Department of Health and Human Services. Its mission is science in pursuit of fundamental knowledge about the nature and behavior of living systems and the application of that knowledge to extend healthy life and reduce the burdens of illness and disability. NIH works toward meeting the mission by providing leadership, direction, and grant support to programs designed to improve the health of the nation through research.

NIH's education programs contribute to ensuring the continued supply of well-trained basic research and clinical investigators, as well as the myriad professionals in the many allied disciplines who support the research enterprise. These efforts also help educate people about scientific results so that they can make informed decisions about their own—and the public's—health.

This curriculum supplement was one such education effort. It is a collaboration among the National Institute of Environmental Health Sciences, the NIH Office of Science Education, Biological Sciences Curriculum Study, and Videodiscovery, Inc.

For more about NIH, visit *http://www.nih.gov*.

About the National Institute of Environmental Health Sciences

The National Institute of Environmental Health Sciences (NIEHS) is one of 27 institutes and centers of the National Institutes of Health (NIH). The mission of NIEHS is to reduce the burden of human illness and disability by understanding how the environment influences the development and progression of human disease. Headquartered in Research Triangle Park, North Carolina, NIEHS supports environmental health research at universities, independent laboratories, and centers throughout the United States.

NIEHS is unique within NIH because its primary focus is on the public health impact of environmental exposures, rather than on one or two specific organs such as the heart or liver and finding ways to treat illnesses people already have. Promoting public health and preventing disease is one of the most important services the government can provide to its citizens. Protecting people from avoidable illness and death spares suffering, saves money, and improves the quality of life for society as a whole.

NIEHS provides the sound scientific foundation for defining the health effects of a broad array of environmental agents. Translating these findings into effective public health and prevention strategies requires that NIEHS communicate its discoveries to federal regulatory agencies such as the Environmental Protection Agency (EPA) and the Food and Drug Administration (FDA), as well as to public health agencies such as the Centers for Disease Control and Prevention (CDC). These organizations, in turn, use this information to calculate new standards to protect health and communicate public health messages to the public. This information is also the scientific basis for many laws passed by Congress to protect the nation's health.

The most effective way to promote public health and prevent disease and disability is to understand the cause of an illness and change the conditions that allow it to occur. NIEHS takes a holistic approach to health, viewing it as an integrated response of all organ systems of the body to the environment. A key strategy for preventing many diseases or minimizing their effects is to eliminate or reduce exposures to chemicals and other toxic agents in our environment, especially our food, water, and air. To help reduce exposure to these agents, NIEHS supports environmental public health activities that increase public awareness about the nature of the chemicals and how they may affect our health and that empower communities to take action to manage environmental health issues.

Environmental public health is defined as the science of conducting and translating research into action to address environmental exposures and health risks of concern to the public. NIEHS recognizes the importance of working in partnership with community groups to address their environmental health concerns. The institute supports programs that build the capacity of community groups and researchers to work together, advance environmental health literacy, increase awareness of environmental health concepts, and engage community residents as partners in the research process.

NIEHS supports environmental public health activities through

- Grants to support university-community partnerships that address local environmental health issues.
- Outreach activities NIEHS requires of academic research institutes it supports.
- Communication tools such as the science journal *Environmental Health Perspectives*.

Research areas of special interest to NIEHS are environmentally related diseases and disorders such as cancer, asthma, Alzheimer's disease, autism, and the potential effects on human health of endocrine disruptors, metals, pesticides, nanotechnology, and climate change. To fully understand these diseases and conditions, environmental health research must examine the interface of exposure, genetic susceptibility, and time and duration of exposure.

NIEHS has a vested interest in developing and training the next generation of diverse environmental health scientists who will be needed to solve the complex problems mentioned above. The *Chemicals, the Environment, and You* curriculum is just one example of NIEHS's efforts to improve science education and literacy, increase the nation's understanding of the role of the environment in disease, empower teachers and other communicators to translate science, and provide the most current and credible information on environmental health science.

For more information see

NIEHS Science Education:
http://www.niehs.nih.gov/health/scied/index.cfm

Environmental Health Perspectives
Science Education:
http://ehp03.niehs.nih.gov/static/scied.action

Summers of Discovery:
http://www.niehs.nih.gov/careers/research/summers/index.cfm

NIEHS Web site:
http://*www.niehs.gov*

About Biological Sciences Curriculum Study

Headquartered in Colorado Springs, Colorado, BSCS was founded in 1958 as a curriculum study committed to an evidence- and inquiry-based approach to science education. BSCS instructional materials and professional development services are based on current research about teaching and learning for all science classrooms, kindergarten through college.

BSCS's materials are extensively field-tested in diverse settings across the country and evaluated for proven effectiveness. The BSCS 5E Instructional Model and inquiry are hallmarks of its materials, placing students at the center of their learning.

The BSCS mission is to transform science teaching and learning through research and development that strengthens learning environments and inspires a global community of scientifically literate citizens. BSCS is a 501(c)3 nonprofit organization. For more information, please visit *http://www.bscs.org*.

Introduction to *Chemicals, the Environment, and You*

What Are the Objectives of the Module?

Chemicals, the Environment, and You has several objectives. The first is to help students understand major concepts that describe the relationship between chemicals in the environment and human health. By focusing on the science of toxicology, the module seeks to introduce students to the ways scientists learn about and measure how chemicals can both help and harm human health.

The second objective is to convey to students the ever-changing nature of our understanding of the influence of chemicals on the health of living organisms. For example, with each introduction of a new synthetic chemical, researchers must learn at what dose and by what route of exposure the chemical might be hazardous to human health. New data have informed people of the dangers of lead in paint and the disease implications of breathing secondhand smoke. Our increasing knowledge about the effects chemicals can have on the human body enables us to make choices to limit our exposure to some chemicals while using other chemicals in ways that improve the quality of our lives.

Science plays an important role in assisting individuals as they make choices about enhancing personal and public welfare. In this module, students see that science provides evidence that can be used to support ways of understanding and treating human disease. Because the mission of the National Institute of Environmental Health Sciences is to reduce human illness from environmental causes, the institute believes that education provides one context in which it can fulfill its mission. The lessons in this module encourage students to think about the relationships among knowledge, choice, behavior, and enhanced human health in this way:

Knowledge (what is known and not known)
+ Choice = Power
Power + Behavior = Enhanced Human Health
(that is, personal and public health)

An additional objective of this module is to encourage students to think in terms of these relationships now and as they grow older.

Why Teach the Module?

Middle school science classes offer the perfect opportunity to integrate many areas of student interest. In this module, students participate in activities that integrate inquiry science, environmental studies, human health, history, decision-making concepts, and mathematics. The real-life context of the module's lessons is engaging for students, and the knowledge gained by participating in the module can be applied immediately to students' lives.

"The activities provided actual real-life occurrences that students could relate to."
—Field-test Teacher

"The lab made me think about medicines and what dose I should take."
—Field-test Student

What's in It for the Teacher?

Chemicals, the Environment, and You meets many of the criteria used to assess teachers and their programs.

- The module is **standards based** and meets science content, teaching, and assessment standards as expressed in the *National Science Education Standards*. It pays particular attention to the standards that describe what students should know and be able to do with respect to **scientific inquiry.**

- As described above, it is an **integrated** module, drawing most heavily from the subjects of science, history, mathematics, and health.
- The module has an online **technology component** that includes mini-documentaries, laboratory information and data tables, and interactive activities.
- Finally, the module includes built-in **assessment** tools indicated by an assessment icon in each lesson.

In addition, the module provides a means for **professional development**. Teachers can engage in new and different teaching practices like those described in this module without completely overhauling their entire yearlong program. In *Designing Professional Development for Teachers of Science and Mathematics (1)*, Susan Loucks-Horsley *et al.* write that replacement modules such as *Chemicals, the Environment, and You* can "offer a window through which teachers can get a glimpse of what new teaching strategies look like in action." By experiencing a short-term unit like this one, teachers can "change how they think about teaching and embrace new approaches that stimulate students to problem solve, reason, investigate, and construct their own meaning for the content." The use of a replacement unit like this one can encourage reflection and discussion and stimulate teachers to improve their practices by focusing on student learning through inquiry.

Table 1 correlates topics often included in the middle school curriculum with the lessons in this module. This information is presented to help teachers make decisions about incorporating this material into the curriculum.

Table 1. Correlation of *Chemicals, the Environment, and You* to middle school topics.

Topics	Lesson 1	Lesson 2	Lesson 3	Lesson 4	Lesson 5	Lesson 6
Chemical composition of all matter	•					
Chemicals in the environment	•	•			•	•
Human health and medicine	•			•	•	•
Individual variation/susceptibility			•	•	•	•
Risk assessment and management		•			•	•
Scientific methods		•	•	•		

Implementing the Module

The six lessons in this module are designed to be taught either in sequence for two or more weeks (as a replacement for a part of the standard curriculum) or as individual lessons that support or enhance your treatment of specific concepts in middle school science. The following pages offer general suggestions about using these materials in the classroom; you will find specific suggestions in the procedures provided for each lesson.

What Are the Goals of the Module?

Chemicals, the Environment, and You is designed to help students develop the following major goals associated with scientific literacy:

- to understand a set of basic scientific principles related to chemicals, human health, and the study of toxicology;
- to experience the process of scientific inquiry and develop an enhanced understanding of the nature and methods of science; and
- to recognize the role of science in society and the relationship between basic science and human health.

What Are the Science Concepts and How Are They Connected?

We have organized the lessons to form a conceptual whole that moves students from an introduction to chemicals and toxicology (*Chemicals, Chemicals, Everywhere*), to an investigation of the effect of various doses of chemicals on seed germination (*The Dose Makes the Poison*), to a discussion of the relationship between dose and response that can be represented by a dose-response curve (*Dose-Response Relationships*). Once students have experienced the process of toxicology testing, they discuss how individual responses to chemicals can vary (*Individual Responses Can Be Different*), and how knowledge about chemicals can be used to assess and manage risk from chemical exposure (*What Is the Risk?*). Finally, students consider how their understanding of how chemicals can affect human health can help them make decisions related to personal and public health (*Environmental Hazards*).

Table 2 summarizes the sequence of major concepts addressed by the six lessons.

How Does the Module Correlate with the *National Science Education Standards?*

Chemicals, the Environment, and You supports teachers in their efforts to reform science education in the spirit of the National Research Council's 1996 *National Science Education Standards (NSES)*. The content of the module is explicitly standards based: Each time a standard is addressed in a lesson, an icon appears in the margin and the applicable standard is identified. Table 3 lists the specific content standards this module addresses (page 5).

Teaching Standards

The suggested teaching strategies in all the lessons support teachers as they work to meet the teaching standards outlined in the *National Science Education Standards*. The module helps teachers of science plan an inquiry-based science program by providing short-term objectives for students. It also includes planning tools such as the *Conceptual Flow of the Lessons* (Table 2) and the *Suggested Timeline* (Table 8) for teaching the module. Teachers can use this module to update their curriculum in response to their students' interest in this topic. The focus on active, collaborative, and inquiry-based learning in the lessons helps teachers support the development of student understanding and nurture a community of science learners.

The structure of the lessons in this module enables teachers to guide and facilitate learning. All the activities encourage and support student inquiry, promote discourse among students, and challenge students to accept and share responsibility for their learning. The use of the 5E Instructional Model combined with active, collaborative learning allows teachers to respond effectively to the diversity of student backgrounds and learning styles. The module is fully annotated, with suggestions for how teachers

Table 2. Conceptual flow of the lessons.

Lesson	Learning Focus	Major Concept
Lesson 1 *Chemicals, Chemicals, Everywhere*	Engage: Students express prior knowledge and become engaged in the study of toxicology.	Everything in the environment is made of chemicals. Both naturally occurring and synthetic substances are chemical in nature. People are exposed to chemicals by eating or swallowing them, breathing them, or absorbing them through the skin or mucosa, and they can protect themselves from harmful chemicals by blocking these routes of exposure.
Lesson 2 *The Dose Makes the Poison*	Explore: Students explore the response seeds have to different doses of chemicals. The Explore phase gives students a common set of experiences upon which to begin building conceptual understanding.	The total amount of chemical that is administered to, or taken by, an organism is called a dose, and the effect a chemical has on a living organism is called the response. The effect a chemical has on a living organism is related to dose and the resultant concentration of the chemical in the organism. Toxicity tests enable toxicologists to learn about responses of living organisms to doses of chemicals.
Lesson 3 *Dose-Response Relationships*	Explain: Students express their conceptual understanding of the laboratory investigation in their own words and using graphs.	Dose and response are related and can be represented by a dose-response curve. Data from toxicology testing can be represented by a dose-response curve, from which scientists can describe the threshold and potency of chemicals.
Lesson 4 *Individual Responses Can Be Different*	Explain/Elaborate: Students broaden their conceptual understanding and apply what they have learned in a new context.	The variety of responses among organisms that get the same dose of chemical is due to individual susceptibility. Dose and individual susceptibility play roles in all situations involving chemicals, including those involving medicines and caffeine.
Lesson 5 *What Is the Risk?*	Elaborate: Students extend the module's concepts in a different activity to help them apply scientific terms and concepts in appropriate ways.	People can make some choices about chemical exposure; however, some exposure is controlled at a level other than an individual one. Collective groups of people, such as communities and governments, seek to control chemical exposure on a community or global level.
Lesson 6 *Environmental Hazards*	Evaluate: Students demonstrate their understanding of concepts and performance of skills.	People can use their understanding of the science of toxicology to identify potential sources of harm to human health from chemicals in the environment. They can use their knowledge to propose possible means to eliminate or reduce exposure to environmental toxic agents.

Table 3. Content Standards: Grades 5–8.

Standard A: As a result of activities in grades 5–8, all students should develop abilities necessary to do scientific inquiry and understandings about scientific inquiry.	**Correlation to *Chemicals, the Environment, and You***
• Design and conduct a scientific investigation.	Lessons 2, 4
• Use appropriate tools and techniques to gather, analyze, and interpret data.	Lessons 2, 3, 4
• Develop descriptions, explanations, predictions, and models using evidence.	Lessons 2, 3, 4, 6
• Think critically and logically to make the relationships between evidence and explanations.	Lessons 3, 4, 6
• Communicate scientific procedures and explanations.	Lesson 3
• Use mathematics in all aspects of scientific inquiry.	Lessons 2, 3, 4
• Develop understandings about scientific inquiry.	Lessons 2, 4, 6
Standard B: As a result of their activities in grades 5–8, all students should develop an understanding of properties of matter.	**Correlation to module**
• There are more than 100 known elements that combine in a multitude of ways to produce compounds, which account for the living and nonliving substances we encounter.	Lesson 1
Standard E: As a result of their activities in grades 5–8, all students should develop understandings about science and technology.	**Correlation to module**
• Perfectly designed solutions do not exist. All technological solutions have trade-offs, such as safety, cost, efficiency, and appearance.	Lessons 1, 5
• Technological solutions have intended benefits and unintended consequences. Some consequences can be predicted, others cannot.	Lessons 1, 4, 5
Standard F: As a result of their activities in grades 5–8, all students should develop an understanding of	**Correlation to module**
• personal health	Lessons 4, 5, 6
• natural hazards	Lessons 1, 5, 6
• risks and benefits	Lessons 1, 5, 6
Standard G: As a result of their activities in grades 5–8, all students should develop an understanding of the history and nature of science.	**Correlation to module**
• Understand science as a human endeavor.	All lessons
• Understand the nature of science.	All lessons
• Understand the history of science.	Lesson 5

can encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.

Assessment Standards

Teachers can engage in ongoing assessment of their teaching and of student learning using the variety of assessment components embedded within the module's structure. The assessment tasks are authentic: They are similar in form to tasks in which students will engage in their lives outside the classroom or in which scientists participate. Annotations guide teachers to these opportunities for assessment and provide answers to questions that can help teachers analyze student feedback.

How Does the 5E Instructional Model Promote Active, Collaborative, Inquiry-Based Learning?

Because learning does not occur through a process of passive absorption, the lessons in this module promote active learning: Students are involved in more than listening and reading. They are developing skills, analyzing and evaluating evidence, experiencing and discussing, and talking to their peers about their own understandings. Students work collaboratively with others to solve problems and plan investigations. Many students find that they learn better when they work with others in a collaborative environment than they can when they work alone in a competitive environment. When all this active, collaborative learning is directed toward inquiry science, students succeed in making their own discoveries. They ask questions, observe, analyze, explain, draw conclusions, and ask new questions. These inquiry experiences include both those that involve students in direct experimentation and those in which students develop explanations through critical and logical thinking.

This view of students as active thinkers who construct their own understanding out of interactions with phenomena, the environment, and other individuals is based on the theory of **constructivism**. A constructivist view of learning recognizes that students need time to

- express their current thinking;
- interact with objects, organisms, substances, and equipment to develop a range of experiences on which to base their thinking;
- reflect on their thinking by writing and expressing themselves and comparing what they think with what others think; and
- make connections between their learning experiences and the real world.

This module provides a built-in structure for creating a constructivist classroom: The 5E Instructional Model. The model sequences the learning experiences so that students have the opportunity to construct their understanding of a concept over time. The model takes students through five phases of learning that are easily described using five words that begin with the letter "E": Engage, Explore, Explain, Elaborate, and Evaluate. The following paragraphs illustrate how the 5Es are implemented across the lessons in this module.

Engage

Students come to learning situations with prior knowledge. This knowledge may or may not be congruent with the concepts presented in this module. The Engage lesson provides the opportunity for teachers to find out what students already know or what they think they know about the topic and concepts to be developed.

The Engage lesson in this module, Lesson 1: *Chemicals, Chemicals, Everywhere*, is designed to

- pique students' curiosity and generate interest,
- determine students' current understanding of the concepts of chemicals and routes of exposure,
- invite students to raise their own questions about chemicals and human health,
- encourage students to compare their ideas with the ideas of others, and
- allow teachers to assess what students do or do not understand about the stated outcomes of the lesson.

Explore

In the Explore phase of the module, Lesson 2: *The Dose Make the Poison,* students explore the effect different doses of chemicals have on seed germination. This lesson provides a common set of experiences within which students can compare what they think about what they are observing and experiencing.

During the Explore lesson, students

- interact with materials and ideas during the seed investigation;
- consider different ways to solve a problem or answer a question;
- acquire a common set of experiences with their classmates so they can compare results and ideas;
- observe, describe, record, compare, and share their ideas and experiences; and
- express their developing understanding of the effects of chemicals on seed germination orally and by making graphs.

Explain

The Explain lesson provides opportunities for students to connect their previous experiences and to begin to make conceptual sense of the main ideas of the module. This stage also allows for the introduction of formal language, scientific terms, and content information that might make students' previous experiences easier to describe and explain.

In the Explain lessons in this module, Lesson 3: *Dose-Response Relationships* and Lesson 4: *Individual Responses Can Be Different*, students

- explain concepts and ideas about their seed investigations in their own words;
- listen to and compare others' explanations of their results with their own;
- become involved in student-to-student discourse in which they explain their thinking to others and debate their ideas;
- revise their ideas;
- record their ideas and current understanding;
- use labels, terminology, and formal language to describe dose-response relationships;
- compare their current thinking with what they previously thought; and
- compare their ideas with what scientists know and understand about toxicology testing and the application of the results to human systems.

Elaborate

In Elaborate lessons, students apply or extend the concepts in new situations and relate their previous experiences to new ones.

In the Elaborate lessons in this module, part of Lesson 4: *Individual Responses Can Be Different* and Lesson 5: *What Is the Risk?*, students

- make conceptual connections between new and former experiences, particularly with respect to the dose of medicine they take and the effect of the caffeine they drink;
- use what they have learned to explain the acetaminophen mystery and the tragedy that happened in Minamata, Japan;
- connect ideas, solve problems, and apply their understanding in these new situations;
- use scientific terms and descriptions;
- draw reasonable conclusions from evidence and data;
- add depth to their understanding of concepts and processes; and
- communicate their understanding to others.

Evaluate

The Evaluate lesson is the final stage of the instructional model, but it only provides a "snapshot" of what the students understand and how far they have come from where they began. In reality, the evaluation of students' conceptual understanding and ability to use skills begins with the Engage lesson and continues throughout each stage of the model, as described in the following section. Combined with the students' written work and performance of tasks throughout the module, however, the Evaluate lesson can serve as a summative assessment of what students know and can do.

The Evaluate lesson in this module, Lesson 6: *Environmental Hazards,* provides opportunities for students to

- demonstrate what they understand about the concepts of toxicology and how well they can

implement the skills of assessing risk and deciding on risk management;
- share their current thinking with others;
- apply their understanding and knowledge of the relationship between chemicals in the environment and human health in a unique, but related, situation;
- assess their own progress by comparing their current understanding with their prior knowledge; and
- ask new questions that take them deeper into a concept or topic area.

To review the relationship of the 5E Instructional Model to the concepts presented in the module, see Table 2.

When a teacher uses the 5E Instructional Model, he or she engages in practices that are very different from those of a traditional teacher. In response, students also participate in their learning in ways that are different from those seen in a traditional classroom. Tables 5 and 6 outline these differences.

What's the Evidence for the Effectiveness of the BSCS 5E Instructional Model?

Support from educational research studies for teaching science as inquiry is growing (for example, Geier et al., 2008; Hickey et al., 1999; Lynch et al., 2005; and Minner et al., 2009). A 2007 study, published in the *Journal of Research in Science Teaching* (Wilson et al., 2010), is also relevant here.

In 2007, with funding from NIH, BSCS conducted a randomized, controlled trial to assess the effectiveness of the BSCS 5Es. The study used an adaptation of the NIH supplement *Sleep, Sleep Disorders, and Biological Rhythms*, developed by BSCS in 2003. Sixty high school students and one teacher participated. The students were randomly assigned to the experimental or the control group. In the experimental group, the teacher used a version of the sleep supplement that was very closely aligned with the theoretical underpinnings of the BSCS 5Es. For the control group, the teacher used a set of lessons based on the science content of the sleep supplement but aligned with the most commonplace instructional strategies found in U.S. science classrooms (as documented by Weiss et al., 2003). Both groups had the same master teacher.

Students taught with the BSCS 5Es and an inquiry-based approach demonstrated significantly higher achievement for a range of important learning goals, especially when the results were adjusted for variance in pretest scores. The results were also consistent across time (both immediately after instruction and four weeks later). Improvements in student learning were particularly strong for measures of student reasoning and argumentation. The following chart (Table 4) highlights some of the study's key findings. The results of the experiment strongly support the effectiveness of teaching with the BSCS 5Es.

Evidence also suggests that the BSCS 5Es are effective in changing students' attitudes on important issues. In a research study conducted during the field test for the NIH curriculum supplement *The Science of Mental Illness* (2005), BSCS partnered with researchers at the University of Chicago and the National Institute of Mental Health. The study investigated whether a short-term educational experience would change students' attitudes about mental illness. The results showed that after completing the curriculum supplement, students stigmatized mental illness less than they had beforehand. The decrease in stigmatizing attitudes was statistically significant (Corrigan et al., 2007; Watson et al., 2004).

How Does the Module Support Ongoing Assessment?

Because teachers will use this module in a variety of ways and at a variety of points in their curriculum, the most appropriate mechanism for assessing student learning is one that occurs informally at various points within the six lessons, rather than something that happens more formally just once at the end of the module. Accordingly, integrated within the six lessons in the module are specific assessment components. These embedded assessment opportunities include one or more of the following strategies:

Table 4. Differences in performance of students receiving inquiry-based and commonplace instructional approaches.

Measure	Mean for Students Receiving Commonplace Teaching	Mean for Students Receiving Inquiry-Based Teaching	Effect Size
Total test score pretest (out of 74)	31.11	29.23	Not applicable
Total test score posttest	42.87	47.12	0.47
Reasoning pretest (fraction of responses at the highest level)	0.04	0.03	Not applicable
Reasoning posttest	0.14	0.27	0.68
Score for articulating a claim (out of 3)	1.58	1.84	0.58
Score for using evidence in an explanation (out of 3)	1.67	2.01	0.74
Score for using reasoning in an explanation (out of 3)	1.57	1.89	0.59

Source: Wilson, C.D., et al. 2010. The relative effects and equity of inquiry-based and commonplace science teaching on students' knowledge, reasoning, and argumentation. *Journal of Research in Science Teaching, 47*(3), 276–301.

Note: *Effect size is a convenient way of quantifying the amount of difference between two treatments. This study used the standardized mean difference (the difference in the means divided by the standard deviation, also known as Cohen's* d*). The posttest scores controlled for the variance in students' pretest scores. The reasoning posttest scores controlled for variance in students' reasoning pretest scores at the highest level.*

- performance-based activities (for example, developing graphs or participating in a discussion of risk assessment);
- oral presentations to the class (for example, presenting experimental results); and
- written assignments (for example, answering questions or writing about demonstrations).

These strategies allow the teacher to assess a variety of aspects of the learning process, such as students' prior knowledge and current understanding, problem-solving and critical-thinking skills, level of understanding of new information, communication skills, and ability to synthesize ideas and apply understanding to a new situation.

An assessment icon and an annotation that describes the aspect of learning teachers can assess appear in the margin beside the step in which each embedded assessment occurs.

How Can Teachers Promote Safety in the Science Classroom?

Even simple science demonstrations and investigations can be hazardous unless teachers and students know and follow safety precautions. Teachers are responsible for providing students with active instruction concerning their conduct and safety in the classroom: Posting rules in a classroom is not enough. They also need to provide adequate supervision and advance warning if there are dangers involved in the science investigation. By maintaining equipment in proper working order, teachers ensure a safe environment for students.

The following are important ways to implement and maintain a safety program.

- Provide eye protection for students, teachers, and visitors. Require that everyone participating wear regulation goggles in any

Table 5. The key components of the BSCS 5E Model: *What the teacher does.*

Phase	What the teacher does that is *consistent* with the 5E Model	What the teacher does that is *inconsistent* with the 5E Model
Engage	• Piques students' curiosity and generates interest • Determines students' current understanding (prior knowledge) of a concept or idea • Invites students to express what they think • Invites students to raise their own questions	• Introduces vocabulary • Explains concepts • Provides definitions and answers • Provides closure • Discourages students' ideas and questions
Explore	• Encourages student-to-student interaction • Observes and listens to the students as they interact • Asks probing questions to redirect the students' investigations when necessary • Asks questions to help students make sense of their experiences • Provides time for students to puzzle through problems	• Provides answers • Proceeds too rapidly for students to make sense of their experiences • Provides closure • Tells the students that they are wrong • Gives information and facts that solve the problem • Leads the students step-by-step to a solution
Explain	• Encourages students to use their common experiences and data from the Engage and Explore lessons to develop explanations • Asks questions that help students express understanding and explanations • Requests justification (evidence) for students'explanations • Provides time for students to compare their ideas with those of others and perhaps to revise their thinking • Introduces terminology and alternative explanations after students express their ideas	• Neglects to solicit students' explanations • Ignores data and information students gathered from previous lessons • Dismisses students' ideas • Accepts explanations that are not supported by evidence • Introduces unrelated concepts or skills
Elaborate	• Focuses students' attention on conceptual connections between new and former experiences • Encourages students to use what they have learned to explain a new event or idea • Reinforces students' use of scientific terms and descriptions previously introduced • Asks questions that help students draw reasonable conclusions from evidence and data	• Neglects to help students connect new and former experiences • Provides definitive answers • Tells the students that they are wrong • Leads students step-by-step to a solution
Evaluate	• Observes and records as students demonstrate their understanding of concept(s) and performance of skills • Provides time for students to compare their ideas with those of others and perhaps to revise their thinking • Interviews students as a means of assessing their developing understanding • Encourages students to assess their own progress	• Tests vocabulary words, terms, and isolated facts • Introduces new ideas or concepts • Creates ambiguity • Promotes open-ended discussion unrelated to the concept or skill

Table 6. The key components of the BSCS 5E Model: *What the students do.*

Phase	What the students do that is *consistent* with the 5E Model	What the students do that is *inconsistent* with the 5E Model
Engage	• Become interested in and curious about the concept/topic • Express current understanding of a concept or idea • Raise questions such as, What do I already know about this? What do I want to know about this? How could I find out?	• Ask for the "right" answer • Offer the "right" answer • Insist on answers or explanations • Seek closure
Explore	• "Mess around" with materials and ideas • Conduct investigations in which they observe, describe, and record data • Try different ways to solve a problem or answer a question • Acquire a common set of experiences so they can compare results and ideas • Compare their ideas with those of others	• Let others do the thinking and exploring (passive involvement) • Work quietly with little or no interaction with others (only appropriate when exploring ideas or feelings) • Stop with one solution • Demand or seek closure
Explain	• Explain concepts and ideas in their own words • Base their explanations on evidence acquired during previous investigations • Become involved in student-to-student conversations in which they debate their ideas • Record their ideas and current understanding • Reflect on and perhaps revise their ideas • Express their ideas using appropriate scientific language • Compare their ideas with what scientists know and understand	• Propose explanations from "thin air" with no relationship to previous experiences • Bring up irrelevant experiences and examples • Accept explanations without justification • Ignore or dismiss other plausible explanations • Propose explanations without evidence to support their ideas
Elaborate	• Make conceptual connections between new and former experiences • Use what they have learned to explain a new object, event, organism, or idea • Use scientific terms and descriptions • Draw reasonable conclusions from evidence and data • Communicate their understanding to others	• Ignore previous information or evidence • Draw conclusions from "thin air" • Use terminology inappropriately and without understanding
Evaluate	• Demonstrate what they understand about the concept(s) and how well they can implement a skill • Compare their current thinking with that of others and perhaps revise their ideas • Assess their own progress by comparing their current understanding with their prior knowledge • Ask new questions that take them deeper into a concept or topic area	• Disregard evidence or previously accepted explanations in drawing conclusions • Offer only yes-or-no answers or memorized definitions or explanations as answers • Fail to express satisfactory explanations in their own words • Introduce new, irrelevant topics

situation where there might be splashes, spills, or spattering. Teachers should always wear goggles in such situations.
- Know and follow the state and district safety rules and policies. Be sure to fully explain to the students the safety rules they should use in the classroom.
- At the beginning of the school year, establish consequences for students who behave in an unsafe manner. Make these consequences clear to students.
- Do not overlook any violation of a safety practice, no matter how minor. If a rule is broken, take steps to ensure that the infraction will not occur a second time.
- Set a good example by observing all safety practices. This includes wearing eye protection when it is required for students.
- Know and follow waste disposal regulations.
- Be aware of students who have allergies or other medical conditions that might limit their ability to participate in activities. Consult with the school nurse or school administrator.
- Anticipate potential problems. When planning teacher demonstrations or student investigations, identify potential hazards and safety concerns. Be aware of what might go wrong and what can be done to prevent the worst-case scenario. Before each activity, alert the students to the potential hazards verbally and distribute specific safety instructions as well.
- Supervise students at all times during a hands-on activity.
- Provide sufficient time for students to set up the equipment, perform the investigation, and properly clean up and store the materials after use.
- Never assume that students know or remember safety rules or practices from their previous science classes.

How Can Controversial Topics Be Handled in the Classroom?

Teachers sometimes feel that the discussion of values is inappropriate in the science classroom or that it detracts from the learning of "real" science. The lessons in this module, however, are based on the conviction that there is much to be gained by involving students in analyzing issues of science, technology, and society. Society expects all citizens to participate in the democratic process, and our educational system must provide opportunities for students to learn to deal with contentious issues with civility, objectivity, and fairness. Likewise, students need to learn that science intersects with life in many ways.

In this module, students have a variety of opportunities to discuss, interpret, and evaluate basic science and health issues in the light of values and ethics. As students encounter issues about which they feel strongly, some discussions might become controversial. How much controversy develops will depend on many factors, such as how similar the students are with respect to socioeconomic status, perspectives, value systems, and religious preferences. It will also depend on how you handle your role as facilitator. Your language and attitude factor into the flow of ideas and the quality of exchange among the students.

The following guidelines may help you think about how to guide your students in discussions that balance factual information with feelings.
- Remain neutral. Neutrality may be the single most important characteristic of a successful discussion facilitator.
- Encourage your students to discover as much information about the issue as possible.
- Keep the discussion relevant and moving forward by questioning or posing appropriate problems or hypothetical situations. Encourage everyone to contribute, but do not force reluctant students into the discussion.
- Emphasize that everyone must be open to hearing and considering diverse views.
- Use unbiased questioning to help students critically examine all views presented.
- Allow for the discussion of all feelings and opinions.
- Avoid seeking consensus on all issues. The multifaceted issues that the students discuss result in the presentation of divergent views, and students should learn that this is acceptable.
- Keep your own views out of the discussion. If your students ask what you think, you may

wish to respond with a statement such as, "My personal opinion is not important here. We want to consider your views."

- Acknowledge all contributions in the same evenhanded manner. If a student seems to be saying something for its shock value, see whether other students recognize the inappropriate comment and invite them to respond.
- Create a sense of freedom in the classroom. Remind students, however, that freedom implies the responsibility to exercise that freedom in ways that generate positive results for all.
- Insist on a nonhostile environment in the classroom. Help your students learn to respond to ideas instead of to the individuals presenting those ideas.
- Respect silence. Reflective discussions are often slow. If you break the silence, your students may allow you to dominate the discussion.
- Finally, at the end of the discussion, ask your students to summarize the points they and their classmates have made. Let students know that your respect for them does not depend on their opinion about any controversial issue.

Using the Student Lessons

The heart of this module is the set of six lessons, which we hope will carry important concepts related to human health and chemicals in the environment to your students. To review the concepts in detail, refer to Table 2 in "Implementing the Module" (page 4).

Format of the Lessons

As you scan the lessons, you will find that each contains several major features.

At a Glance gives you a convenient summary of the lesson.

- The **Overview** provides a short summary of what students do.
- **Major Concepts** states the central idea(s) the lesson is designed to convey.
- **Objectives** lists two to six specific understandings or abilities students should have after completing the lesson.

Background Information gives you the science content that underlies the key concepts of the lessons. The information provided here is *not* intended to form the basis of lectures to students. Instead, it is designed to enhance your understanding of the content so that you can more accurately facilitate class discussions, answer student questions, and provide additional examples.

Notes about the Lessons places each lesson in the context of the concepts presented in the *Background Information*. It provides a short commentary about the practical application of the concepts to the activities in the lesson.

In Advance provides instructions for collecting and preparing the materials required to complete the activities in the lesson.

- **Web-Based Activities** tells you which of the lesson's activities make use of segments on the Web site.
- **Photocopies or transparencies** lists the copies that need to be made from masters, which follow the student lessons.
- **Materials** lists all the materials needed for each of the activities in the lesson. A complete materials list for the entire module can be found on pages 18 and 19.
- **Preparation** outlines the things you need to do to be ready to teach each of the activities in the lesson.

Procedure outlines the steps for each activity in the lesson. It provides implementation suggestions and answers to questions. Lessons 1–5 each include an **Extension Activity** that describes ways to extend or enrich the lesson.

Within the procedures, annotations provide additional commentary.

- **Tip from the Field Test** includes actual field-test teachers' suggestions for teaching strategies, class management, and module implementation.
- **Assessment** provides strategies for assessing student progress throughout the module and is identified by an assessment icon (see below).
- **Icons** identify specific annotations:

NSES identifies teaching strategies that address specific science content standards as defined by the *National Science Education Standards*.

WWW identifies when to use the Web site as part of the teaching strategies. A print-based alternative (with "-p" after step numbers) is provided in each lesson for all Web-based activities in case access to the Web site is not available.

identifies when assessment is embedded in the module's structure. An annotation suggests strategies for assessment.

The **Masters** required to teach the lessons are in a separate section at the end of the module.

Timeline for Teaching the Module

There are several ways to complete the six lessons in this module. The first timeline (Table 7) outlines the optimal plan for completing the lessons. The plan assumes you will teach the activities on consecutive days. It is important that Activities 3 and 4 from Lesson 2 and Activity 1 from Lesson 3 follow each other on three consecutive days. If your class requires more time for laboratory procedures, discussion of issues raised in this module, or completing the Web-based activities, adjust your timeline accordingly.

Table 7. Suggested optimal timeline.

Timeline	Activity	Cross-Curricular Opportunities
3 weeks ahead	Reserve computers and bookmark the Web site.	None
1 week ahead	Copy masters. Make transparencies. Gather materials.	None
Day 1 Wednesday	**Lesson 1** Activity 1: What Is a Chemical? Activity 2: Protect the Toxicologist	None
Day 2 Thursday	Activity 3: Case Studies of Routes of Exposure	Language Arts
Day 3 Friday	**Lesson 2** Activity 1: Dose and Concentration Activity 2: Planning the Seed Investigation	Mathematics
Day 4 Monday	Activity 3: Setting Up the Seed Investigation	None
Day 5 Tuesday	Activity 4: Gathering Data	Mathematics
Day 6 Wednesday	**Lesson 3** Activity 1: Graphing the Response to Chemical Dose	Mathematics
Day 7 Thursday	**Lesson 4** Activity 1: Different Doses for Different People	None
Day 8 Friday	Activity 2: A Poisonous Dose?	Mathematics/Health
Day 9 Monday	Activity 3: The Chemical Caffeine: How Do You Respond?	Mathematics/Health
Day 10 Tuesday	**Lesson 5** Activity 1: People at Risk Activity 2: What Is *Your* Risk?	Social Studies Language Arts
Day 11 Wednesday	**Lesson 6** Activity 1: The Field Trip Activity 2: What Can I Do?	None

The second timeline (Table 8) outlines an abbreviated schedule for completing the lessons in the curriculum supplement by assigning some activities as homework, using the Web site in place of the laboratory experience, and deleting one activity.

Master List of Supplies

Table 9 is the master list of supplies for the supplement based on a class of 30 students.

Table 8. Abbreviated timeline.

Timeline	Activity
3 weeks ahead	Reserve computers and bookmark the Web site.
1 week ahead	Copy masters. Make transparencies. Gather materials.
Day 1 Wednesday	**Lesson 1** Activity 1: What Is a Chemical? Activity 2: Protect the Toxicologist Activity 3 (assigned as homework): Case Studies of Routes of Exposure
Day 2 Thursday	**Lesson 2** Activity 1: Dose and Concentration Activity 2: Planning the Seed Investigation
Day 3 Friday	Use the Web site to gather data for the seed investigation. **Lesson 3** Activity 1 (assigned as homework): Graphing the Response to Chemical Dose
Day 4 Monday	Discuss the homework and Web version of investigation
Day 5 Tuesday	**Lesson 4** Activity 1: Different Doses for Different People Activity 2: omit
Day 6 Wednesday	Activity 3: The Chemical Caffeine: How Do You Respond?
Day 7 Thursday	**Lesson 5** Activity 1: People at Risk Activity 2: What Is *Your* Risk?
Day 8 Friday	**Lesson 6** Activity 1: The Field Trip Activity 2: What Can I Do?

Table 9. Master list of supplies for *Chemicals, the Environment, and You*, based on a class of 30 students, by lesson (L) and activity number (E, extension activity).

Lesson (L)	L1 -1	L1 -2	L1 -3	L1 -E	L2 -1	L2 -2	L2 -3	L2 -4	L2 -E	L3 -1	L3 -E	L4 -1	L4 -2	L4 -3	L4 -E	L5 -1	L5 -2	L5 -E	L6 -1	L6 -2
Beaker (50-mL)		1					60					1								
Beaker (100-mL)							10					1								
Beaker (1000-mL) or large jars					3							4								
Caffeinated soft drink (12 oz.)														30						
Chemicals (variety)	✓					✓														
Clear containers (different sizes)										3										
Clock with second hand														✓						
Clothing (variety)		✓																		
Coin (only for print version)																			30	
Computer with Web access	✓	✓	✓				✓		✓				✓			✓			✓	
Current events stories				✓														✓		
Eyedropper					✓		10					✓								
Food coloring (blue)		✓																		
Graduated cylinder (50-mL)		✓					10													
Graduated cylinder (10-mL)							10													
Index cards (4 x 6)	✓																			
Jar with lid (50 mL or larger)		1																		

Lesson (L)	L1 -1	L1 -2	L1 -3	L1 -E	L2 -1	L2 -2	L2 -3	L2 -4	L2 -E	L3 -1	L3 -E	L4 -1	L4 -2	L4 -3	L4 -E	L5 -1	L5 -2	L5 -E	L6 -1	L6 -2
Latex gloves, pair					✓		30						✓			✓				
Masking tape							✓													
Overhead markers										✓		✓								
Overhead projector	✓		✓		✓					✓		✓	✓			✓	✓	✓		
Paper napkin (one-ply, 12 x $11^{5}/_{8}$ in.)							120													
Permanent marker							10													
Plain paper																✓	✓			
Plastic resealable sandwich bag						1	60													
Poster board, white					1															
Purified water		✓					✓													
Radish seeds						✓	600													
Red marker (only for print version)																			1	
Safety glasses					✓		30													
Science notebook	30		✓		✓	✓	✓	✓				✓								
Shoe box (large with cover)		1																		
Transparency										✓			✓			✓	✓			
Tray							10													

Using the Web Site

The Web component of *Chemicals, the Environment, and You* is a wonderful tool that you can use to help organize your use of the module, engage student interest in learning, and help orchestrate and individualize instruction. The site features simulations, animations, and videos that articulate with the lessons. To access the curriculum's home page, go to *http://science.education.nih.gov/supplements/chemicals*. (If your classes don't have access to the Internet, you can use the print alternatives included with the lessons.)

Hardware and Software Requirements

The Web site can be accessed with any computer browser. Adobe Flash Player should be installed on the hard drive of each computer that will access the site. It's freely available at *http://get.adobe.com/flashplayer/*.

Getting the Most out of the Web Site

The ideal use of the Web site requires one computer for each student group. However, if you have only one computer available, you can still use the site. You can, for example, project the monitor image for the whole class. If you do not have access to the Web site, you can use the print-based alternative provided for each Web activity.

Collaborative Groups

We designed many of the activities in this module to be completed by groups of students working together. Although individual students working alone can complete many of the specific steps, this strategy will not stimulate the types of student-student interactions that are one of the goals of active, collaborative, inquiry-based learning. Therefore, we recommend that you organize collaborative groups of between two and six students each, depending on the number of computers available. Students in groups larger than this will have difficulty organizing the student-computer interactions equitably, which can lead to one or two students' assuming the primary responsibility for the computer-based work. Although large groups can be efficient, they do not allow all students to experience the in-depth discovery and analysis that the Web site was designed to stimulate.

If you are teaching all six lessons as a unit, we recommend that you keep your students in the same collaborative groups for all of the activities. This will allow each group to develop a shared experience with the software and with the ideas and issues that the activities present. A shared experience also will enhance your students' perceptions of the lessons as a conceptual whole.

If your student-to-computer ratio is greater than six students to one computer, you will need to change the way you teach the module from the instructions in the lessons. For example, if you have only one computer available, you may want students to complete the Web-based work over an extended time period. You can do this in several ways. The most practical one is to use your computer as a center along with several other centers at which students complete other activities. In this approach, students rotate through the computer center, eventually completing the Web-based work you have assigned.

A second way to structure the lessons if you have only one computer available is to project the monitor image for the whole class to see. Giving selected students in the class the opportunity to manipulate the Web activities in response to suggestions and requests from the class can give students some of the same autonomy in their learning they would have gained from working in small groups.

Web Activities for People with Disabilities

The Office of Science Education provides access to the Curriculum Supplement Series for people with disabilities. The online versions of this series comply with Section 508 of the Rehabilitation Act. If you use assistive technology (such as a Braille or screen reader) and have trouble accessing any materials on our Web site, please let us know. We'll need a description of the problem, the format in which you would like to receive the material, the Web address of the requested material, and your contact information.

Contact us at
supplements@science.education.nih.gov
or
(301) 402-2469

Chemicals, Chemicals, Everywhere

At a Glance

Overview

Students divide substances into categories: made of chemicals/not made of chemicals, synthetic/naturally occurring, and toxic/nontoxic. When the teacher reveals that all the substances are made of chemicals, students discuss how their concept of what a chemical is might differ from the scientific definition. Students observe a mystery chemical and determine what precautions they might need to take when handling an unknown substance. Then, students read case studies of real exposures to chemicals.

Major Concepts

Everything in the environment is made of chemicals. Both naturally occurring and synthetic substances are chemical in nature. People are exposed to chemicals by eating or swallowing them, breathing them, or absorbing them through the skin or mucosa, and they can protect themselves from harmful chemicals by blocking these routes of exposure.

Objectives

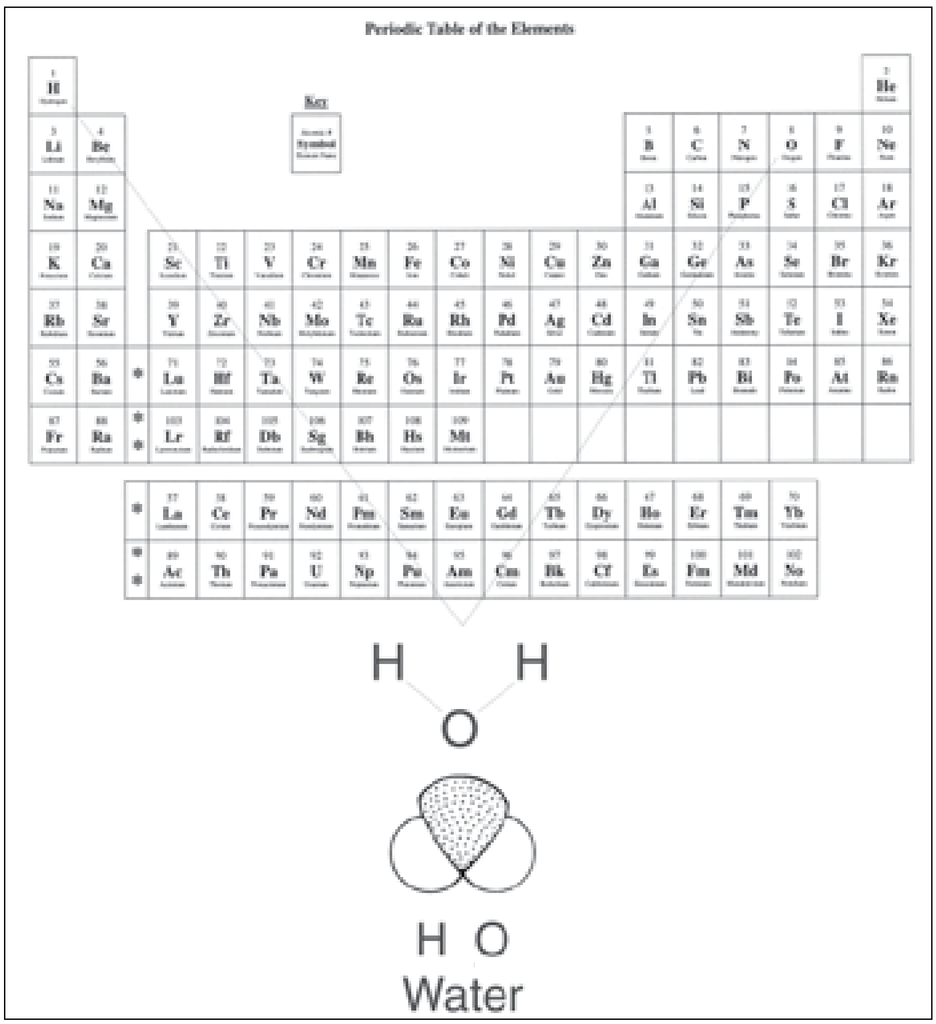
After completing this lesson, students will

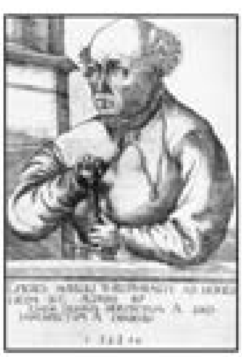
- understand that everything in their environment is made of chemicals;
- indicate that both naturally occurring and synthetic substances are chemical in nature;
- recognize that their view of a chemical as "bad" or "good" relates to their perception of a chemical's potential toxicity to humans or other living organisms;
- realize that toxicologists study chemicals to find out if they are harmful to living organisms;
- understand that people are exposed to chemicals by eating or swallowing them, breathing them, or absorbing them through the skin or mucosa; and
- demonstrate that people can protect themselves from harmful chemicals by blocking these routes of exposure.

Background Information

What Is a Chemical?

Simply stated, **a chemical is any substance that has a defined molecular composition.** Molecules, which are the smallest units into which a compound can be divided and still be that compound, can be made up of one or more elements. Sometimes, the elements are the same, such as in oxygen: Two oxygen atoms are chemically bonded together to form the gas oxygen, or O_2. Sometimes, the elements that form molecules are of different types, such as those in water: Two hydrogen atoms combine with one oxygen atom to form a molecule of water, or H_2O. All forms of matter are made of one or more of the more than 100 elements combined in many different molecular combinations. This means that all forms of matter are made of chemicals.





Paracelsus.

(Reproduced with the permission of the Albertina Wien (Vienna).)

The Science of Toxicology

Long ago, humans observed that some chemicals derived from nature were poisonous. Poisonous chemicals produced naturally by living organisms (such as plants, animals, and fungi) are called **toxins**. Historically, knowledge of toxins was a powerful tool to use against enemies: Many murderers in ancient Greece and later throughout Europe used toxins (Klassen, 2008). A significant contribution to the field of toxicology was made by the scientist Paracelsus (1493–1541). He recognized that the same chemical could have both therapeutic (medicinal) and toxic (poisonous) properties depending on how much of it was used. His work paved the way for the concept of the dose-response relationship (see Lesson 3 for more information about dose and response) (Klassen, 2008; Gilbert, 2004).

With the onset of the industrial revolution and the emergence of the science of synthetic chemistry, a variety of new chemicals was made by humans. It is estimated that more than 65,000 chemicals have been manufactured for commercial use in industrialized countries (Eaton and Gallagher, 1997). Whether on purpose or not, humans come into contact with these chemicals during manufacturing, handling, or consumption. Exposure to a vast array of synthetic chemicals can occur when a person ingests food or drink, works in an agricultural setting with pesticides, or lives in a home among solvents, paints, plastics, and fuels. Although many of the chemicals greatly benefit us, some can have a toxic effect on human systems. These substances are called **toxicants**, a broad category that includes naturally occurring toxins.

How do people know if a chemical is toxic? The science of **toxicology** informs them of the nature of poisons. A **toxicologist** is a scientist who is trained to study the harmful effects of chemicals on living organisms. These harmful effects can include death, but not all toxicants are lethal. Some other harmful effects that toxicologists study are disease, tissue damage, genetic alterations, and cancer. Because there are so many ways that toxicants can affect living things and there are so many different kinds of chemicals in the environment, toxicology is a very broad science and there are many different kinds of toxicologists (Klassen, 2008).

Routes of Exposure

Toxicants can harm an organism only if they are absorbed by the organism and reach the organs that are the target of their toxicity. This can happen through three routes:

- ingestion,
- inhalation, and
- absorption through the skin (Gilbert, 2004).

In humans and other animals, toxicants usually affect one or more target organs such as the lungs, skin, or gastrointestinal tract. For example, if a person inhales asbestos fibers, the fibers get stuck in the airways of the lungs and irritate the lung lining, causing lung impairment over time. Dermatitis can result if the asbestos fibers irritate skin cells.

Sometimes the toxicant crosses from the external environment of the lung, skin, or gastrointestinal tract into the bloodstream (Klassen, 2008). Many parts of the human body are designed to absorb chemicals quickly and effectively. The stomach, intestines, and colon absorb nutrients from our diet. These organs easily absorb nutrients and other chemicals because of

What Do Toxicologists Do?

Descriptive toxicologists evaluate the toxicity of drugs, food additives, and other products. They ask the question, What happens if …? about the amount of a toxicant and the response that a living system has to the toxicant. The descriptive toxicologist might work in a pharmaceutical laboratory or in an academic setting doing data analysis, animal testing, and/or human clinical trials (Society of Toxicology, 2012).

Mechanistic toxicologists study how a chemical causes toxic effects on living organisms. They study biomedical research, biochemistry, and physiology to understand how a chemical is absorbed, distributed, and excreted. In order to develop antidotes, a mechanistic toxicologist uses information about how a chemical harms an organism. This kind of toxicological work is often done in an academic setting or in private industry (Society of Toxicology, 2012).

Photo: Corel

Clinical toxicologists are usually physicians interested in the prevention, diagnosis, and treatment of poisoning cases. Clinical toxicologists specialize in toxicology issues concerning drugs used for treatment, such as side effects and overdoses; drugs of abuse, such as alcohol and cocaine; and accidental poisonings. These toxicologists have specialized training in emergency medicine and poison management. Veterinarians can be clinical toxicologists who study poisons in animals (Society of Toxicology, 2012)

Photo: Cameron Davidson

Forensic toxicologists study the application of toxicology to the law. They work with pathologists and law enforcement officers at a crime scene. The forensic toxicologist uses chemical analysis to help establish the cause of death and determine the circumstances of death in a postmortem investigation (Klassen, 2008)

Environmental toxicologists study the effects of pollutants on organisms, populations, ecosystems, and the biosphere. Toxicologists concerned with the effects of environmental pollutants on human health fit into this group. Most commonly, however, environmental toxicologists study the impacts of chemicals on nonhuman organisms such as fish, birds, terrestrial animals, and plants (Klassen, 2008).

Regulatory toxicologists use scientific data to decide how to protect humans and animals from excessive risk. Regulatory toxicologists aim to protect the public from chemical exposure by establishing regulatory standards for food, drugs, water, air, and insecticides, to name only a few. Government bureaus such as the U.S. Food and Drug Administration (FDA) and the U.S. Environmental Protection Agency (EPA) employ regulatory toxicologists (Klassen, 2008; Society of Toxicology, 2012).

their large surface area, thin diffusion distance, and high blood flow. The lungs are also designed for rapid absorption. Chemicals that are inhaled are quickly absorbed into the bloodstream through the thin walls of the air sacs in the lungs. The skin protects the body from harmful agents in the environment. However, the skin is in direct contact with the environment. While the dense outer layer of skin cells is a good barrier to chemical absorption, it is not perfect, even when intact. When the skin is cut or abraded, it absorbs chemicals very rapidly (Project Greenskate, 2000).

Students' Misconceptions about Chemicals

Students often harbor misconceptions about chemicals. When asked what a chemical is, rather than define the word, students tend to give examples of synthetic, toxic chemicals like pesticides. When asked to name some things made of chemicals, students list items such as shampoo, window cleaner, processed foods, and "fake sugar" (aspartame). Students believe that chemicals pollute rivers and air. Students often do not realize that natural substances in the world around them also are made of chemicals. When asked if it would be better if there were fewer chemicals in the world, one student replied that fewer human-made chemicals would mean less pollution. When pressed, students will agree that some synthetic chemicals, like a pain reliever, can be good; however, students also recognize that even "good" chemicals like pain relievers can be toxic if a person takes too much.

Notes about Lesson 1

The purpose of this lesson is to help move students from the view that chemicals are toxic, synthetic substances that are bad for human health and the environment to the more inclusive view that all things in the environment, including their bodies, are made of chemicals. Some of both naturally occurring and synthetic chemicals can have a detrimental effect on human health and the environment, but many do not. Those that have a harmful effect on human health do so because they get into the body through inhalation, ingestion, and absorption.

In Advance

Web-Based Activities

Activities 1, 2, and 3 have Web components.

Materials and Preparation

Photocopies and Transparencies	Equipment and Materials
1 copy of Master 1.1 **for the class** 1 transparency of Master 1.2 (optional) 1 transparency of Masters 1.3 and 1.4 1 copy of Master 1.5, Case Study #1, **for each student**; for number of copies of Case Studies #2–5, see *Preparation* for Activity 3	• computers, overhead projector • 12 samples of things made of chemicals • 1 set of item cards from Master 1.1 • 8 4-by-6-inch index cards • blue food coloring • 50-mL graduated cylinder • 50 mL of purified water • 50-mL or larger glass jar with a lid • 1 large shoe box with a lid • variety of clothing in a large basket or box • science notebook **for each student**

Notes: *Because everything in the environment is made of chemicals, any item will work for the 12 samples. Use the chemicals students test in Lesson 2, Activity 3, plus others that do and do not fit students' concept of chemicals. The Master 1.1 item cards depict objects that are too big for the materials table or are potentially dangerous. The jar should fit into the shoebox. The clothing could include, for example, elbow pads, shorts, different kinds of hats, boots, sunglasses, earplugs, mittens, and latex gloves.*

Preparation

Activity 1

Arrange for students to have access to computers.

Collect samples of things made of chemicals. Place them on a materials table.

Tip from the field test: To make gathering the materials easier, ask students to bring in one item they think is made of chemicals and one they think is not made of chemicals.

Duplicate and cut out the Item Cards from Master 1.1, *Item Cards*. Fold them in half to make tent cards. Place the Item Cards on the materials table with the things made of chemicals.

Fold the index cards in half to make tent cards and label them with one of the following titles:

- made of chemicals

- not made of chemicals
- synthetic
- naturally occurring
- toxic
- nontoxic
- good
- bad

Make a transparency of Master 1.2, *Periodic Table of Elements* (optional). Make a transparency of Master 1.3, *Elemental Composition of the Human Body*.

Activity 2

Arrange for students to have access to computers.

Make 50 mL of a mystery chemical:
- Measure 5 mL of blue food coloring into a 50-mL graduated cylinder.
- Add purified water to the graduated cylinder until you have 50 mL of blue solution.
- Pour the mystery chemical into a 50-mL or larger glass jar and screw on the lid tightly. Place it inside the shoe box. Place the shoe box behind your desk.
- Ask students to bring in articles of clothing. Place them and any you have gathered in a basket or box behind your desk.

Activity 3

Arrange for students to have access to computers.

Make a transparency of Master 1.4, *Questions for Case Studies*. Duplicate Case Study #1 from the Master 1.5, *Case Studies of Routes of Exposure*, 1 for each student. Decide whether each student or teams will complete Case Studies #2–5 and duplicate the appropriate number.

Procedure

ACTIVITY 1: What Is a Chemical?

1. **Place the samples of things made of chemicals and the Item Cards on the materials table.**

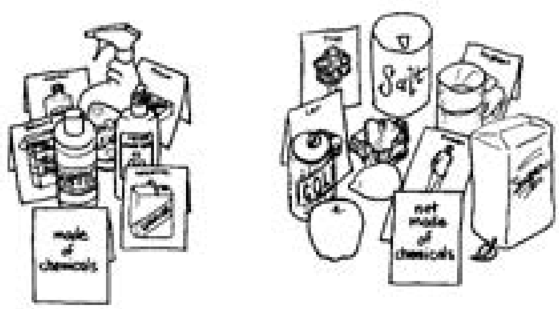
2. **Ask the students to look at the materials table and select one thing that they think is made of chemicals and one thing they think is not made of chemicals. Direct students not to remove the items, but to record the name of the items in their science notebooks.**

Tip from the field test: In large classes where it might be difficult for students to see the materials, prepare a list of the names of all the materials and make a copy for each student. Instruct students to circle those materials on the list that are made of chemicals.

You might find that students want more information. They might want to know what you mean by "made of chemicals." They might want you to be more specific about whether they should consider only synthetic items or those that may be toxic. Acknowledge that you have given them limited information, but ask them to do their best to make their choices. Do not provide any assistance at this time.

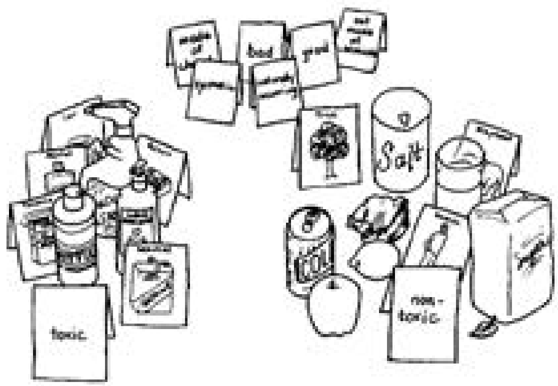
This activity provides you with a good assessment of students' prior knowledge of the concept of chemicals.

3. **Once all the students have recorded the items in their notebooks (or circled the items on their list), ask each student to name one item that is made of chemicals and one that is not. As students tell you their choices, stand by the materials table and separate the items according to student choices into two categories: made of chemicals and not made of chemicals. Continue until all students have shared their ideas. Use two of the tent cards to label the two categories: "made of chemicals" and "not made of chemicals."**



4. **Direct students to look at the groups of substances they think are and aren't made of chemicals. Conduct a discussion by asking questions similar to these:**
   - Why do you think these are (or are not) chemicals?
   - Can you redivide these items into several different categories, such as synthetic (made by people) or naturally occurring? Good for humans or the environment or bad for humans or the environment? Toxic (harmful) or nontoxic (not harmful)?
   - Can a natural substance be made of chemicals?
   - Can a synthetic substance not be made of chemicals?
   - Is a natural substance always nontoxic, or a synthetic substance always toxic?

As you conduct this discussion, rearrange the items on the table several times and use new tent cards to label the new categories: “synthetic” or “naturally occurring”; “toxic” or “nontoxic”; and “bad” or “good.”



5. **As you progress through the discussion in Step 4, students may realize that they do not know a useful definition for “chemical.” Have this definition ready for them:**

   chemical: any substance that is made of specific elements combined into molecules

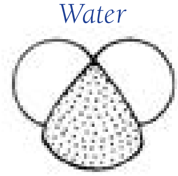
Content Standard B:
…There are more than 100 known elements that combine in a multitude of ways to produce com-pounds, which account for the living and nonliving substances we encounter.

6. **As a class, view the segment on the Web site titled *Everything Is Made of Chemicals.***

> To view the segment, go to *http://science.education.nih.gov/supplements/chemicals/student*. Click on *Chemicals, Chemicals, Everywhere* and select the segment titled *Everything Is Made of Chemicals.*

Note: If you do not have access to the Web site, set up a computer center where students can view the segment on their own or in small groups at a later time. At this time, display the transparency of Master 1.2, *Periodic Table of Elements*, and discuss the following:

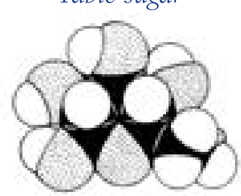
Water



- Ask students to consider one substance, water, in light of the definition. Is water made of elements combined into molecules?

  Students are familiar with the molecular composition of water: H_2O. Point out the elements hydrogen and oxygen on the periodic table.

Table sugar



- Help students recognize that sugar and salt also are made of a combination of elements that form molecules.

  Table sugar is a crystalline carbohydrate, $C_{12}H_{22}O_{11}$. Salt is sodium chloride, NaCl.

7. **After viewing the Web site segment or discussing the periodic table, continue by helping students recognize that all of the substances on the materials table are made up of specific molecules, even if the students don't know exactly what they are. Once they recognize this, students will begin to realize that all things are made of chemicals. Ask students to tell you, based on their new understanding, some other things around them that are made of chemicals. Let students continue until you see that they understand that everything around them, or everything in their environment, is made of chemicals.**

8. **To make sure that the students understand that they, too, are made of chemicals, display a transparency of Master 1.3, *Elemental Composition of the Human Body.* Let your students know that these elements are combined in many different ways to form thousands of different chemicals that make up the human body.**

9. **Discuss with students how their original idea about what a chemical is, which led them to their choices in Step 2, is different from the scientific definition of a chemical. Why do they think this is so?**

   Students will recognize that they hear most about the chemicals that are toxic to humans or the environment. Because of this, students often think of chemicals as only those synthetic substances that are introduced to the environment and cause harm. Help students recognize that they also know a lot about synthetic chemicals that are beneficial to humans, such as pain relievers and other medicines. They also know about naturally occurring chemicals that are toxic to humans, such as hydrogen sulfide (sewer gas) and carbon monoxide, to name two. By the end of the discussion, help students recognize that chemicals can be synthetic or naturally occurring and make up every substance on Earth, even our bodies.

   Bridge to Activity 2 by helping students understand that many chemicals, both synthetic and naturally occurring, can be beneficial to humans and the environment. Those chemicals that are not beneficial are the ones we want to know more about so that we can protect ourselves and the environment from harm.

ACTIVITY 2: Protect the Toxicologist

1. **Bring out the shoe box from behind your desk. Tell the students that inside the shoe box is a mystery chemical. Discuss with the students some things they might want to know about the contents of the shoe box before they open it. Ask why it would be important to know these things.**

   Be sure that students recognize that they would want to know what the chemical is (for example, name; naturally occurring or synthetic; solid, liquid, or gas; how much of the chemical is in the container). Most importantly, they would want to know if it is toxic to the humans in the classroom because they would not want to accidentally expose themselves to a harmful substance.

2. **Tell the students that they are asking a lot of the same questions that a toxicologist might ask. Write the word *toxicologist* on the board. Ask students to identify the root of the word *toxic*. Underline it on the board. Tell students that toxicologists are scientists who are specially trained to examine the nature of the harmful effects of chemicals on living organisms. They try to understand which chemicals are toxic to living organisms and in what amounts those chemicals are toxic. While they want to know which chemicals might cause death, they also are interested in other toxic effects, such as disease, tissue damage, genetic alterations, and cancer.**

Content Standard G: Students should develop an understanding of science as a human endeavor.

3. **Select a student (or ask for a volunteer) and tell the student that he or she is a toxicologist. Tell students that you want the student toxicologist to open the shoe box and look at the mystery chemical, but you do not know anything about the chemical. The student toxicologist needs to protect himself or herself in case the chemical is harmful to humans.**

   Present to the class the large basket or box of clothing. Ask the class to work together to think of items that the toxicologist should wear for protection from exposure to the chemical. Find items in the basket as students suggest them and give the items to the student toxicologist to put on until he or she is dressed in a protective manner that satisfies the class.

Tip from the field test: You may not have access to a wide variety of true protective gear. Use regular clothing, but ask students what problems there might be with certain items. For example, if students suggest that the toxicologist's hands need to be covered, you could pull out a pair of mittens. Direct the toxicologist to put on the mittens, but ask the class if the mittens are the best choice and why or why not.

This activity is engaging and fun for the students, but it also helps you assess students' knowledge of an important concept of toxicology: routes of exposure.

   As students select an item, question why a toxicologist needs to wear it. Probe for understanding that a toxicologist is concerned about exposure to a chemical by eating or drinking it, by breathing it, and by absorbing it through the skin. Look to see whether the student toxicologist's skin, eyes, mouth, and nose are covered.

4. **Once the student toxicologist is dressed protectively, explain that real toxicologists know that chemicals can enter the body in three ways, called routes of exposure: through the mouth by ingestion, through the nose and mouth by inhalation, and through the skin by absorption. Write the list of the three routes of exposure on the board:**

Routes of Exposure
✓ ingestion
✓ inhalation
✓ absorption through the skin

Use the list as a checklist and ask students if they think the student toxicologist is adequately protected from all routes of exposure. If not, have them adjust the protective clothing or suggest useful clothing that is not in the basket.

Point out that the mystery chemical could be a solid, a liquid, or a gas. Discuss each form of a chemical and how the form can help determine which routes of exposure are most likely. For example, a gas might be easily inhaled as soon as the container is opened, while a solid might only be harmful if a person touches it or ingests it. In addition, chemicals can change form. For example, dry ice is solid carbon dioxide that quickly becomes a gas. Liquid mercury can evaporate into a gas, causing exposure by inhalation.

Thank the student toxicologist and ask him or her to return the protective clothing to the basket.

5. **Tell students that people who work around toxic chemicals protect themselves in ways similar to those the students suggested for the student toxicologist. Provide time for students to view the segment *Ride Along with HAZMAT* on the Web site.**

To find the segment, go to *http://science.education.nih.gov/supplements/chemicals/student* and choose Lesson 1, then *Ride Along with HAZMAT.*

Photo: Corel

6. **Tell the students that you will dress protectively and remove the mystery chemical from the container when they are not in the room (because they are not protected). Let them know that they will be able to examine the chemical during the next class if you decide it is safe to do so.**

ACTIVITY 3: Case Studies of Routes of Exposure

1. **Set up the class so that each team of students has access to a computer, such as in a computer lab. Instruct teams to do the activity titled *What's Wrong Here*? on the Web site. Circulate around the room and listen as groups work through each situation.**

> To view the activity, go to *http://science.education.nih.gov/supplements/chemicals/student* and choose Lesson 1, then *What's Wrong Here?*

2. **Tell students that now they will consider some true chemical exposures. Display a transparency of Master 1.4, *Questions for Case Studies*. Then, distribute a copy of Case Study #1 from Master 1.5, *Case Studies of Routes of Exposure*, to each student.**

3. **Ask students to work in teams and to read Case Study #1. Instruct them to answer the questions on the transparency in their science notebooks.**

4. **Once teams have read and answered the questions about Case Study #1, conduct a class discussion about the case study by answering the questions on the transparency.**

   Sample Answers to Questions for **Case Study #1** on Master 1.4

   Question 1. What happened? Where did it happen? When did it happen?

   A Dartmouth College scientist died of mercury poisoning in 1997 in New Hampshire after being exposed to the chemical in 1996.

   Question 2. What chemical was involved?

   The chemical was dimethylmercury (die-METH-ul-MER-kyoo-ree).

   Question 3. What was the route of exposure?

   The route of exposure was absorption through the skin.

   Question 4. What were the symptoms of toxicity?

   The symptoms of toxicity were permanent nervous system damage, numbness of fingers, unsteady walking, difficulty speaking, blurred vision, hearing problems, coma, and death.

   Question 5. How could a person have prevented his or her exposure to the chemical?

   Answers will vary. The researcher used precautions thought to be adequate at the time.

NSES

Content Standard E: Students should develop understandings about science and technology.
Content Standard F: Students should develop understanding of natural hazards, and risks and benefits.
Content Standard G: Students should develop understanding of science as a human endeavor.

Question 6. Have any changes occurred since the incident? Describe them.

Researchers now know that dimethylmercury can seep through latex gloves. They now use neoprene gloves with long cuffs or wear two pairs of gloves, one of them laminated and one of them heavy duty.

5. **There are four more case studies, two describing chemical exposure through inhalation and two describing chemical exposure through ingestion. Continue to have students read, discuss, and answer the questions about each case study.**

This is a good time to assess your students' understanding of the three ways chemicals can enter the human body and cause harm: ingestion, inhalation, and absorption.

Tip from the field test: Give a different study to each team and ask the teams to read their study. Then, instruct teams to present their case study to the class. Teams can explain their case study and answer the questions from the transparency so that everyone in the class learns about the case and discusses the route of chemical exposure. The case studies vary in length, allowing you to individualize the reading assignment for students of varying reading abilities.

Sample Answers to Questions for Case Studies #2–5 on Master 1.4:

Case Study #2

Question 1. What happened? Where did it happen? When did it happen?

Gas leaked from a chemical plant in 1984 in India.

Question 2. What chemical was involved?

The chemical involved was methylisocyanate (METH-ul-EI-soh-SIE-uh-nate).

Question 3. What was the route of exposure?

The routes of exposure were inhalation and absorption through the eyes and the nose.

Question 4. What were the symptoms of toxicity?

The symptoms of toxicity were eyes and lungs burning, vomiting, lung impairment, loss of motor control, neurological disorders, and damaged immune system.

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Question 5. How could a person have prevented his or her exposure to the chemical?

Answers will vary. Students should recognize that people who lived in Bhopal had little choice over their exposure. People could have made the choice not to live near a chemical plant.

Question 6. Have any changes occurred since the incident? Describe them.

The chemical plant was sold to a company in Calcutta. Proceeds from the sale supported hospitals and clinics in Bhopal.

Case Study #3

Question 1. What happened? Where did it happen? When did it happen?

Jane had lead poisoning; it happened in her home during her first two years of life.

Question 2. What chemical was involved?

The chemical involved was lead.

Question 3. What was the route of exposure?

The route of exposure was ingestion.

Question 4. What were the symptoms of toxicity?

The symptoms of toxicity were abdominal pain, constipation, vomiting, and lethargy; in severe cases, learning disabilities, decreased growth, hyperactivity, impaired hearing, and even brain damage can occur.

Question 5. How could a person have prevented his or her exposure to the chemical?

Prevention for children includes annual blood tests to check lead levels; clean play areas, floors, windowsills, and hands; professional paint removal; and drinking milk.

Question 6. Have any changes occurred since the incident? Describe them.

Students can assume that Jane's mother acted on the doctor's suggestions for minimizing the family's exposure to lead.

Case Study #4

Question 1. What happened? Where did it happen? When did it happen?

Jimmy Green died from sniffing gasoline in the spring of 1999.

Question 2. What chemical was involved?

The chemical was gasoline.

Question 3. What was the route of exposure?

The route of exposure was inhalation.

Question 4. What were the symptoms of toxicity?

The symptoms of toxicity were short-term memory loss, hearing loss, arm and leg spasms, permanent brain damage, liver and kidney damage, and death.

Question 5. How could this person have prevented his or her exposure to the chemical?

Jimmy Green voluntarily exposed himself to gasoline fumes. He could have prevented his exposure by choosing not to sniff gasoline.

Question 6. Have any changes occurred since the incident? Describe them.

Parents and students are now informed of the dangers of inhalants.

Case Study #5

Question 1. What happened? Where did it happen? When did it happen?

In 1971, more than 6,500 people were poisoned in Iraq.

Question 2. What chemical was involved?

The chemical was methylmercury (METH-ul-MER-kyoo-ree).

Question 3. What was the route of exposure?

The route of exposure was ingestion.

Question 4. What were the symptoms of toxicity?

The symptoms of toxicity were nervous system disorders.

Question 5. How could a person have prevented his or her exposure to the chemical?

If people had been better informed, they would have planted the seed instead of eating it.

Question 6. Have any changes occurred since the incident? Describe them.

No changes were mentioned in the case study, but students might discuss the need for better warning labels and instructions for grain shipped between countries.

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Extension Activity

Ask students to find current event stories in newspapers, magazines, or television programs that talk about chemical exposure. Challenge students to find one event that involves a chemical exposure that harms humans or other living things and one that involves a chemical exposure that benefits humans or other living things.

You will be able to use a chemical exposure described in these articles in the extension activity in Lesson 5.

Tip from the field test: If students in your school are required to bring in current event articles for several other classes, coordinate with teachers making similar assignments so that students are not duplicating efforts. Alternatively, collect articles yourself and display them in the classroom.

The Dose Makes the Poison

At a Glance

Overview

Students observe beakers of water that contain different amounts of a mystery chemical. They discuss how each amount of the chemical might affect them if the chemical was beneficial or harmful to their bodies. Then, students set up investigations to test the effects of different doses of chemicals on seed germination and collect data for two consecutive days. Their investigations model the kinds of investigations toxicologists do to determine dose-response relationships in living systems.

Major Concepts

The total amount of chemical administered to, or taken by, an organism is called a dose, and the effect a chemical has on a living organism is called the response. The effect a chemical has on a living organism is related to its dose and the resultant concentration of chemical in the organism. Toxicity tests enable toxicologists to learn about responses of living organisms to doses of chemicals.

Objectives

After completing this lesson, students will

- recognize that the total amount of a chemical administered to, or taken by, the organism is called a dose,
- understand that the effect a chemical has on a living organism is called the response,
- recognize that the effect a chemical has on a living organism is related to its dose and the resultant concentration of chemical in the organism, and
- demonstrate how toxicity tests enable toxicologists to learn about responses of living organisms to doses of chemicals.

Background Information

Dose, Concentration, and Threshold

The beneficial and harmful effects that a chemical has on an organism depend, in part, on the amount of the chemical that gets into the organism. The total amount of a chemical that is administered to, or taken by, the organism is called the **dose**. The effect of a chemical depends not only on the amount of the chemical that gets into the organism but also on the resulting **concentration** of the chemical in the body (the amount of chemical compared with the body size), the length of exposure to the chemical, and the route of exposure.

The measure of dose in toxicology is important; a large dose of a beneficial chemical can have a harmful effect, and a small dose of a harmful chemical can have no adverse effect. In the words of the 16th-century physician Paracelsus, "All substances are poisons; there is none which is not a poison. The right dose differentiates a poison from a remedy" (Klassen, 2008).

Approximate Lethal Doses of Common Chemicals (calculated for a 160-lb. human from data on rats)

Chemical	Lethal Dose
Sugar (sucrose)	3 quarts
Alcohol (ethyl alcohol)	3 quarts
Salt (sodium chloride)	1 quart
Herbicide (2,4-D)	1/2 cup
Arsenic (arsenic acid)	1–2 teaspoons
Nicotine	1/2 teaspoon
Food poison (botulism)	microscopic

Source: Marczewski, A.E., and Kamrin, M. *Toxicology for the citizen.* Retrieved August 17, 2000, from *http://www.iet.msu.edu/Tox_for_Public/citizen.htm.*

- A chemical is considered toxic if it produces adverse effects in a living organism at levels of exposure that are likely to occur. These adverse effects can range from slight symptoms, such as headache, nausea, or rashes, to severe symptoms, such as coma, convulsions, and death. Toxicologists recognize that for most types of toxic responses to a chemical, there exists a dose **threshold** below which no toxicity is evident. As the dose increases, more severe toxic responses occur.

Toxicity Testing

How does a toxicologist know when a chemical is toxic to humans? When available, toxicologists study data from human populations that have been exposed to specific chemicals. The data usually come from studies of workplace exposure or incidents such as the Union Carbide chemical plant accident in India. In this way, toxicologists further their understanding of the effects of chemicals on humans. In the absence of human data, toxicologists test the toxicity of different doses of chemicals on cell and tissue cultures, plants, and other animals, such as rats and mice. These studies guide toxicologists in their understanding of which chemicals might be harmful to humans and in what amounts.

The use of animals in toxicology research is not taken lightly. Following is the Society of Toxicology's Animals in Research Policy Statement on the Society of Toxicology's Web site (*http://www.toxicology.org*):

- Research involving laboratory animals is necessary to ensure and enhance human and animal health and protection of the environment.
- In the absence of human data, research with experimental animals is the most reliable means of detecting important toxic properties of chemical substances and for estimating risks to human and environmental health.
- Research animals must be used in a responsible manner.
- Scientifically valid research designed to reduce, refine, or replace the need for laboratory animals is encouraged.

Toxicologists know that the kinds of questions they want to answer cannot always be answered by observing and describing humans exposed to chemicals. They need to devise experiments that involve a system that resembles the human system. By studying a model of the human system, rats or mice, for example, toxicologists hope to apply the knowledge they gain to understanding the harmful effects of chemicals on humans. Although the basic tenet of toxicological studies is that "experimental results in animals, when properly qualified, are applicable to humans," toxicologists recognize that different species can respond to doses of toxic substances differently (Klassen, 2008). For example, on the basis of dose per unit of body surface, toxic effects in humans are usually about the same as for experimental animals; on a body-weight basis, though, humans are about 10 times more vulnerable than small experimental animals, such as mice (Klassen, 2008).

Because of both practicality and ethics, scientists who use animals in research carefully select the species and design experiments to achieve scientifically valid results. They obey strict regulations about the use of animals in experiments (Society of Toxicology, 2012). Typically in these experiments, toxicologists expose experimental animals to high doses of toxic agents so that they minimize the number of animals they use. This experimental design assumes that the results of tests at high doses on a small number of animals can be extrapolated to estimate the risk of low doses to a large population of humans.

Toxicity testing is not designed to demonstrate that a chemical is safe for humans, but is used to identify the types of toxic effects a chemical can produce. One early test performed on a chemical is the Ames test, named after Bruce Ames of the University of California–Berkeley. In this test, specially engineered bacteria are exposed to a chemical. If the bacteria mutate, the chemical reacted with DNA and is a potential mutagen or carcinogen. Scientists use the Ames test to economically weed out mutagenic chemicals because it avoids testing on higher animals.

Often, scientists use cell cultures in toxicology testing. Scientists expose isolated cells to a chemical and observe the response. If the cells die during the experiment, the chemical may be too toxic for use by humans. As with the Ames test, tests on cell cultures help scientists narrow the list of chemicals they need to test further on animals by eliminating those that are clearly too toxic.

If these preliminary tests suggest a chemical might be used safely with humans, scientists consider testing with animals. One of the first animal tests that scientists perform on a new chemical determines its acute toxicity. Toxicologists determine what dose of the chemical, under the intended route of exposure, causes 50 percent of the animals (mice or rats) to die (lethal dose, or LD_{50}). Toxicologists also determine the effective concentration at which 50 percent of the animals exhibit a measurable response (EC_{50}).

Scientists perform subacute toxicity tests to learn about the toxicity of a chemical after repeated doses. To test a chemical that is likely to enter the body through ingestion, scientists add doses of a chemical (high, low, and intermediate) to the feed for the experimental animals, usually rats or mice. Each animal receives a specified dose over the course of 90 days. Scientists observe the animals once or twice daily for signs of toxicity, including changes in body weight, diet consumption, changes in fur color or texture, respiratory or cardiovascular distress, motor and behavioral abnormalities, or palpable masses. They record premature death and collect blood and tissue samples from all animals for further study. If the chemical is likely to pose a risk to humans through skin contact or inhalation, scientists perform tests that incorporate those routes of exposure. They conduct long-term or chronic exposure studies in a similar manner, but the exposure time is increased to a time period that can range from six months to two years.

Efforts are under way by at least two groups to reduce the use of animals in some kinds of toxicity testing (NIEHS, 2012 and 2009). For example, researchers have developed a collagen matrix barrier that serves as a kind of artificial skin. If a chemical or chemical mixture penetrates the artificial skin, it is likely to irritate, corrode, or burn human skin.

For example, in the illustration on page 45, the drawing shows how a chemical is tested using the collagen matrix barrier. A sample of the test chemical is dropped onto the matrix. If no chemical penetrates the matrix, the solution in the bottle below the matrix remains clear. If the chemical penetrates the matrix, it will cause a color change in the solution in the bottle below. The photo on the right shows the indicator solution changing color after the test chemical has penetrated the matrix. This method, using artificial skin, can replace the current practice of using three animals to test every new chemical. Because more than 2,000 chemicals are introduced each year and many are tested before they are introduced on the market, this replacement means a significant reduction in the number of experimental animals used in toxicity testing (NIEHS, 2012).

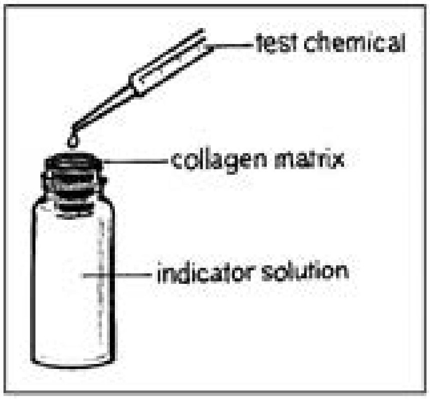


Photo: Courtesy InVitro International

Researchers are also developing techniques that are more accurate than the traditional methods. In the past, when researchers wanted to know if a blood pressure medicine was working in an animal, they inserted a catheter into an artery in the animal's leg. The animal then needed to be restrained so that scientists could take readings over a four- to five-hour period. Today, a sensor implanted in the animal's abdominal cavity allows researchers to continually measure results while the animal can move freely and remain with its family. Its heart rate is more relaxed and normal, so the results do not mirror the compounding effect of stress.

The rate at which new technology is being used to help researchers reduce their reliance on laboratory animals is accelerating. People who are concerned about animal welfare are working with researchers to encourage better experimental design and more humane techniques. Together, they are working to replace laboratory animals with scientifically valid alternatives, reduce their numbers, and refine techniques to minimize pain and suffering.

Even as progress is made in the name of animal welfare, however, conflicting pressures arise from the public's interest in knowing more about the health and safety data on major industrial chemicals. For example, in October 1998, Vice President Al Gore announced his plan to collect data on 2,800 high-production-volume chemicals. Animal rights groups recognized that such testing would require the destruction of more than 1 million animals. For a year, to minimize the number of animals and avoid needless testing, animal welfare activists lobbied to halt or modify the plan. One year later, the U.S. Environmental Protection Agency (EPA) made new recommendations for high-production-volume chemical testing that should reduce animal use. They now will consider previous results from chemical safety databases to ensure that testing is not redundant and will postpone the testing of some chemicals in the hope that nonanimal tests will become available.

Notes about Lesson 2

In this lesson, students perform toxicity tests on seeds, paying careful attention to the dose and concentration of chemicals. Students might not be aware that plants differ from animals in many ways: They have no nervous system or efficient circulatory system, and they have a photosynthetic mechanism and cell walls that animals do not. Therefore, the students' results from toxicity tests on seeds cannot be extrapolated to suggest a chemical's risk or safety to humans without further testing on animal systems, which is inappropriate for the classroom. However, students can understand the importance of using model systems in science when human subjects cannot be used because of the potential risk. Students can understand that many questions in science suggest a variety of investigation methods and that their use of models in scientific inquiry can help them establish relationships based on evidence from their own observations.

In Advance

Web-Based Activities

Activities 2 and 4 have optional Web components.

Materials and Preparation

Photocopies and Transparencies
1 transparency of Master 2.1 1 copy of Master 2.2 **for each team** 1 copy of Master 2.3 **for each student** (print version only)

Note: *If you want students to calculate percent concentration on their own, in Master 2.2, mask the numbers in the concentration column before copying.*

Materials

Activity 1

For the class:

- overhead projector
- shoe box from Lesson 1
- 1 small jar containing the mystery chemical from Lesson 1
- 1 eyedropper
- 1 pair of safety glasses
- 1 pair of latex gloves
- 3 1,000-mL beakers or 3 large jars of the same size, each containing 500 mL of water
- 1 piece of white poster board to use as a backdrop for the demonstration
- 1 resealable plastic sandwich bag containing radish seeds
- 1 beaker containing 250 mL of water (optional)

For each student:

- science notebook

Activity 2

For the class:

- computer
- chemicals from Lesson 1
- mystery chemical from Lesson 1
- 1 resealable plastic sandwich bag containing radish seeds

For each student:

- science notebook

Activity 3

For each team of 3 students (print version):

- 3 pairs of safety glasses
- 3 pairs of latex gloves
- 1 100-mL beaker filled with 50 mL of a chemical; see *Preparation* for Activity 3
- 1 permanent marker
- length of masking tape
- 6 50-mL beakers
- 1 50-mL graduated cylinder
- 1 10-mL graduated cylinder
- 100 mL of purified water in a beaker
- 1 eyedropper
- 6 resealable plastic sandwich bags
- 12 paper napkins
- 60 radish seeds in a resealable plastic sandwich bag
- 1 tray

For each student:

- science notebook

Activity 4

For each team of 3 students:

- bags of seeds treated with chemicals from Activity 3 (print version only)
- 1 copy of Master 2.3 from Activity 3 (print version only)
- Web version of data for Day 2 (optional; see *Preparation* for Activity 4)

For each student:

- science notebook

Extension Activity

For the class:

- computers with Web access
- materials for designing a bulletin board display

Notes on Materials:

1. The **mystery chemical** is the solution of blue food coloring and water used in Lesson 1.

2. Check that no students are allergic to **latex**. If any are, assign their team a chemical that you know will not irritate the skin, such as sugar water or cola. The team members with the latex allergy then can work safely without gloves. Alternatively, they can use vinyl gloves, if available.

3. Instead of **50-mL beakers**, you could use 6 clean baby food jars or 6 test tubes set up in a rack made out of a shoe box.

4. For the **paper napkins**, use regular, white, one-ply napkins (12 x 11 5/8 inches, unfolded) that you can buy in bulk at the grocery store. If you use something different, test your setup to make sure that the napkins or paper towels you use can absorb 20 mL of liquid in a plastic bag.

Preparation

Activity 1

Pour 500 mL of water into each of the 3 1,000-mL beakers. Label the beakers #1, #2, and #3.

Put a handful of radish seeds in a resealable plastic sandwich bag. Gather the materials you need for the demonstration.

Make a transparency of Master 2.1, *Opening Questions*.

Activity 2

Gather the materials you will need for this activity.

Copy Master 2.2, *Making Solutions for Toxicity Testing*, 1 copy for each team. Set up a computer center at which students can view the *Chemicals* Web site.

Activity 3

Decide whether you will use the print or Web version of the laboratory investigation. It is tempting to avoid the preparation and materials that a laboratory investigation requires, but students benefit from conducting a scientific investigation, using tools to gather data, and developing a hands-on understanding of the use of models in scientific inquiry. The simulation presented on the Web site enables teachers and students without access to laboratory equipment to gather data to use in Lesson 3, but it should not replace actual laboratory experience. In addition, Lesson 2's laboratory investigation provides students with an opportunity to meet Content Standard A of the *National Science Education Standards*: All students should develop abilities necessary to do scientific inquiry and understandings about scientific inquiry (NRC, 1996).

For the print version (preferred) of the laboratory investigation:

Prepare the chemicals, 1 chemical for each team of 3 students:

1-p. Choose a wide variety of chemicals for testing:

- water-soluble plant food
- liquid detergent
- soft drink
- instant coffee
- nontoxic environmental cleaner
- tempera paints
- all-purpose disinfectant cleaner (Lysol)
- artificial sweetener
- shampoo
- window cleaner
- salt
- sugar
- fruit and vegetable rinse

Tip from the field test: During the field test, the following chemicals yielded data that made the most interesting dose-response curves for students to graph in Lesson 3: salt, Miracle Gro, fruit punch soft drinks, window cleaner, and Lysol. The results from other chemicals were also of interest to students, so be sure to include a wide variety of familiar chemicals, such as shampoo, soft drinks, coffee, and sweetener, even if their dose-response curves are less exciting. One of the reasons to use a variety of chemicals is to demonstrate the range of responses that are possible.

2-p. Measure 50 mL of each liquid chemical into a 100-mL beaker. Label the beaker with the name of the chemical (for example, window cleaner).

3-p. Make solutions of nonliquid chemicals by mixing them with water. Then, measure 50 mL of each liquid solution into a 100-mL beaker. Label the beaker with the name of the chemical.

When available, follow directions on the container to make solutions of nonliquid chemicals, such as plant food or instant coffee. When no directions are available, make as saturated a solution as possible: Heat the water and slowly stir in a small amount of the chemical until it no longer dissolves easily in the water. In pilot testing this activity, we made a sugar solution with 40 g of sugar in 100 mL of water and a salt solution with 24 g of salt in 100 mL of water. Be sure to make enough solution for all your classes.

4-p. Place each chemical on a tray, 1 tray and chemical per team.

Purchase radish seeds. Put 60 radish seeds into a resealable plastic sandwich bag. Continue until you have a bag for each team of 3 students.

Radish seeds found in a local garden store work well for this investigation. They will germinate in 1 to 3 days. If you prefer faster germination (6–24 hours), you can purchase Wisconsin Fast Plants™, Brassica rapa *seeds (which are close relatives of the radish) from Carolina Biological Supply. Be aware that the* Brassica rapa *seeds are quite a bit smaller than radish seeds, so consider your students' dexterity when deciding which seeds to use.*

Tip from the field test: Counting the 60 seeds can be time consuming. Estimate the number of seeds by measuring approximately ¼ teaspoon of regular radish seeds (less if you use *Brassica rapa* seeds) for each bag. There will be a little more than 60 seeds in each bag. Students tend to lose a few as they set up the investigation, so it doesn't hurt to have a few extra seeds in the bag or on hand at the materials table.

Activity 4

If your students conducted the Web version of Activity 3, arrange for them to have access to computers for this activity.

Extension Activity

Arrange for students to have access to the Web. Gather materials needed to design a bulletin board display or ask students to provide them.

Procedure

ACTIVITY 1: Dose and Concentration

1. **Place the shoe box with the mystery chemical from Lesson 1 in it and the three beakers of water on a table in the front of the room.**

2. **Display a transparency of Master 2.1, *Opening Questions*.**

3. **Allow the students a few minutes to puzzle through the questions on the transparency. Assure them that it is perfectly acceptable not to know the answers to all the questions right now. Remind students that toxicologists study chemicals and perform toxicity tests because they don't know the answers to questions like these about every chemical.**

4. **Once students have answered the opening questions, draw their attention to the shoe box that holds the mystery chemical from Lesson 1. Announce to the students that a toxicologist partially analyzed the mystery chemical and informed you that the chemical**

would not enter your body through inhalation or contact with the skin, so it is safe to handle the chemical as long as you don't ingest it.

5. **Demonstrate appropriate laboratory safety measures by putting on safety glasses and a pair of latex gloves. Open the shoe box and remove the jar of mystery chemical.**

6. **Direct students' attention to the three large beakers of water. Let students know that each beaker holds exactly the same amount of water as the other two. As the students watch, use the eyedropper to add**
   - 1 drop of mystery chemical into Beaker #1,
   - 4 drops into Beaker #2, and
   - 16 drops into Beaker #3.

   Gently swirl or stir each beaker until the drops of mystery chemical are totally distributed in the water. Use the white poster board as a backdrop and ask students to tell you what they can observe.

   Students will observe that the water in the three beakers has turned a shade of blue. In Beaker #1, the color of the water is a very pale blue. In Beaker #2, the water is a darker blue. In Beaker #3, the water is the deepest blue.

7. **Suggest that the beakers of water represent human bodies. Ask students to tell you what they know about the relative sizes of the three "bodies." Once they recognize that all the bodies are the same size, discuss the added chemicals using questions such as these:**

   - **If we found out that the mystery chemical is harmful to people, which of these beakers would you rather be right now and why?**

   Students probably will say that they would rather be Beaker #1 because it contains the smallest amount of the harmful chemical.

   - **Are you sure that the amount of chemical in Beaker #2 is enough to cause harm? Is there enough in Beaker #3 to cause harm?**

   Students may realize that they do not know how much of the chemical must be present to cause harm, but they would want to err on the safe side and choose Beaker #1. Some students may wonder if even the small amount in Beaker #1 is harmful.

   - **What if we learned that the chemical is good for you? Which beaker would you choose to be and why?**

   Students probably will choose Beaker #3 because it has more of the beneficial chemical in it. Some students may recognize that they don't know enough about the chemical to know how much of it is good for a person. They may wonder if it is possible for too much of even a good chemical to be harmful.

- **Some chemicals are good for you in small doses but bad for you in large doses. If that were the case here, which beaker would you want to be?**

Some students may opt for Beaker #1 because the amount of chemical is small. Others may choose the middle road, Beaker #2, so that there is enough of the chemical to be beneficial but not enough to do harm. Others may say that they cannot choose because they do not know enough about the amount of chemical that is beneficial or the amount of chemical that is harmful.

8. **Point out to students that the questions they have about how much of a chemical is harmful and how much is beneficial are the same kinds of questions that toxicologists study. Help students understand some basic vocabulary of toxicology by asking them these questions and writing the terms on the board.**

- **When toxicologists look at the total amount of chemical that is given to, or taken by, an organism, they talk about dose. In which beaker did the body receive the largest dose of chemical?**

Beaker #3 received the largest dose: 16 drops of the chemical.

- **Toxicologists study the concentration of a chemical in an organism by comparing the dose of chemical to the size of the organism. In which of these three beakers is the concentration of chemical highest?**

Beaker #3 has the highest concentration of all the beakers because it has the largest dose of chemical compared with the constant volume of water. For the same-size person, ingesting more of a chemical results in a higher concentration of the chemical in that person's body. It follows that if several people of various sizes take the same amount of a chemical, the final concentration to which each person is exposed can vary, depending on the size of the person.

To help clarify the difference between dose and concentration, you can use a fourth beaker. This time, fill it with only 250 mL of water, half the amount of the other three beakers. Ask students to describe to you the relative size of this new "body" compared with the other beakers. Tell students that you are going to give this new body the same dose as you gave Beaker #2: 4 drops. Add that dose to the beaker. Ask students to observe the color and compare the concentration of chemical in the fourth beaker with the concentrations in the other three beakers. Is this concentration more or less than the others? Students should see that the water in the fourth beaker does not look like the water in Beaker #2, even though the dose was the same. The color is deeper, showing that the concentration of chemical in the smaller body is greater for the same dose than it is in the larger body.

9. **Ask students to come up with ways to find out if the mystery chemical at different doses (1, 4, and 16 drops) is harmful or beneficial to living things.**

   Students might suggest that someone could drink the three solutions of chemical and see what happens. If you ask for volunteers, however, you probably will not get any; you can discuss with students why this method may provide information but would not be a responsible way to test the toxicity of a particular dose of chemical. Ask students to think of other living things that they could use for testing. Use the *Background Information* in this lesson to discuss how animals are used in research. Be sure to discuss the Society of Toxicology's policies and guidelines for animals in research (2012).

10. **Help students recognize that they are not equipped to safely and ethically handle toxicology tests on animals. Tell them that there are many animal welfare laws, regulations, guidelines, and policies that govern the use of animals in research. Let students know that there are other living organisms that they can use for testing the mystery chemical in the classroom. Hold up a bag of seeds and ask students to tell you if they think the seeds are living organisms.**

Photo courtesy of American Association for Laboratory Animal Science

Seeds are living organisms that grow into plants. As living organisms, plants respond to chemicals in their environment, particularly in water. Plants are not the same as humans or other animals in structure, however, so results from tests that determine toxicity to plants might not be applicable to humans. Students will discuss this problem with the model system of plants when they analyze their data in Lesson 3.

11. **Tell the students that they are going to perform toxicology tests on seeds, but first they need to formulate a question and design an investigation.**

ACTIVITY 2: Planning the Seed Investigation

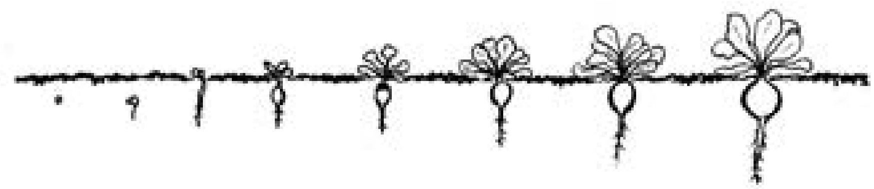
1. **Put on your desk some of the chemicals from Lesson 1. Show the students the mystery chemical. Show the students the seeds in the bag. Ask the students what they want to know about the chemicals and the seeds.**

   Conduct this discussion as a brainstorming session, perhaps writing on the board all of the questions the students formulate. Help the students arrive at a general question, such as this one:
   - What effect does the chemical have on the seeds?

2. **Ask the students to refine their question by considering what they learned in the beaker demonstration about dose.**

   The students' question should address both effect and dose. If students do not provide such a question on their own, suggest one like this:
   - What effect does the chemical have on seeds, and how is the effect different if the seeds receive different doses of the chemical?

3. **Refresh students' memories about the function of seeds in the life cycle of a plant. In doing so, discuss with students what they would expect a seed to do if it is exposed to moisture.**



Seeds have three parts: the protective outer seed coat, the embryo that becomes the new plant, and the endosperm that provides the food to nourish the embryo. Most students have looked at the germination of a bean seed in elementary school. Remind them that before a seed germinates, it absorbs moisture and it swells and bursts its seed coat. At this time, the embryo starts to grow and the root tip, or radicle, pushes through the eye of the seed. This "sprouting" is the first evidence of growth that students can observe with the naked eye. Several days later, seed leaves emerge and the embryonic stem begins to extend upward. At this time, chlorophyll pigment is visible. If planted in favorable conditions with the right moisture, temperature, and light, the plant will develop leaves, lengthen its stem, flower, produce fruit, and develop mature seeds. Once the seeds dry, the cycle is complete and the seeds are ready to produce new plants.

4. **Ask students to further refine their question from Step 2 based on the discussion of what seeds do under normal conditions.**

Guide students to a question like this one:

- How does the chemical affect the germination of the seeds, and how is the effect different if the seeds receive different doses of the chemical?

5. **Distribute copies of Master 2.2, *Making Solutions for Toxicity Testing.* Ask students to interpret the information presented in the handout by asking questions similar to these:**

- **In which beaker is the *dose* of chemical going to be the highest?**
- **In which beaker is the *concentration* of chemical going to be the highest?**

In both cases, the highest dose and highest concentration is in Beaker #6. Beaker #6 contains the greatest volume of chemical. Because the total amount of solution remains the same in each beaker, the highest concentration will be in the beaker that has the largest amount of chemical in it, Beaker #6.

- **How do you calculate the percent concentration of chemical in the solution?**

The percent concentration refers to the amount of chemical compared with the total volume in the beaker. For example, students put 2.50 mL of chemical and 17.50 mL of water in Beaker #3. The total amount of liquid in the beaker is 20 mL. Therefore, the amount of chemical divided by the total amount of liquid is

$$\frac{2.50 \text{ mL of chemical}}{20.00 \text{ mL of liquid}} = 0.125, \text{ or } 12.5\% \text{ concentration}$$

If you choose to do so, have students calculate the percent concentration for each beaker.

Tip from the field test: Some students may need a review of the conversion of decimals into percentages.

- **Why do you think you need a beaker that is just water (0% concentration)?**

Remind students that they need to have a control for their experiment. In this way, students can see what happens to seeds under normal conditions and compare that with what they observe in the seeds treated with various concentrations of chemicals.

- **Suppose you expose seeds to the different concentrations of chemical suggested in the chart on this worksheet. What predictions can you make about how they will respond?**

Give students time to make some general predictions about what they think could happen to seeds exposed to high, medium, and low concentrations of different chemicals. Students will have a chance to write specific predictions about their own chemical once it is assigned or chosen, so make this discussion brief.

6. **Instruct teams to put their copies of Master 2.2 in their science notebooks so that they can use them during the next class period.**

7. **Make the Web site available at a computer center for students who want more practice determining concentrations of chemicals.**

   Go to the Web site and choose Lesson 2 (*http://science.education.nih.gov/supplements/chemicals/student*). This brings up the page on which students can manipulate chemical concentrations. Instruct the students not to click *Do Experiment* at this time.

NSES

Content Standard A:
Students use mathematics in all aspects of scientific inquiry.

ACTIVITY 3: Setting Up the Seed Investigation

The following procedures describe how to conduct a hands-on laboratory investigation, which is the preferred method of instruction for this activity.

Important note to teachers: Activity 3 requires at least three consecutive school days (without interruption by a weekend or holiday). Usually, that means you need to start no later than the Wednesday of a full week of school.

For those classes not equipped to conduct a laboratory investigation, the Web site includes a simulation of the results students can expect from the Dose-Response Seed Germination Experiment using three different chemicals. Go to *http://science.education.nih.gov/supplements/chemicals/student* and choose *The Dose Makes the Poison: Dose-Response Relationships*. This brings up the page on which students can manipulate chemical concentrations. Click on *Do Experiment* to access the simulation of the experiment. After completing that, continue with Activity 4, Step 3.

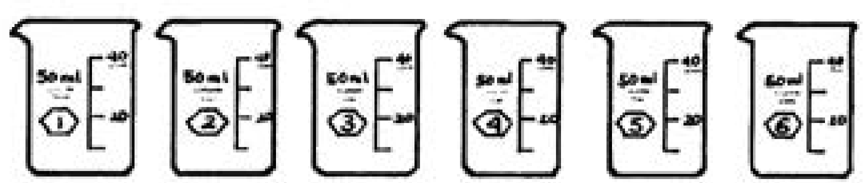
Print Version

1-p. Direct students' attention to the beakers of chemicals you prepared. Distribute chemicals on the trays, one chemical to each team.

Prepare at least one chemical per team and perhaps more if you want to give teams a variety of choices for testing. Alternatively, you can assign chemicals to teams. Ask one team to test the mystery chemical, or you can test it for the class.

2-p. Ask teams to get out their copy of Master 2.2, *Making Solutions for Toxicity Testing*, from the previous class period. Ask students, How are you going to label your beakers of solutions so that you know what is in each one?

Answers will vary, but impress upon students that it is important to keep accurate records in toxicology testing. At a minimum, students should number the beakers 1 to 6 to correspond with the beaker numbers on the chart on Master 2.2.



3-p. Direct students to gather their materials, put on their gloves and safety glasses, and follow the chart on Master 2.2 to make their solutions.

If necessary, review proper measuring techniques for fluids in a graduated cylinder before the students attempt to make their solutions. Make sure they know how to measure at eye level so that they can see when the meniscus is right on the line that demarcates the target volume. Demonstrate to students how they can use the eyedropper to add or subtract small amounts of volume.

Tip from the field test: If students have not measured liquid volume before, they might need to practice before completing this step of the activity. Refer to measurements from Master 2.2, *Making Solutions for Toxicity Testing,* and, using clear and colored water, set up a practice lab for inexperienced students.

4-p. **Once teams have completed their solutions and have six small beakers of chemical solutions on their work tables, ask students to discuss how they might test the toxicity of these solutions on seeds.**

This discussion can be brief, but it helps students design their own investigation rather than simply following directions without giving a thought to their purpose. Students will recognize that they want to put the seeds in contact with the chemical solutions in some way. Many will remember seed germination activities from previous years and will suggest moist paper towels in petri dishes or plastic bags. Show students the assembly they will use in this investigation.

NSES

Content Standard A: Students design and conduct a scientific investigation.

Ask students how they will know if a chemical was toxic to seeds.

Ask students what they predict should happen to healthy seeds in a nontoxic environment (the seeds will germinate). Help students recognize that they will want to look at nongermination as an indicator of toxicity in their investigation.

Ask students how they will know it was the chemical or a particular dose of the chemical that caused the observed effect and not some other factor.

Take this opportunity to discuss experimental design:

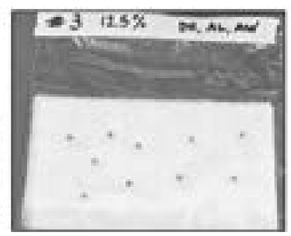
- Emphasize careful measuring and cleanliness (making sure not to contaminate the beakers or graduated cylinders with solutions of chemicals that are different from the intended solution).
- Discuss the experimental control. Remind students that a control is a group of experimental subjects that are not exposed to the chemical being investigated so they can be used as a comparison against tested subjects. The control will be the seeds they do not expose to any chemical other than water (the 0% chemical solution in Bag #1). They will compare the germination of seeds in this control with the germination of the seeds in Bags #2–6. Then they will determine whether the addition of the chemical affects the germination of seeds.
- Discuss the importance of controlling variables. Ask students to think of some variables they will want to control. Some possibilities might be
    - number of seeds tested for each solution
    - volume of chemical solution put on each group of seeds

When students return to class with their work-sheets complete, review their answers to assess their understanding of the investigation and underlying toxicological principles. Do they know the primary route of exposure of a human to their chemical? Can they describe how concentration is determined in a beaker? Are they able to make a reasonable prediction about the outcome of the investigation based on an understanding of dose, concentration, and response?

- amount of light
- temperature
- kinds of containers in which the seeds are placed
- number of paper napkins used for each group of seeds
- type of water source

5-p. Distribute copies of Master 2.3, *Toxicity Testing on Seeds*, one to each student. Direct teams to work together to set up the investigation.

Tip from the field test: During the field test, some students and teachers tried to short-cut the solution preparation and set-up steps by adding water and then chemical directly to the bag in which they already had placed the paper napkins and seeds. This resulted in an unequal distribution of chemical; some areas on the napkins had a high concentration of chemical and others had a low concentration. In addition, the seeds flowed to the bottom of the bag and got lost under the layers of napkin. The seeds should be added to the bag only after the napkins are saturated with completely mixed solutions of chemicals. Encourage your students to work carefully and methodically through the preparation of the chemical solutions (see Step 3-p above) and then the preparation of the seed bags as outlined on Master 2.3, *Toxicity Testing on Seeds*.



6-p. Provide space for the trays of seeds from each team. Tell the students that they will check on their seeds during the next class.

Tip from the field test: Storing multiple sets of seeds for multiple science classes can be a challenge. Remember that germinating seeds do not need light, so the seed bags for each team can be stacked. One field-test teacher gave each team a dissecting tray and told the teams to stack their seed bags in the tray. She then stacked the trays for each class. In this way, she was able to fit the ongoing investigations for four science classes on one shelf in her classroom.

7-p. Students might need to complete the rest of the work on Master 2.3 at home. Remind students to construct a data table in their science notebooks (or to put the data table from Master 2.3 in their notebooks). Ask them to fill out Day 1 on the data table with observations of their seeds at the start. Instruct them to answer the questions at the end of the worksheet.

ACTIVITY 4: Gathering Data

1-p. As students come into the room, ask them to get their team's seed investigation from Activity 3 and bring it to their team's table.

2-p. Ask students to observe their seeds and share with the class what is happening with their seeds.

Ask students to make observations that are *qualitative* (descriptive) and *quantitative* (measurable). An example of a qualitative observation might be that the seeds seem to be "puffed up" and are turning the paper napkin yellow underneath them. An example of a quantitative observation might be that 6 out of the 10 seeds in Bag #2 have germinated.

3. Direct the students to the question that guided the seed investigation:

- **How does the chemical affect the germination of the seeds, and how is the effect different if the seeds receive different doses of the chemical?**

Note to teachers: The term *dose* is used rather loosely here because it is difficult to know how much chemical penetrates each seed. It is reasonable to assume, however, that seeds exposed to a higher concentration of chemical receive a higher dose. Getting students accustomed to thinking about the term *dose* will prepare them for activities later in the unit.

Help students see that they can begin to answer this question based on their observations by asking them the following questions:

- **How do you know that a chemical is having an effect?**

You can look at the control and see what a population of seeds does under normal conditions and compare control seeds with seeds exposed to the chemical.

NSES

Content Standard A:
Students use appropriate tools and techniques to gather, analyze, and interpret data.

NSES

Content Standard A:
Students develop descriptions, explanations, predictions, and models using evidence.

> **Tip from the field test:** Begin to talk about the seeds in each bag as a "population" of individuals. This reference will help students understand how to translate their data into a dose-response curve in Lesson 3.

- **What is happening to the population of seeds in the control?**

Seeds are germinating.

- **What is happening to the populations of seeds in the other five bags? Is the same thing happening in all the bags to which chemicals were added?**

Answers will vary: Some seeds might be germinating, some might not. Students might notice differences in seed germination between the seeds in the bag with the lowest dose of chemical and those in the bag with the highest dose of chemical.

- **What is the reaction that your populations of seeds have to your chemical? This reaction is called the response.**

Answers will vary, but students should begin to describe what is happening with their populations of seeds in terms of a **response**. The response to the chemical might be that seeds do not germinate as quickly as they do in the control bag. Students might be able to see that more seeds are responding to the chemical (not germinating) in the bags with the highest dose of chemical.

- **Why might the whole population in each bag (all 10 seeds) not respond in the same way?**

By asking this question, you will help students begin to think about **individual susceptibility**, a concept students will explore further in Lesson 3. Just as there are individual differences among people, there are individual differences among seeds that affect how each seed responds to the chemical. In addition, students can begin to critique their experimental procedure and decide if they think they had enough liquid in each bag, spaced the seeds evenly, or in some way influenced the results through experimental error.

- **How do you measure the response your populations of seeds has to the chemical?**

Since the seeds' response to the chemical is a variation in germination, the measurement would be to count the number of seeds in each bag that germinated and those that did not germinate. By focusing students on measurable observations rather than only qualitative ones, you will make it easier for students to graph the results of their investigation in Lesson 3.

4-p. Instruct students to fill in Day 2 of their data table on Master 2.3, which they placed in their science notebooks (see Activity 3, Step 7-p). Remind students that they will observe the seeds again on the next day to see if there are further changes.

5-p. Direct students to place their trays of seeds in the same spot as the day before.

Extension Activity

The hazard of chemicals in the environment is one that is often exaggerated.

Because we are exposed to many chemicals, both naturally occurring and synthetically produced, it makes sense to understand when to worry and when not to worry. The problem arises when people do not know the dose of a chemical required to cause an adverse effect. In many cases, people assume that any exposure to a chemical that can cause harm is harmful.

To illustrate the flaw in this reasoning, the American Council on Science and Health publishes a Holiday Dinner Menu each year. In this menu, scientists from the council analyze the foods we eat at Thanksgiving to determine our exposure to natural chemicals known to cause adverse effects in rats. For example, people consume natural chemicals such as ethyl benzene in their coffee, hydrogen peroxide in their tomatoes, and furan in their sweet potatoes. How are humans not being poisoned by their own food supply?

1. **Invite students to log on to the American Council on Science and Health Web site to learn more about the importance of dose with respect to the dangers of chemicals in our food source: *www.acsh.org/publications/booklets/menu98.html*.**

2. **Ask those students who choose to explore this extension to share their findings with the class.**

3. **Encourage students to design a bulletin board that illustrates how much of a food containing a harmful chemical a human would have to consume to get a toxic dose of the chemical. Such calculations are presented on the council's Web site. Past years' examples have included the amount of turkey a person would have to eat to get a toxic dose of malonaldehyde and the amount of bread a person would have to eat to get a toxic dose of furfural. The calculations for the bread example are shown in the box on the next page.**

Calculating a toxic dose of furfural

The bread in Thanksgiving stuffing contains furfural, a chemical that can cause cancer in rats when they are fed high doses of it. But, before you start to worry about your Thanksgiving dinner, take into account the difference in body weight between a human and a rodent. How much bread would *you* have to eat to consume an amount of furfural equal to the amount that increased the risk of cancer in rodents?

Here are the facts:

- One slice of white bread contains 167 micrograms of furfural.
- The carcinogenic dose of furfural for a rodent is 197 milligrams per kilogram of body weight per day, fed every day of its life. (This is the same as 197,000 micrograms/kilogram/day because there are 1,000 micrograms in a milligram.)
- The weight in kilograms of a middle school student who weighs 110 pounds is 50 kilograms because there are 2.2 pounds in every kilogram.

Here is the solution:

$$\frac{197{,}000 \text{ micrograms}}{1 \text{ kilogram}} \times \frac{50 \text{ kilograms}}{\text{person}} = 9{,}850{,}000 \text{ micrograms per day, a carcinogenic dose for an average middle school student}$$

$$\frac{9{,}850{,}000 \text{ micrograms}}{167 \text{ micrograms/slice}} = 58{,}982 \text{ slices of bread}$$

What does this mean?

The average middle school student would have to eat 58,982 slices of bread a day to get a carcinogenic dose of furfural, assuming he or she responded the same way experimental animals do. When looking at this example, remember the conditions of animal studies: Doses are fed every day of the rodent's life (usually two years). To get an equivalent carcinogenic dose, a human would have to consume those 58,982 slices every day for years.

LESSON 3
Explain

Dose-Response Relationships

At a Glance

Overview

Students complete their observations of the germinating seeds on the third consecutive day. They express their data on a graph and develop a dose-response curve for their chemical. Students then compare the data from their investigation of a chemical with those of other teams and other chemicals. Students learn to analyze dose-response curves to determine threshold and potency.

Major Concepts

Dose and response are related and can be represented by a dose-response curve. Data from toxicology testing can be represented by a dose-response curve, from which scientists can describe the threshold and potency of chemicals.

Objectives

After completing this lesson, students will

- be able to describe the response of seeds to certain doses of chemicals,
- recognize that dose and response are related and be able to represent that relationship on a graph,
- compare the threshold and potency of chemicals, and
- be able, based on their seed investigation, to draw conclusions that relate to chemicals in the environment.

Background Information

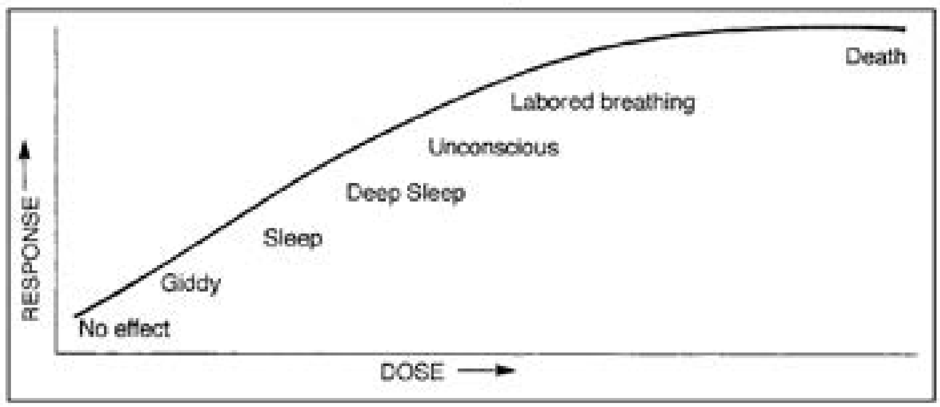
Dose-Response Curves

The characteristics of exposure to a chemical and the spectrum of effects caused by the chemical come together in a correlative relationship that toxicologists call the **dose-response relationship**. This relationship is the most fundamental and pervasive concept in toxicology (Klassen, 2008; Gilbert, 2004). To understand the potential hazard of a specific chemical, toxicologists must know both the type of effect it produces and the amount, or dose, required to produce that effect.

The relationship of dose to response can be illustrated as a graph called a dose-response curve. There are two types of dose-response curves: one that describes the graded responses of an *individual* to varying doses of the chemical and one that describes the distribution of responses to different doses in a *population* of individuals. The dose is represented on the *x*-axis. The response is represented on the *y*-axis.

The following graph shows a simple example of a dose-response curve for an individual with a single exposure to the chemical ethanol (alcohol), with graded responses between no effect and death (Marczewski and Kamrin, 2000).

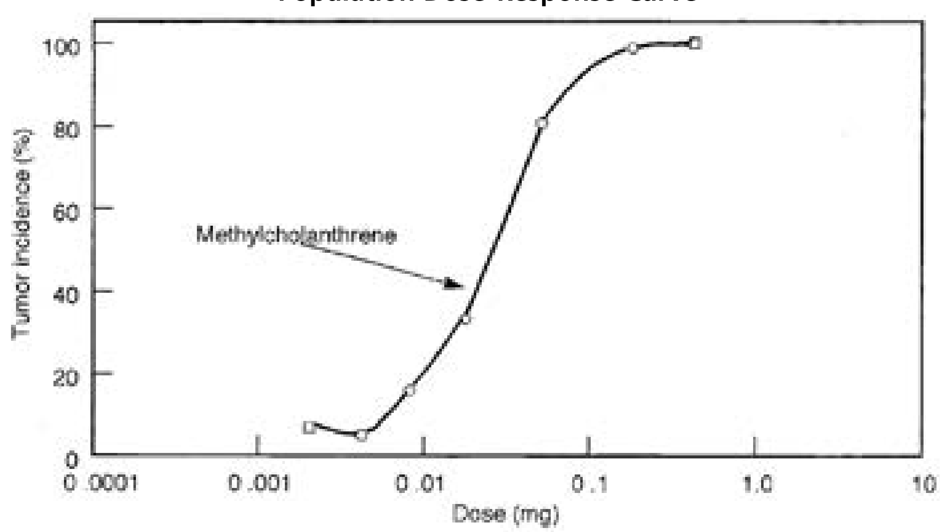
Individual Dose-Response Curve



From: Marczewski, A.E., and Kamrin, M. *Toxicology for the citizen* (Figure 6). Institute for Environmental Toxicology, Michigan State University, reprinted with permission.

A simple example of a dose-response curve for a population of mice in a study of a carcinogenic chemical might look like the following graph:

Population Dose-Response Curve

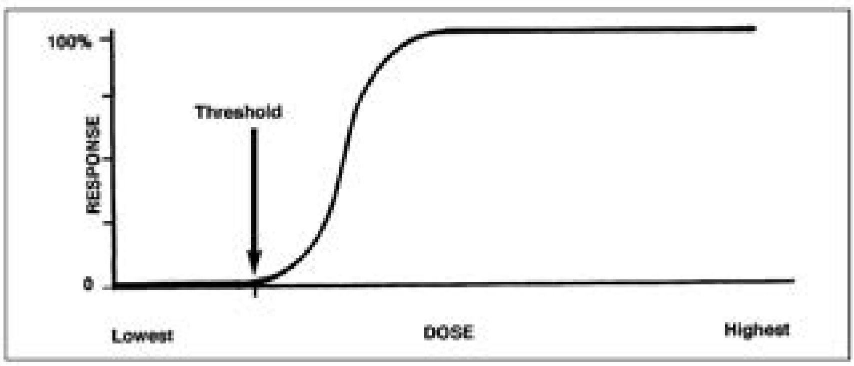


Adapted from: Eaton, D.L., and Klaassen, C.D. 1996. Principles of toxicology. In *Casarett & Doulls' Toxicology: The Basic Science of Poisons* (5th ed.). New York: McGraw-Hill.

An important aspect of dose-response relationships is the concept of **threshold**. For most types of toxic responses, there is a dose, called a threshold, below which there are no adverse effects from exposure to the chemical. The human body has defenses against many toxic agents. Cells in human organs, especially in the liver and kidneys, break down chemicals into nontoxic substances that can be eliminated from the body in urine and feces. In this way, the human body can take some toxic insult (at a dose that is below the threshold) and still remain healthy.

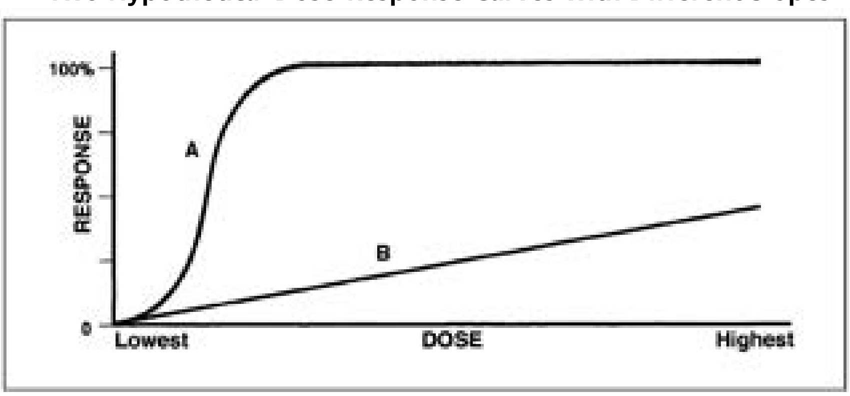
The identification of the threshold beyond which the human body cannot remain healthy depends on the type of response that is measured and can vary depending on the individual being tested. Thresholds based on acute responses, such as death, are more easily determined, while thresholds for chemicals that cause cancer or other chronic responses are harder to determine. Even so, it is important for toxicologists to identify a level of exposure to a chemical at which there is no effect and to determine thresholds when possible.

Hypothetical Dose-Response Curve Showing Threshold



When a threshold is difficult to determine, toxicologists look at the slope of the dose-response curve to give them information about the toxicity of a chemical. A sharp increase in the slope of the curve can suggest increasingly higher risks of toxic responses as the dose increases, as illustrated by line A on the next graph. A relatively flat slope suggests that the effect of an increase in dose is minimal (line B).

Two Hypothetical Dose-Response Curves with Different Slopes



A comparison of dose-response curves among chemicals can offer information about the chemicals as well. A steep curve that begins to climb even at a small dose suggests a chemical of high potency. The **potency** of a chemical is a measure of its strength as a poison compared with other chemicals. The more potent the chemical, the less it takes to kill (Klassen, 2008). In the previous dose-response graph, line A describes a chemical that is more potent than the chemical described by line B, as can be seen by the relative positions of the lines along the dose axis and their slopes.

Although some dose-response tests use lethality as an index, toxicologists also make observations of responses that do not include death. Other symptoms of toxic response to a chemical include fever, hair loss, headache, nausea, rash, urine abnormalities, and numbness in arms and legs. Regardless of the response that is used for measurement with respect to dose, toxicologists find that the form of the dose-response curve is similar.

Notes about Lesson 3

In this lesson, students will use the data they collected on the germination of their seeds in the presence of a chemical to create a dose-response curve for their chemical. In doing so, students will be able to compare visually the slope of their chemical's curve with those of other students. Students also can compare the potency of the chemicals by measuring germination of seeds. It is important for students to remember that they cannot make inferences about the potency of the chemicals with respect to human health; they can only use their data to inform them of the chemicals' potential toxicity to humans. In this way, students must think critically and logically to make the relationships between evidence and explanations.

In Advance

Web-Based Activities

Activity 1 has an optional Web-based component.

Materials and Preparation

Photocopies and Transparencies	Extension Activity
1 transparency of Master 3.1 1 copy of Master 3.2 **for each team**	• overhead projector • blank transparency • overhead markers **For each team of 3 students:** • bags of seeds treated with chemical from Lesson 2 (print version) • materials for laboratory investigation from Lesson 2, Activity 2 **For each student:** • Master 2.3, Toxicity Testing on Seeds, from Lesson 2 • data from the Web site (optional) • 1 copy of Master 3.2 • pencil

Preparation

Activity 1

If your students conducted the Web version of Lesson 2, arrange for them to have access to computers.

Make a transparency of Master 3.1, *Dose-Response Curves*. Make copies of Master 3.2, *Graph Paper*, one for each team.

Extension Activity

Gather the materials needed for students to conduct their investigation.

Procedure

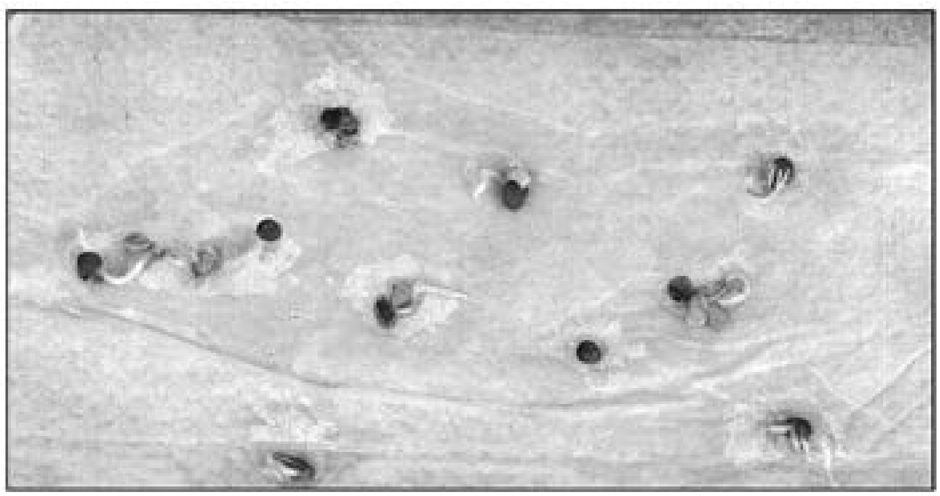
ACTIVITY 1: Graphing the Response to Chemical Dose

If students are investigating seed germination using the Web site, direct them to access the data on the site and proceed to Step 3 of this activity (see Lesson 2, Activity 4).

1-p. **As the students enter the room, ask them to get their bags of seeds treated with chemicals from Lesson 2 and bring them to their team's table.**

2-p. **Direct students to observe each of their six bags of seeds. Ask them to record in the Day 3 column of their data table the number of seeds in each population that have germinated and the number of seeds that have not germinated.**

Students might see more than just germination: Some plants now might be developing leaves. Encourage students to note any growth in the margin of their data table.



Content Standard A: Students use appropriate tools and techniques to gather, analyze, and interpret data.

3. **Once students have completed their data table, tell them that scientists graph data like theirs to help them understand the relationship between dose and response and make judgments about the safety of particular chemicals. Be sure to point out that students can assume that the dose the seeds receive is related to the concentration of the chemicals in each bag. Display the sample graphs of dose-response relationships on the transparency of Master 3.1, *Dose-Response Curves*.**

Point out to students that, in the top graph, the dose of alcohol is along the *x*-axis and the response is graded along the *y*-axis, from no effect to death. On the second graph, the dose of chemical in milligrams is along the *x*-axis. The response, the incidence of tumors in a population of mice, is along the *y*-axis. Use the *Background Information* to provide information for students about the two types of dose-response curves: for individuals and for a collection of subjects.

It might be of interest to your students to think about a word that often describes a person who has had too much to drink: *intoxicated*. Using their knowledge of toxicology, students should recognize that the base of the word *toxic* accurately describes what happens when a person is drinking. A person who is drinking alcohol is exposing himself or herself to a toxic substance that, at a high enough dose, can cause death. Impress upon students that the dose-response curve on the overhead provides evidence that binge drinking (which provides a high dose of alcohol in a very short time) can be very dangerous, and even deadly.

4. **Tell students that you would like them to graph the data they recorded for Day 3 of their seed investigation. Using a blank transparency, work with students to design a graph that shows the relationship between dose and response. To do that, students will need to help you decide the following:**

   - **Which of the two types of dose-response graphs will they use?**

   Students will want to use the dose-response graph that represents data from a population of individuals.

   - **What is the response that you want to graph?**

   This is sometimes counterintuitive for students. The response that they want to graph is the one caused by the chemical (the response that was different from the response of the control group). In most cases, the response is the lack of germination, so students would graph the number of seeds in the population that did *not* germinate.

   - **What measurement should be on the *x*-axis?**

   The dose is recorded along the *x*-axis, in increasing concentrations from 0% to 100%. Help students recognize that they need to space their measurements accurately along the *x*-axis, but not at even intervals since their concentrations are 0%, 6.25%, 12.5%, 25%, 50%, and 100%.

   - **What measurement should be on the *y*-axis?**

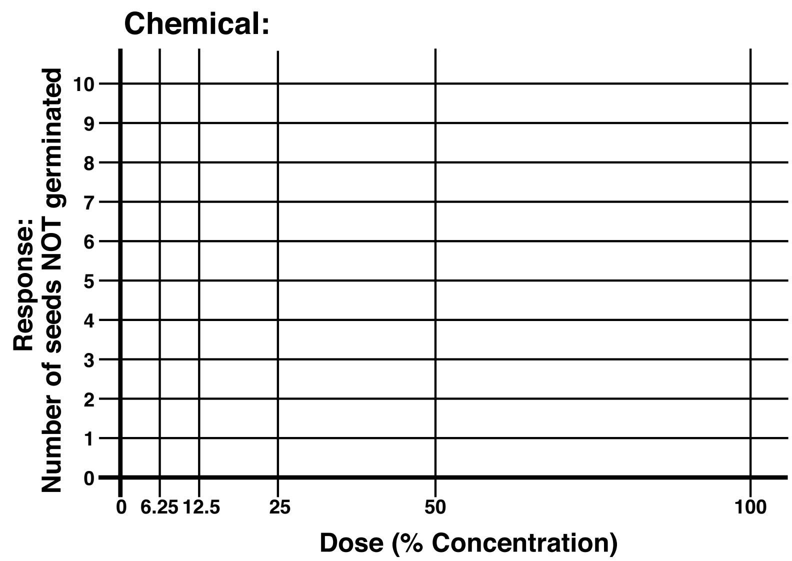
   The response is recorded along the *y*-axis, as the number of seeds in the population that did not germinate, from 0 to 10.

NSES

Content Standard A:
Students use mathematics in all aspects of scientific inquiry.

When you are finished making a sample of the graph, it should look like the following graph:

Dose-Reponse Curve for Seed Germination Investigation



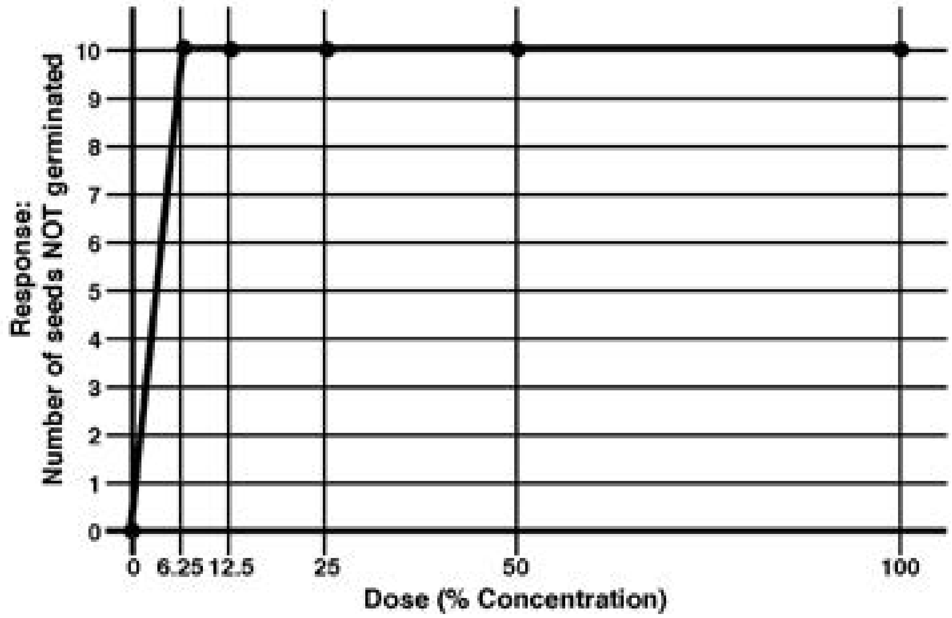
5. **Distribute copies of Master 3.2, *Graph Paper*, one to each team. Direct teams to make a dose-response graph for their chemical on Graph A.**

   Remind students to label their graph with the name of their chemical.

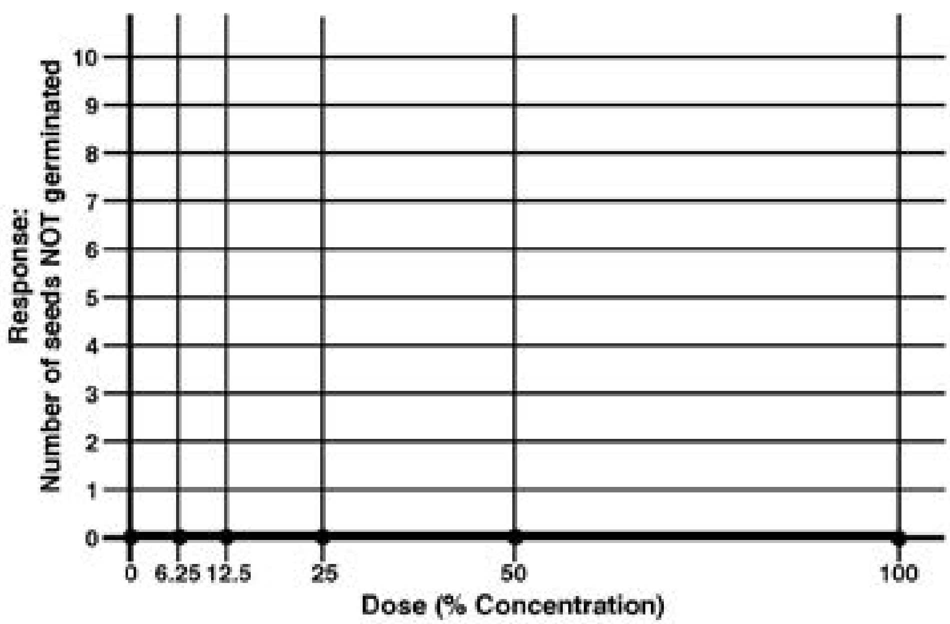
6. **Once teams have made a graph of their chemical, instruct them to get data from two other teams that tested different chemicals. Tell teams to graph the data on Graphs B and C, remembering to label each graph with the name of the chemical.**

Tip from the field test: Included here are several dose-response graphs for chemicals tested by students who participated in the field test.

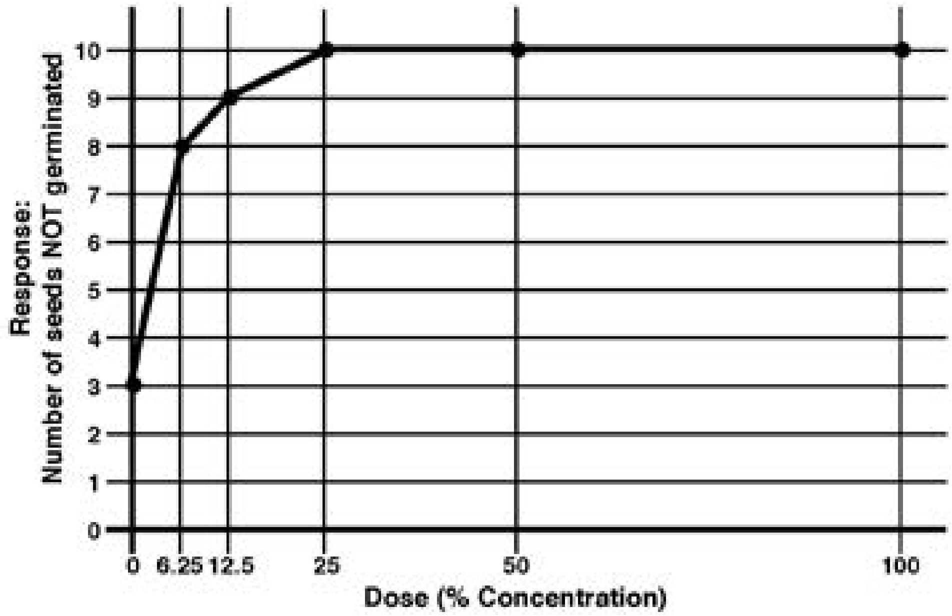
Chemical: Pine-Scented Cleaner



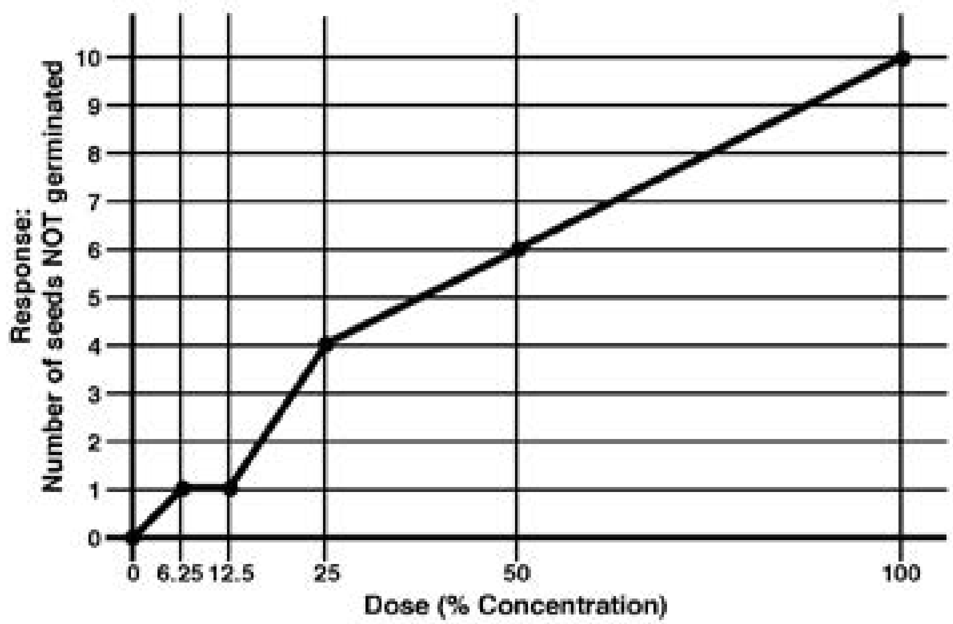
Chemical: Coffee



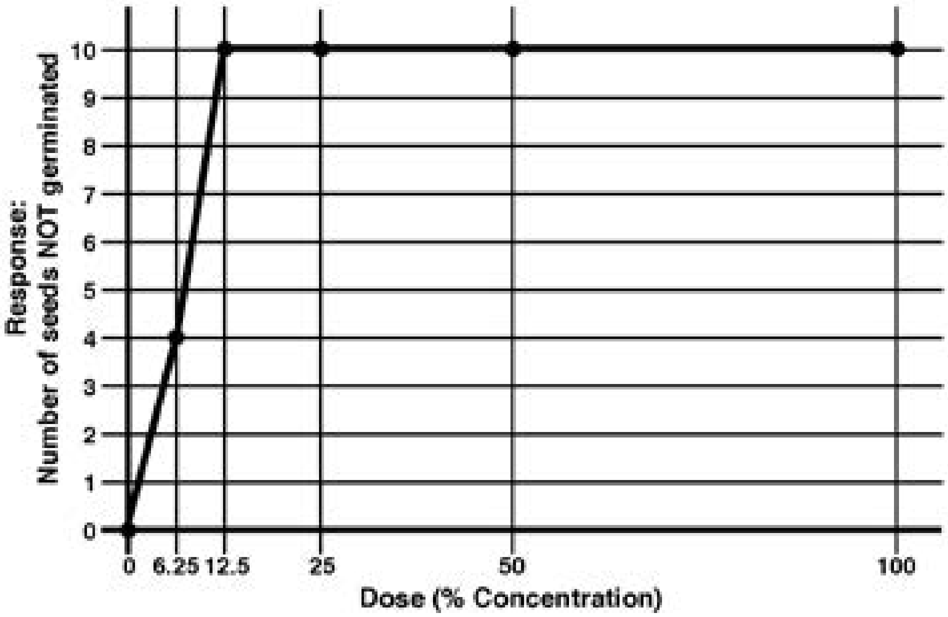
Chemical: Insect Repellent



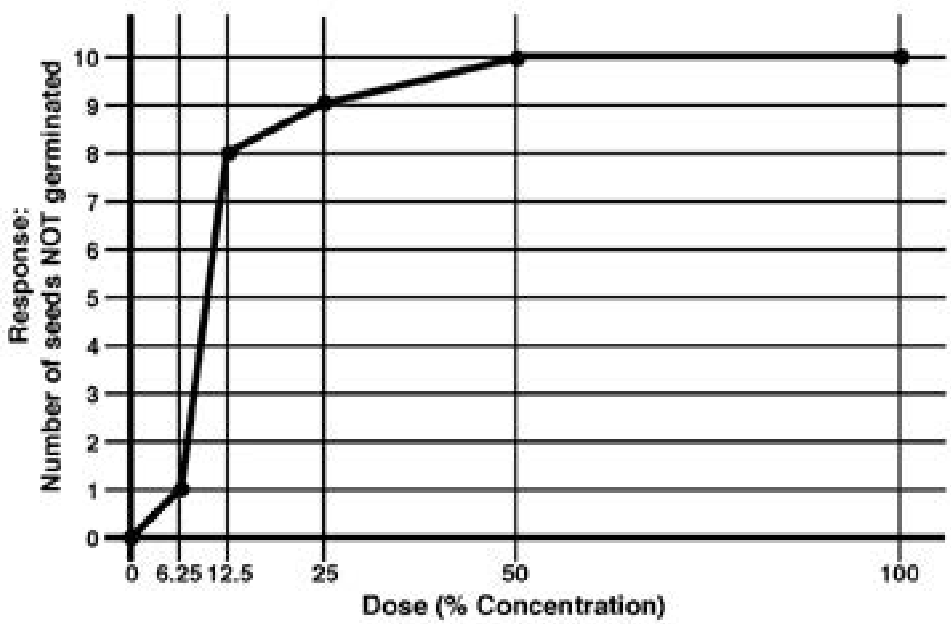
Chemical: Fruit Punch Soda



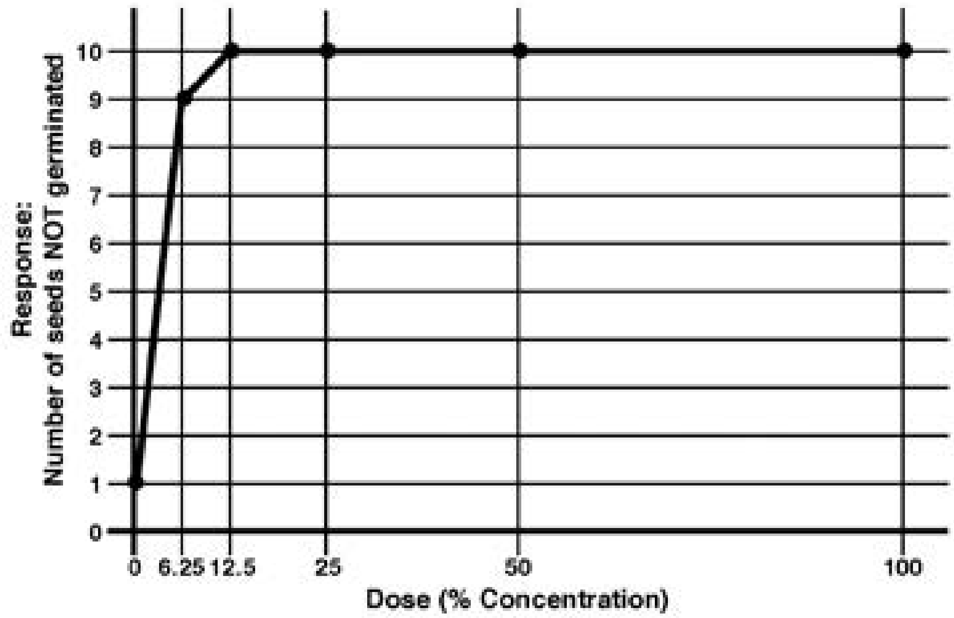
Chemical: Salt



Chemical: Window Cleaner



Chemical: Water-Soluble Plant Fertilizer



7. **Circulate around the room and, as they work, ask the teams to study the team graphs to decide which chemical had the highest potency or which chemicals have a clear threshold.**

   Of the chemicals graphed above, Lysol (pine-scented cleaner) is the most potent and coffee is the least potent. Field-test students found that it was difficult to determine threshold. They knew only that they exceeded the threshold below which there was no effect when they used Lysol, salt, window cleaner, bug repellent, fruit punch soda, and plant fertilizer. To pinpoint the exact threshold, students would need to repeat their investigation using additional concentrations between 0% and 6.25%. When they tested coffee, students found no threshold: Coffee had no effect on seed germination, even at 100% concentration.

Listen to students' descriptions of the dose-response curves to see if they understand the concepts of threshold and potency.

8. **Discuss with students what conclusions they can make, if any, about the safety or potential harm of the chemicals tested for humans. Ask students to evaluate the use of plants as a model system for toxicology testing.**

   Students should recognize that plants do not have the same structure as humans or other animals, so results from tests that determine toxicity to plants may not apply to humans. In fact, there are chemicals that are toxic to plants that do not harm humans and, conversely, there are chemicals that do not harm plants but are capable of harming animals like humans. For this reason, it is best to test chemicals on systems that most closely resemble the human system if knowledge about effects on humans is the goal. Even so, students may recognize that data from toxicity tests on seeds could help inform them of possible toxicants to humans.

NSES

Content Standard A: Students develop descriptions, explanations, predictions, and models using evidence.

Content Standard A: Students think critically and logically to make the relationships between evidence and explanations.

Toxicologists use to their advantage their understanding that it is possible for some chemicals to cause injury to one kind of living matter without harming another kind of living matter. By understanding this biological phenomenon, scientists can, for example, help farmers develop pesticides that are lethal to fungi or insects but do not harm crops, or antibiotics that kill infectious bacteria (also living organisms) but have low toxicity in humans.

Extension Activity

Ask students to describe other questions they would like to answer about the effects of their chemical on plants. Allow space and time for students to investigate their questions.

For example, students might want to know if their chemical has an effect on the growth of plants. They can sprout seeds and then water the seedlings with varying concentrations of chemical solutions. By setting up an investigation that can last a longer time, students can experiment with the concept of exposure over time. They can administer a small dose of chemical repeatedly for many days and compare the responses to those in plants that receive only one large dose of chemical.

Individual Responses Can Be Different

At a Glance

Overview

Students are aware after Lesson 3 that not all chemicals have the same effect on seed germination. In this lesson, students look at the variation among responses of seeds to the same dose of the same chemical. In reviewing their seed investigation, students note that sometimes not all seeds in the same bag responded in the same way. Students then use information about acetaminophen to learn more about dose and individual susceptibility. They learn that individual variability accounts for the different responses in the same types of organisms exposed to the same dose of a chemical. Students conduct an investigation into their own susceptibility to caffeine and compare individual responses.

Major Concepts

The variety of responses among organisms exposed to the same dose of chemical is due to individual susceptibility. Dose and individual susceptibility play roles in all situations involving chemicals, including those involving medicines and caffeine.

Objectives

After completing this lesson, students will

- understand that the variety of responses among seeds exposed to the same dose of chemical is due to individual susceptibility and
- recognize that dose and individual susceptibility play roles in human exposure to chemicals, such as drugs and caffeine.

Background Information

Toxic Effects of Chemicals

The human body is a complex organism. It responds to both external and internal conditions. For example, when the body gets too hot, it begins to cool itself by turning on its cooling system: sweat. When sensors in the brain detect that the body has cooled enough, the brain turns off the sweat glands.

Sometimes the body's balance is upset by chemical agents that put stress on different body functions. Some chemicals increase heart rate or sweating. Others decrease the rate of breathing. A chemical can have a wide-ranging effect, or it can cause a very limited change in a particular organ of the body. A chemical is toxic if the body's response to it is an adverse one, such as headaches, nausea, rashes, convulsions, or death.

Chemicals vary widely in their toxic potential. The variation among chemicals is due to their chemical structure. A chemical's structure determines

- how the chemical is metabolized,
- the rate at which it is absorbed, and
- how it is excreted.

Small differences in structure can cause big differences in toxicity (Marczewski and Kamrin, 2000).

Individual Susceptibility

The effect of a chemical also depends on another set of variables. Organisms will have various responses to chemical exposures because each organism is unique. For example, if a population of people was exposed to the same amount of the same chemical, some people might have very severe reactions to the chemical while others might have no reaction at all. Those with a severe reaction are considered more "susceptible" to the chemical. Individual susceptibility varies but is influenced by age, gender, health status, genetics, and lifestyle.

Photos: Corel

Photos: Corel

Children and elderly people often have an increased susceptibility to chemicals. For example, children have higher rates of respiration and consume more calories per unit of body weight than adults do. This can result in a greater exposure to and dose of a chemical for children compared with adults. The metabolism of chemicals also can vary because children's metabolic systems are still developing. In contrast, changes in physiologic functions, such as diminished kidney function, can impair the ability to excrete chemicals in an elderly person.

Some people's susceptibility is related to their overall health. People with asthma may be more susceptible to air pollution. Lifestyle factors such as smoking, drinking, and drug use may affect a person's susceptibility to toxicants. On the other hand, people with good nutrition and health are more resilient, so they can metabolize and excrete toxic substances faster.

Chemicals sometimes affect males and females differently. For example, women absorb and metabolize alcohol differently from men. Women will generally have a higher blood alcohol concentration after ingesting the same amount of alcohol as men. While some of the difference in blood alcohol concentration can be attributed to the difference in size between men and women, scientists have also found that women have less-active enzymes that metabolize alcohol, causing a larger proportion of the ingested alcohol to reach the blood (NIAAA, 1997). When drinking heavily, women are more susceptible to alcoholic liver disease, heart muscle damage, and brain damage. In addition, pregnant women can share an exposure to a chemical with the fetus through the placenta, and women who are nursing may expose their babies to the chemical through breast milk.

Inherited differences among people account for some of the different ways people respond to chemicals. For example, some people are genetically more susceptible to poisoning from the insecticide parathion. Most commonly, people are exposed to parathion by eating foods grown with the use of the insecticide. Differences in individual reactions to the chemical depend on which of the two variants, or alleles, of a particular gene the individual carries. One variant results in low activity of the enzyme paraoxanase, and one variant results in high activity of the enzyme. Scientists have determined that the enzyme paraoxanase breaks down parathion into inactive, nontoxic products that are excreted in the urine. Those people who have the highly active enzyme and are exposed to parathion have mild symptoms such as abdominal discomfort, vomiting, and diarrhea, followed by headache and weakness, because their bodies are able to break down the parathion into nontoxic products at a higher rate. Those people with the gene that results in low activity of the enzyme can have much more severe symptoms when exposed to the same amount of parathion. These people may experience sudden collapse, coma, sweating, and difficulty breathing because their bodies cannot break down parathion quickly and the chemical remains in the body for a longer time.

Courtesy of the Bayer Corporation

Understanding the variety of responses that different individuals can have to different doses of a chemical is important to the study of pharmaceuticals. Written on the label of any drug are indications describing who can use the drug and how much to take. In addition, warning statements describe who should not use the drug. Such information is the result of the knowledge scientists have gained about the way the chemical affects a diverse population over time.

The Chemical Caffeine

Caffeine is a chemical that most people ingest at some time in their lives, and many people ingest caffeine daily. People consume caffeine in coffee, tea, cocoa, chocolate, soft drinks, and some drugs. It is a naturally occurring chemical that comes from the coffee bean, tea leaf, kola nut, and cacao pod.

As a central nervous system stimulant, caffeine in moderate doses can increase alertness, reduce fine motor coordination, alter sleep patterns, and cause headache, nervousness, and dizziness. In massive doses, caffeine is lethal. However, it is hard to get a lethal dose of caffeine just by ingesting it in food and drink: A lethal dose of caffeine is 170 milligrams of caffeine

Photos: Corel

for every kilogram of body weight, or about 10 grams for an average-sized adult. One would have to drink 80–100 cups of coffee in rapid succession to reach that threshold (Chudler, 2010).

Caffeine is absorbed rapidly into the bloodstream from the gastrointestinal tract. It can exert its effects within 15 minutes after it is consumed and reaches maximum concentration in the bloodstream within about one hour. The blood distributes caffeine throughout the body, where the caffeine increases metabolic rate by about 10 percent. Once in the body, caffeine will stay around for hours: It takes about six hours for one-half of the caffeine to be eliminated. Gender affects a person's response to caffeine: Females metabolize caffeine 20–30 percent more quickly than do males (ABC, 1997).

Because caffeine constricts the cerebral blood vessels, blood pressure rises and heart rate increases in the presence of caffeine. When people who regularly ingest caffeine stop ingesting it, they can suffer severe headaches because the blood vessels in their brain are dilating.

Research into the detrimental effects of caffeine has not uncovered any connections between ingestion of caffeine and heart disease, stroke, or cancer. There are some studies that show that large doses of caffeine, such as five to seven cups of coffee a day, can delay fertility (ITIS, 2010).

Compared with other drinks popular with adults, the caffeine content in soft drinks is lower. Coffee can contain between 80 and 175 milligrams of caffeine (per 7 ounces) depending on how it is brewed; espresso has 100 milligrams in just 1.5 to 2.0 ounces. Tea can contain 40–60 milligrams of caffeine (per 7 ounces). Ice tea contains 70 milligrams of caffeine in 12 ounces.

Many soft drinks popular among youth contain caffeine. The following table lists some soft drinks (12-ounce size) and the amounts of caffeine they contain.

Amount of Caffeine in Soft Drinks

Jolt Cola	71 mg
Josta	58 mg
Mountain Dew	55 mg
Surge	51 mg
Diet Coke	45 mg
Coca-Cola	45 mg
Dr Pepper	41 mg
Sunkist Orange Soda	40 mg
Pepsi Cola	37 mg
Barqs Root Beer	23 mg
7-Up	0 mg
Minute Maid Orange Soda	0 mg
Mug Root Beer	0 mg

Source: Center for Science in the Public Interest. Soft drinks and health: Caffeine content of foods and drugs. Retrieved August 17, 2000, from *www.cspinet.org/new/cafchart.htm.*

Notes about Lesson 4

In this lesson, students can use information from their seed investigation to help them understand some of their own voluntary exposures to chemicals. When they take a medicine, they are exposing themselves to a chemical. When they follow the correct dosage for that medicine, they are taking advantage of what scientists know about how much exposure to the chemical results in the desired response. In addition, although they might not think of it in these terms, students are exposing themselves to the chemical caffeine each time they drink a caffeinated soft drink or eat a piece of chocolate. Students intuitively know that caffeine, a stimulant, affects some people more than others: It may keep some people awake at night, while others can drink a caffeinated drink right before bedtime and still sleep. In this lesson, students measure their own heart rates after drinking a soft drink containing caffeine to see if they can quantify some of those individual differences.

In Advance

Web-Based Activities

Activity 2 has a Web-based component.

1 transparency of Masters 4.1 and of 4.2 (optional) 1 copy of Masters 4.3 (print version only), 4.4, and 4.5 **for each student**

Materials

Activity 1

For the class:

- overhead projector
- overhead markers
- 3 large beakers filled with equal amounts of water and drops of mystery chemical from Lesson 2, Activity 1
- 3 clear containers of distinctly different sizes, each filled with distinctly different amounts of water, labeled #1, #2, #3
- jar of mystery chemical from Lessons 1 and 2
- eyedropper

For each student:

- science notebook with seed investigation data table
- pencil

Activity 2

For the class:

- computers
- overhead projector

Activity 3

For the class:

- clock with a second hand

For each student:

- 1 12-ounce can of caffeinated soft drink, or equivalent amount of water
- pencil

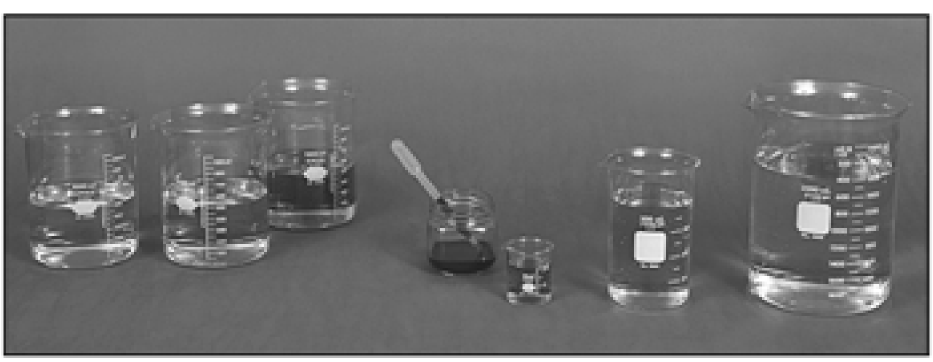
Extension Activity

- none

Preparation

Activity 1

If necessary, fill the three beakers from Lesson 2 with equal amounts of water. Add 1 drop of the mystery chemical to Beaker #1, 4 drops to Beaker #2, and 16 drops to Beaker #3.



Collect three clear containers of different sizes and label them #1, #2, and #3. Fill each container with water, making sure that each container holds obviously different amounts of water, with #1 having the least and #3 having the most.

Make a transparency of Master 4.1, *Acetaminophen Dosage Chart*.

Activity 2

Decide whether you will use the Web or print version of this activity. If you choose the Web version, arrange for students to have access to computers.

If you use the print version, conduct the activity with the whole class. Later, let students review the problem online on their own.

Activity 3

At least one week before conducting Activity 3, send home personalized parent letters (Master 4.4, *Parent Letter*) to inform parents of the investigation and to get permission for the students to consume a caffeinated soft drink during science class. You can use the letter to ask each student to bring in his or her own can of the designated caffeinated soft drink.

Arrange to have enough cans of the same kind of caffeinated soft drink for each student who participates in the investigation. There are several ways to do this:

- purchase all the soft drinks yourself through your school budget,
- ask for parent or business donations to cover the cost, or
- request that each student bring in one can of the same kind of soft drink, labeled with his or her name, for his or her consumption only.

Before the day of Activity 3, have students practice taking a resting heart rate so they are used to finding their pulse, counting the beats for 15 seconds, and multiplying the number they count by four to get a resting heart rate for one minute (see Activity 3).

Procedure

ACTIVITY 1: Different Doses for Different People

1. **Ask students why they think toxicologists look at both whether a chemical has an effect on living things and what happens at different doses. Why do students think it matters to look at doses?**

   Students may bring up the term *overdose*, which refers to a situation in which a person receives too much of a particular chemical, usually a drug. Students should realize that the proper dose of a chemical is what makes it beneficial to people and that knowing the dose is useful in determining the appropriate human consumption of that chemical. Some chemicals, such as vitamins and minerals, are beneficial at a particular dose, but human health suffers if the chemicals are present in high or very low doses (you can have too much or not enough). Other chemicals, such as drugs and pesticides, are usually more harmful as the dose increases.

2. **Tell students that you are going to demonstrate one reason why paying attention to dose is important in the study of toxicology.**
   - First, on one side of a desk at the front of the room, place the three large beakers filled with equal amounts of water and different amounts of mystery chemical from the demonstration in Lesson 2. Remind students that this is the demonstration they saw before they began their seed investigation.
   - Then, place three different-size clear containers on the desk. Fill each container with water, making sure that it is obvious that each container holds a different amount of water (#1 holds the least and #3 holds the most).
   - Using the eyedropper from Lesson 1, place two drops of mystery chemical in each of the containers. Swirl the containers to mix the chemical and the water.

3. **Ask students to observe the three new containers and compare them with the setup of the demonstration from Lesson 2. Discuss their observations by asking questions like these:**

   - **Is this new demonstration the same as the one I did for you before you began your seed investigation? Why or why not?**

   Students will recognize that the demonstration is different. Today, you are using different-size containers (and different amounts of water) and the same amount of chemical; earlier you used the same-size containers and different amounts of chemical.

   - **What was the variable in the earlier demonstration?**

   The variable was the amount of chemical you added to each beaker of water. The dose was the variable. The amount of water was the constant.

   - **What is the variable I am using today?**

   Today, the variable is the amount of liquid in each container. The dose of chemical is a constant.

   - **How would you describe the concentrations of chemicals in each of the containers in today's demonstration?**

   The concentration of chemical in each container is different in today's demonstration because the amount of water in each container is different although the amount of chemical is the same. Because concentration is a measurement of the amount of chemical compared with the volume of water, the concentration of chemical in Container #1 is higher than the concentration in #2 or #3.

NSES

Content Standard A:
Students think critically and logically to make the relationships between evidence and explanations.

- **What do you think the containers in today's demonstration are illustrating? Why do you think it matters that the containers are different sizes?**

The different-size containers represent the different variations in size of people who might be exposed to the mystery chemical. In smaller people (Container #1), 2 drops of chemical result in a higher concentration of chemical in their bodies than do 2 drops in either of the larger people (Containers #2 and #3). This higher concentration could be beneficial (if it approaches the threshold that creates beneficial results) or it could be harmful (if the higher concentration exceeds the threshold for safe use of the chemical).

- **When might understanding this relationship of dose to size matter?**

When people use drugs to treat illness, they are exposing themselves to chemicals. To understand how much of a chemical is needed to get the desired effect, such as lowering fever or reducing pain, you need to understand that the same dose of chemical will have different effects on different-size people because it results in different concentrations in their bodies.

Ask students to write about the two demonstrations and clearly discuss what is different about the two.

Tip from the field test: This is a simple demonstration that, when coupled with students' understanding of the earlier demonstration, moves students to use the language of toxicology: dose, response, concentration.

4. **Keep the containers of water on the desk while you display the transparency of Master 4.1 *Acetaminophen Dosage Chart.* Ask questions such as these to discuss the concept of dose with respect to body size:**

- **What is acetaminophen?**

Students might need you to tell them that acetaminophen is the active ingredient in Tylenol products. It is a chemical that, when taken into the human body, elevates the pain threshold and reduces fever.

- **For all people, what is the response they want to get from exposure to a dose of acetaminophen?**

They want to reduce their fever or pain.

- **What does the dosage chart tell you about the relationship between dose and body size?**

The dose increases as the body size of the individual increases. Students can see from the chart that each tablet of Children's Chewable Acetaminophen provides a dose of 80 milligrams of acetaminophen. As a child grows, the amount of acetaminophen needed to reduce fever and pain increases. For example, a child weighing 40 pounds needs a dose of three tablets at 80 milligrams of acetaminophen per tablet, or 240 milligrams of medicine. A child weighing 80 pounds needs six tablets at 80 milligrams each, or a dose of 480 milligrams of acetaminophen.

Tip from the field test: Use this time to teach students how to read a dosage chart. Show them where to find information about the number of milligrams of acetaminophen each measurement contains (for example, one tablet contains 80 milligrams of acetaminophen). Impress upon them the importance of knowing a person's size (weight) to determine correct dosage. Familiarity with dosage charts makes it easier for students to work the problem in Activity 2.

Dosage Chart for Children's Chewable Acetaminophen (80 mg/tablet)

Weight (lb)	Weight (kg)	Age (yr)	Dose
under 24	under 11	under 2	consult doctor
24–35	11–16	2–3	2 tablets
36–47	17–21	4–5	3 tablets
48–59	22–27	6–8	4 tablets
60–71	28–32	9–10	5 tablets
72–95	33–43	11	6 tablets

Warning: Take no more than five doses per day.

Dosage is determined by body weight. Age is not an accurate measure for dose but is included on many charts in case weight is unknown. Dose is expressed in number of tablets (or capsules, teaspoons, or droppers). Dosage charts always include information about milligrams per unit of measure.

- **Look again at today's demonstration. Which size child from the chart might each container in today's demonstration represent?**

Container #1 represents the smallest child, #2 a medium-size child, and #3 the largest child.

- **If the 2-drop dose the smallest child received in Container #1 was correct for the child's size, what can you say about the dose the other two children received?**

The concentration of chemical in the larger children's bodies would be lower and might not be enough to provide the desired effect.

- **If the 2-drop dose in Container #3 resulted in a toxic response for the largest child, what can you say about the dose for the two smaller children?**

The dose for the two smaller children would almost certainly be toxic because the concentration of chemical in their bodies is higher.

NSES

Content Standard F:
Students should develop understanding of personal health.

5. **Tell the students that size is one difference in people that can affect how susceptible they are to chemicals. Ask students what other factors about an individual might make the individual more or less susceptible to chemicals such as acetaminophen. List the factors on the board.**

   Start the list with size (weight). Other factors that can affect susceptibility to chemicals are age, lifestyle or behavior (such as being an alcoholic), gender, genetics, and general health.

6. **Tell students that toxicologists know that these variable factors determine an individual's susceptibility to the effects of environmental toxicants. Write *individual susceptibility* as the title of the list you made on the board in Step 5. Tell students that, because of their understanding of individual susceptibility, toxicologists expect that individuals may respond differently to the same dose of a chemical.**

7. **Ask students to apply the concept of individual susceptibility to their observations of the seeds in their investigation. If students need help, prompt them with questions such as these:**

   - **Did all of the seeds in each of your bags respond to their dose of chemical in the same way?**

   Answers will vary, but most likely students will have had bags in which not all of the seeds reached the same stage of germination by Day 3.

   - **What factors in the seeds might account for the differences in germination among them?**

   Seeds are processed from many different plants, so the genetic makeup might not be exactly the same among 10 seeds. Age might be a factor because some seeds might be older than other seeds. General health of the seeds could be a factor because some seeds might be less healthy than other seeds.



Photos: Corel

- **Why did you use 10 seeds to test each of the concentrations of chemical?**

By using 10 seeds, you can compensate for possible responses due only to individual susceptibility by observing the response in the majority of the seeds. If you tested only one seed, you wouldn't know if the response you observed was due only to the dose of the chemical or was a reflection of the seed's individual susceptibility to the chemical.

ACTIVITY 2: A Poisonous Dose?

The following procedures describe how to conduct the Web version of this activity, which is the preferred method of instruction. Instructions for the print version follow.

Use a computer lab where you can set up multiple computers. Go to *http://science.education.nih.gov/supplements/chemicals/student*. Select Lesson 4—*Individual Responses Can Be Different*. Start the activity by watching the video. Encourage students to work in pairs to solve the problem. Then go to Activity 3.

Print Version

If your students do not have access to the Web site or you would like an opportunity to assess students individually on their understanding of a toxicology problem involving humans, use the following print version of Activity 2.

1-p. Display the first page of the transparency you made from Master 4.2, *A Poisonous Dose? The Case History.* Read the transparency with the students.

2-p. Distribute copies of the first page of Master 4.3, *A Poisonous Dose? The Problem.* Ask students to work in teams of three to complete Part I. Circulate around the room to help students read the dosage chart, understand the math, and draw some conclusions.

Students should select letter **e**: Both b and d are correct. Andy received 1 teaspoon four times a day, or 4 teaspoons in all. Because there are 6.25 dropperfuls of acetaminophen in each teaspoon and 80 milligrams of acetaminophen in each dropper, the calculation of the amount of acetaminophen Andy received from his aunt should read:

$$4 \text{ teaspoons} \times \frac{6.25 \text{ dropperfuls}}{1 \text{ teaspoon}} \times \frac{80 \text{ milligrams}}{1 \text{ dropperful}} = 2000 \text{ milligrams of acetaminophen}$$

The calculation of the maximum number of milligrams a child Andy's size should receive should read:

$$5 \text{ doses} = 10 \text{ dropperfuls} \times \frac{80 \text{ milligrams}}{1 \text{ dropperful}} = 800 \text{ milligrams of acetaminophen}$$

As students work through the math, they see that the dose of acetaminophen the aunt gave Andy is much higher than the recommended maximum dose. Students can hypothesize, based on their understanding of dose and concentration and its relationship to size, that Andy was sick from too much acetaminophen.

3-p. Distribute copies of the second page of Master 4.3, *A Poisonous Dose?*

***The Problem.* Instruct students to continue to work in their teams of three to complete Part II up to the conclusion. Then ask students to work individually on the conclusion by writing about how they think the accidental overdose of acetaminophen happened.**

NSES

Content Standard A: Use mathematics in all aspects of scientific inquiry.

Content Standard E: Students should develop understandings about science and technology. Technological solutions have intended benefits and unintended consequences. Some consequences can be predicted, others cannot.

The calculation of the amount of acetaminophen in four doses of Children's Suspension Liquid should read:

$$4 \text{ doses} = 4 \text{ teaspoons} \times \frac{160 \text{ milligrams}}{1 \text{ teaspoon}} = 640 \text{ milligrams of acetaminophen}$$

Andy's mother uses **a teaspoon** to measure a dose of Children's Suspension Liquid. Andy's aunt used **a teaspoon** to measure Infants' Concentrated Suspension Drops. The dosage chart says to use **a dropper** to measure infants' drops.

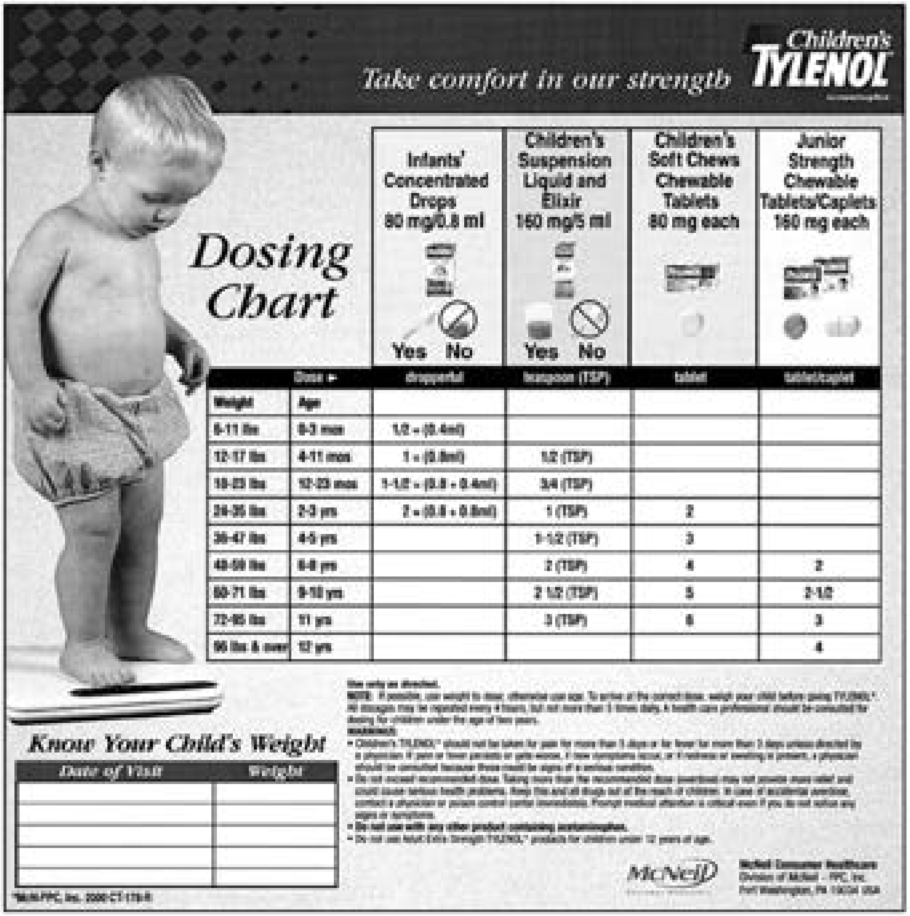
Students can conclude that incorrect amounts of acetaminophen were given to Andy because his aunt did not understand that the acetaminophen in infants' formula is concentrated: It cannot be measured using the same units (teaspoons) as the children's formula. In fact, a teaspoon of infants' formula is more than three times stronger than a teaspoon of children's formula. Instead of teaspoons, infants' formula should be measured in droppers, which is indicated on the dosage chart. Unfortunately, the similarity in the appearance of the two liquids leads parents, care givers, and even doctors to believe that the two medicines are interchangeable.

Students may ask why the infants' formula is stronger, when medicine formulas usually get stronger for people only as their body size gets bigger. Because it is so difficult to give medicine to a baby, it is important to pack as much acetaminophen as possible into the smallest volume of liquid. The higher concentration of the acetaminophen in infants' formula ensures that parents can administer the appropriate amount of medicine with the least amount of trouble.

Collect students' written conclusions of what happened to Andy. Assess students' writing for understanding of the roles dose and concentration played in Andy's overdose and how the confusion over the two kinds of acetaminophen led to the problem.

4-p. Display the second page of the transparency you made from Master 4.2, *A Poisonous Dose? The Case History.* Review with students the diagnosis and treatment.

The doctor handling Andy's case had seen severe liver damage and even death from liver failure among children who experienced accidental acetaminophen poisoning. She knew that an overdose



Courtesy of Children's TYLENOL a product of McNeil Consumer Healthcare

of acetaminophen is 150 milligrams for each kilogram of body weight. For Andy, who weighs 12 kilograms, an overdose would be 1,800 milligrams. In Part I, students calculated that Andy received 2,000 milligrams of acetaminophen, clearly an overdose. The doctor administered an antidote (*N*-acetylcysteine) within 8 to 12 hours of the poisoning, and the boy recovered.

5-p. Ask students how they think a mistake like the one that poisoned Andy could be avoided.

Because of situations like Andy's, changes in the labels and inserted instructions for acetaminophen products now inform people of the potential dangers of taking too much acetaminophen and more clearly describe appropriate dosage. Adults are reminded to use the dropper for the infants' formula acetaminophen, which is the appropriate unit of measure.

ACTIVITY 3: The Chemical Caffeine: How Do You Respond?

Note: Before beginning this investigation, be sure to have a signed permission letter from parents or guardians for the students to ingest a caffeinated soft drink (use Master 4.4, *Parent Letter*). Those students for whom you do not have permission can participate in the investigation by drinking water; they will provide a control for the activity.

1. **Because their heart rates might be elevated from their walk to class, spend several minutes allowing students to rest and talk quietly. Find out what students know about the chemical caffeine. Use material from the *Background Information* to discuss caffeine briefly. Then, if you have not already done so, teach students how to find their pulse, count their heartbeats, and calculate their resting heart rate.**

   You can find your pulse most easily by pressing two fingers against the artery in your neck or on the inside of your wrist. It is easiest to count beats for only 15 seconds and then multiply the number you count by four to find your resting heart rate for one minute. Repeat the counting several times until most students have calculated a resting heart rate that is close to the same number several times in a row. Alternatively, you can have partners verify each other's heart rate.

2. **Distribute Master 4.5, *The Chemical Caffeine: How Do You Respond?*, one to each student. On your signal, ask students to measure their heartbeats one more time for 15 seconds, stopping when you call time. Instruct students to calculate their resting heart rate for one minute by multiplying the number they counted by four. Direct them to record it on the data table on the master.**

3. **Ask students to work in pairs. Distribute the cans of the same kind of caffeinated soft drink, one to each student. Instruct students to follow the directions on the master. Remind them to continue to sit at rest. They can talk to their partner but should keep their bodies still so that they do not elevate their heart rate with activity.**

Tip from the field test: Assign some reading to students from which they can take a break periodically to measure their heart rate. Planning ahead for quiet activity helps keep the students focused on the task.

4. **When all the students have filled in their data tables and calculated the difference between their resting heart rate and the highest heart rate after ingesting a caffeinated soft drink, discuss their findings by asking questions such as these:**

   - **Did your heart rate go up, down, or stay the same after you drank a caffeinated soft drink?**

   On average, most students should have seen their heart rate go up after drinking the caffeinated soft drink. Some sample data from a field-test class looked like this:

   Measurements of Heart Rate at Rest and After Caffeine for a Field-Test Class

Male or Female	Resting Heart Rate	Highest Post-Caffeine Heart Rate
F	80	88
M	88	100
M	76	116
M	68	76
M	72	92
M	80	92
F	76	92
F	68	84
F	68	92
F	72	80
M	80	74
M	64	84
F	68	88
F	84	84
M	80	96
M	72	104

   - **On the basis of your observations, what generalization can you make about the effect of caffeine on the human body?**

   Caffeine appears to increase heart rate.

   - **Why was it important that all students drank the same kind and amount of soft drink?**

   Students will recognize that the variable they are interested in testing is individual susceptibility to caffeine. They need to keep as many other factors in the investigation constant, such as amount and kind of soft

NSES

Content Standard A: Students should develop abilities necessary to do scientific inquiry and understandings about scientific inquiry.

drink (because different soft drinks have different amounts of caffeine), time of day for the investigation, and temperature of the classroom.

- **Did all the members of the class have exactly the same results when they drank a caffeinated soft drink?**

While most members of the class will see their heart rate increase, the amount of increase will vary significantly.

- **Compare your results with those of other members of the class. What is your individual susceptibility to caffeine?**

Ask students to compare how much their heart rates increased after exposure to caffeine. Those whose heart rates increased significantly can draw the conclusion that they are very susceptible to caffeine. Those whose heart rates did not increase very much, or went down, can draw the conclusion that they are less susceptible to caffeine.

- **Why might some people be more individually susceptible to the effects of caffeine than others?**

Students vary from one another in gender, size, frequency of caffeine consumption, metabolic rates, and so on. This variability makes each student react differently to exposure to caffeine.

- **What do the results of your investigation tell you about the possible risks to some people of ingesting the chemical caffeine?**

Although research has shown that caffeine is safe to consume in moderate amounts, doctors suggest that people who have high blood pressure or trouble with irregular heartbeats avoid caffeine.

Extension Activity

Ask students to examine the labels from some product packages for directions for use and warnings. Suggest that students look at a variety of products, such as household cleaners, cold medicines, and vitamins. Instruct students to summarize information about the following for each product:
- route of exposure
- dose
- individual susceptibility

Students' summaries will vary depending on the products they choose. Encourage them to examine at least one product that is meant for human ingestion, such as a medication, because the product label should contain information about dose and individual susceptibility. Remind them that labels from some products, such as household cleaners, will have information about routes of exposure but probably will not include information about dose or individual susceptibility.

LESSON 5
Elaborate

What Is the Risk?

At a Glance

Overview
Students apply their growing understanding of the concepts of toxicology (dose, response, individual susceptibility, potency, and threshold) to their discussion of the 1950s tragedy in Minamata, Japan. They learn how to assess the risk to people of specific chemical hazards and make decisions about how to manage that risk.

Major Concepts
People can make some choices about chemical exposure; however, some exposure is controlled at a level other than an individual one. Collective groups of people, such as communities and governments, seek to control chemical exposure on a community or global level.

Objectives
After completing this lesson, students will
- use their knowledge about dose, response, individual susceptibility, and route and frequency of exposure to understand a historical situation involving hazardous chemical exposure;
- assess the risk to people in Minamata of mercury poisoning using a risk-assessment flow chart;
- compare their own risk of mercury poisoning with that of the people of Minamata; and
- understand the kinds of critical choices people make about chemical exposure and that some exposure is controlled at a level other than an individual one, such as the community or global level.

Background Information

The Minamata Case Study

When people living in Minamata, Japan, in the 1950s began slurring their speech occasionally or dropping their chopsticks at a meal, no one thought much of it. Some people cruelly laughed, claiming their clumsy friends were acting like the cats that were "dancing" strangely in the street and falling to their death in the sea. When it seemed like more and more people were suffering from the mysterious lack of coordination, the community began to realize that something was seriously wrong. But, people did not know that they were seeing the first signs of a debilitating nervous condition caused by ingesting mercury (Japanese Environmental Health Department, 2002).

We now know the tragic story of Minamata. The Minamata Bay was polluted with the industrial waste from the Chisso Corporation, which manufactured acetaldehyde used to make plastics. The mercury the company used in the production process was discharged into the bay, incorporated into bacteria, and passed through the food chain to people living in the area. The people in the town were slowly being poisoned by their most important food source: fish.

The consequences of such blatant polluting seem obvious to people today. But at the time, science had not yet documented the hazards of mercury, and environmental awareness was not pervasive. In fact, the Minamata case has become a classic lesson in the tragedy of industrial pollution and the need to anticipate the unexpected consequences of introducing chemicals into the environment. Although the story is now half a century old (and "ancient history" for today's middle school students), it has a well-documented cause and effect, as well as a resolution. In this way, it provides a good model for teaching about risk assessment and management that students can apply to their analysis of current exposures to chemicals.

Minamata photographs by W. Eugene Smith and Aileen M. Smith.

Risk Assessment

Today, when toxicologists study the extent and type of negative effects associated with a particular level of chemical exposure, they can use what they learn to assess the threat of that chemical to people's health. To do this, toxicologists measure a person's risk of exposure to the chemical. For example, even though dioxin is considered the most toxic synthetic chemical known, it does not pose the greatest risk to humans because the potential for significant dioxin exposure is quite small. In addition, while the lethal dose of a chemical is an important measurement to make, it is quite possible that a chemical will produce a very undesirable toxic effect at doses that cause no deaths at all. These lower doses may be the amount to which people are regularly exposed.

How a person is exposed to a chemical also determines the factor of risk. In the case of a single exposure, the amount of chemical and way the body is known to respond to the chemical determine the severity of the toxic response. In the case of repeated exposures to a chemical, it is not only the amount of chemical that counts, but also the frequency of exposure. If the body is able to rid itself entirely of the chemical before the next exposure, it is possible that each exposure is akin to a single exposure to the chemical. If, however, the body still retains some of the chemical from the previous exposure, accumulation of the chemical can occur and eventually can reach toxic levels, even if each exposure is small.

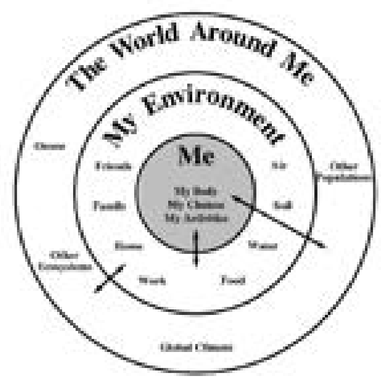
Many of the measurements that guide toxicologists in their assessment of human risk are based on studies of animals other than humans. This fact, coupled with the individual susceptibility of different members of the human population, makes it difficult to know with absolute certainty the level of risk to which each individual is exposed. With adequate information, however, toxicologists can predict the health risks associated with specific chemical exposures and help the human population make informed decisions about how to limit those exposures.

Managing Risk

The built-in uncertainty of risk assessment makes it essential for people to possess enough knowledge to make decisions about their own exposures to chemicals. With adequate knowledge, individuals can make decisions concerning their exposure to tobacco smoke, pollutants in water, and chemicals in food. By modifying their individual behavior, people can have some control over the chemicals they absorb into their body.

Not all decisions about chemical exposure and control can be made at an individual level, however. Local, national, and global communities of people are exposed to chemicals over which they have very little individual control. People are exposed to air pollution from factories and cars or chemicals used by farmers on crops without any individual consent. To manage a community's risk from chemicals in the environment, organizations and agencies set standards to protect human health.

There are choices about chemical exposure over which individuals have control (represented by the inner circle in the adjacent diagram). Individuals are also affected by their immediate environment (their friends and family, as well as the air, soil, and water around their homes and workplaces); the middle circle of the diagram describes influences on an individual over which he or she has less control. Finally, the outer circle describes the world that surrounds individuals over which they have little control but that can have an impact on them. The arrows between each concentric circle indicate that individuals, their environment, and the world at large all affect each other.



One step in community risk management is to determine how much risk is acceptable to people. If the chance that exposure to a particular chemical causes cancer is only 1 in 1 million, people are often less concerned than if the chance is 1 in 10. The picture becomes more complicated when societal issues weigh in (Marczewski and Kamrin, 2000). Is the exposure voluntary (as in smoking cigarettes) or involuntary (as in pollution from a factory)? Does it occur in the workplace or at home? Are there acceptable alternatives to the use of the toxic chemical? How would use of a safer chemical change the economic picture?

To establish some individual control over community management of chemical exposure, people can choose to be involved with organizations and agencies that are concerned with the prevention of toxic chemical exposure on a community level.

Notes about Lesson 5

In this lesson, students have the opportunity to apply many of the concepts of toxicology to a scenario that involved toxic chemicals in Minamata, Japan. By looking at a situation from the 1950s, students can recognize how far scientists and the general public have come in their understanding of chemical hazards and their knowledge of how to minimize risk from these hazards. Students can begin to identify situations in their own lives in which they make conscious decisions to limit their chemical exposure and those over which they have little control.

In Advance

Web-Based Activities

Activity 1 has a Web-based component.

Photocopies and Transparencies	Materials
1 transparency of Master 5.1 1 copy of Master 5.2 **for each student**	• computer • overhead projector • plain paper • current event stories students began collecting in Lesson 1, Extension Activity (optional)

Preparation

Activity 1

Arrange for students to have access to computers.

Make a transparency of Master 5.1, *Risk Assessment and Management*.

Duplicate Master 5.2, *Minamata Disease*, one for each student. To allow students to read only small amounts of the information at a time, fold along the dashed lines.

Activity 2

Gather the same materials used in Activity 1.

Extension Activity

Remind students to bring in the current event stories they began collecting in Lesson 1.

Be sure to have a transparency of Master 5.1, *Risk Assessment and Management*.

Procedure

ACTIVITY 1: People At Risk

1. **Remind students that there are chemicals in the environment that cause health problems for humans. Tell students that toxicologists study the extent and type of health problems associated with a particular level of chemical exposure. Then, they use what they learn to assess the threat of that chemical to the health of people in particular situations. This kind of analysis is called a *risk assessment*. Display the top half of a transparency of Master 5.1, *Risk Assessment and Management*.**

2. **Distribute the folded sheets made from Master 5.2, *Minamata Disease*.**

   Tell students that they are going to practice the steps to making a risk assessment by using a well-known case from Japan in the 1950s. Instruct students to read Part I of Master 5.2. Then, discuss the answers to the questions in Step 1 on the Master 5.1 transparency.

   - **Is a new health problem present?**

   Yes. Fish, cats, and birds were sick and dying. Also, people were acting strangely.

   - **What are the symptoms?**

   People were stumbling, unable to write, fumbling with their buttons, having difficulty balancing, falling from boats, suffering from convulsions, and dying.

   - **What do the affected individuals have in common?**

   Many work as fishermen or were in the families of fishermen.

   Once students have answered the questions on the transparency, ask them to offer ideas about what they think was contaminating the fish.

Minamata photographs by W. Eugene Smith and Aileen M. Smith.

NS ES

Content Standard F:
Students should develop understanding of personal health, natural hazards, and risks and benefits.

3. **Instruct students to unfold the first fold, revealing Part II. Ask them to read the paragraphs and then answer the questions in Step 2 of Master 5.1.**

   - **What is causing the problem?**

   Pollution was contaminating the fish with mercury, and people were getting sick when they ate the fish.

   - **What is the source of the problem?**

   The Chisso Corporation was dumping the mercury, so the company was the source of the problem. It might be interesting to discuss the role the community had in allowing the pollution of the bay to continue by accepting compensation for poor fishing conditions. Could the townspeople have demanded cleaner water instead of being satisfied with a monetary solution to the problem of fewer fish for harvest?

   Once students have answered the questions on the transparency, ask them to suggest answers to the question at the end of Part II: What made this contamination of the fish so dangerous to humans?

4. **Instruct students to unfold the next fold, revealing Part III. Ask students to read the paragraph and then answer the questions in Step 3 of the risk assessment (Master 5.1).**

- **What are the sources of exposure to the chemical?**

People were exposed to mercury by eating contaminated fish. The contamination of the fish was serious because it was a primary food source for the community.

- **How much exposure are people in the area receiving?**

People in Minamata, especially fishermen and their families, ate fish often. They were getting a small amount of mercury often over a period of time. Any amount of contaminated fish over 30 pounds per year is likely to provide a harmful exposure to mercury.

- **Is the exposure acute or chronic? (Is it likely to happen only once or often over the course of time?)**

The exposure to mercury happened in Minamata over a long period of time: It was a chronic chemical exposure.

5. **Ask students *not* to unfold the last fold until directed to do so during the next activity. Discuss the information from the reading and answer the concluding question on the risk assessment (Master 5.1): How great is the risk to people?**

Photo: Corel

Because of their dependence on fish as a primary source of food, the potential risk of mercury poisoning from contaminated fish for people living in Minamata was very high.

6. **Play the video segment on the Web site that describes the Minamata story.**

Go to the Web Portion of Student Activities page and choose Lesson 5 (*http://science.education.nih.gov/supplements/chemicals/student*). Play the video documentary for the students.

Because the time period and geographic location of the Minamata tragedy are so far removed from students' experiences, the visual representation of the story on the Web site helps it come alive for students.

NSES

Content Standard E:
Students should develop understandings about science and technology. Perfectly designed solutions do not exist. All technological solutions have tradeoffs, such as safety, cost, efficiency, and appearance…. Technological solutions have intended benefits and unintended consequences. Some consequences can be predicted, others cannot.

ACTIVITY 2: What Is *Your* Risk?

1. **Remind students that mercury is used today in thermometers and batteries. (Although newer thermometers now use red alcohol, many old ones contain mercury.) Tell students that although they do not live in Minamata in the 1950s, inappropriate disposal of items containing mercury poses a threat to their environment, even today. Since garbage is either incinerated or covered up in landfills, mercury can make its way into the environment through emission of burning gases into the air or groundwater contamination. Fish contaminated with mercury can make their way into the food supply.**

2. **Ask students how they think they can avoid mercury poisoning from contaminated fish.**

   Photo: Corel

   Most students will say that they could stop eating fish, thereby eliminating their risk just by avoiding exposure to the mercury-contaminated fish. Some students may indicate that the risk of mercury poisoning provides a great excuse to avoid a less-than-favorite food: fish.

   Ask students if it is possible always to avoid a chemical in order to eliminate possible exposure. What about a chemical in the air? Could students choose not to breathe in order to avoid exposure to an air pollutant?

   This question brings up the issue of control. If your food supply is varied enough, you can choose not to eat fish and still remain healthy. (This might not be an option for an island population that depends on fish for protein.) You cannot, however, choose not to breathe as a way to avoid exposure to an air pollutant. You would need to find other ways to limit your exposure to the air pollutant, like staying inside, not exercising outside, or wearing a mask that filters the air.

3. **Tell students that one of the reasons for understanding the role of toxicology in human health is to empower the students to make choices that decrease their risk of becoming ill due to exposure to harmful chemicals. Once they know the risk from a chemical exposure, they can manage their risk by deciding how to deal with the risk. Walk the students through the steps of Risk Management on the bottom half of the transparency of Master 5.1. Contrast the situation in Minamata, Japan, in the 1950s with the life of a today's typical U.S. middle school student.**

   First, ask the students to think about risk assessment:

   - What is a person's risk of mercury poisoning?

   Because of their dependence on fish as a primary source of food, the potential risk for a person living in Minamata in the 1950s was high. For today's middle school students, the risk is relatively low. The average middle school student does not consume enough fish to pose a problem, and most of the fish is commercially caught in regulated waters. Only a middle school student who lived near contaminated water and regularly ate the fish from the contaminated water would be at a higher risk.

Then, continue answering the questions in the Risk Management section of Master 5.1:

- How do the people involved perceive the risk? Are their perceptions accurate?

Possible answers: At first, Minamata residents did not know of the risk or worry about it. Once they began to see the effects of mercury poisoning, the Minamata residents perceived the risk as very serious. Their perceptions were accurate: Their primary food source was contaminated by industrial pollution, and that pollution was having a direct effect on the health of the community.

Middle school students should perceive their risk as minimal. If a student perceives his or her risk as high, that perception would not be accurate according to the risk assessment above.

- Who is responsible for the harmful substance and its presence in the environment? What role does the responsible party have in any cleanup?

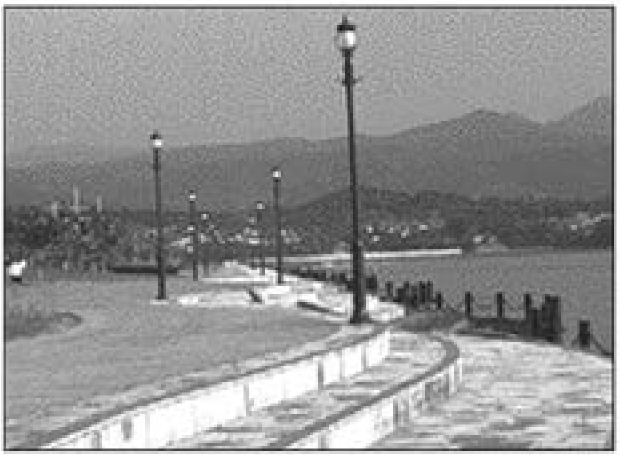
Allow time for students to discuss who they think was responsible for the situation in Minamata and what they think the responsible party should have done. Then, instruct them to unfold the last fold on Master 5.2 and read Part IV.

The Chisso Corporation was responsible for discharging polluted effluent into the bay. The corporation ultimately was held liable for its negligence in the 1970s. More complicated, however, are the social and economic pressures that influenced the placement of the plant in Minamata: People in the fishing village were interested in progress and enjoyed the prosperity that the industry brought to the town.

Middle school students could be indirectly responsible for some of the mercury contamination in their local area because of the way they dispose of batteries. Students and family members can take responsibility for disposing of potentially harmful materials in a safe way and using safer alternatives, such as rechargeable batteries.

- What are the benefits and trade-offs that a person must weigh when making a decision about the risk?

Fish provide many health benefits to the cardiovascular system and to brain development. The dietary proteins that fish provided to the residents of Minamata were very important to good health. However,



Photos courtesy of the City of Minamata, Japan.

we now know that mercury poisoning from eating contaminated fish results in serious brain damage. The U.S. Environmental Protection Agency has advised that there are health benefits to eating fish and that consumption of fish should continue, but at a rate not to exceed 30 pounds per year. Because middle school students rarely reach an annual level of consumption of 30 pounds of fish, they can enjoy all the health benefits of eating fish without being concerned about any negative trade-offs.

- What action should people take to minimize their risk? Can the risk be managed by individuals, the community, and/or governments?

In Minamata, industrial manufacture of acetaldehyde needed to stop. The corporation still operates in Minamata but produces liquid crystals, preservatives, fertilizers, and other chemicals. Over several years, 1.5 million cubic meters of contaminated sludge was dredged from the bay. Over the main dumping site there now are museums, memorial sites, parks, and a study center. In 1997, the water in the bay was declared safe again for fishing and swimming. People have chosen to move away from Minamata to make their living elsewhere: The town has only 70 percent of the number of people it once had.

Middle school students can eat fish sensibly, dispose of mercury-containing products safely, and support organizations that provide hazardous waste cleanup in their communities. Regulatory agencies can measure mercury contamination in fish and regulate fishing or sales of fish from contaminated waters.

Review a local or current situation in which people are being exposed to a hazardous chemical. Use the Master 5.1, *Risk Assessment and Management*, transparency to discuss students' ideas about the level of risk for the community and ways to manage that risk.

Extension Activity

Tip from the field test: This is a good time to go back to the current event articles the students have been collecting since Lesson 1. Choose one or two of the most interesting situations and assess risk for the population and decide how to manage the risk.

Because a current situation most likely will be unresolved, you will need to lead an open-ended discussion and help students recognize that there might not be answers for some of their questions at this time. This process of asking questions and not knowing the "right" answers is representative of the nature of science and scientific inquiry.

Before discussing the current event with the class, ask students to do a risk assessment individually. Collect students' written summaries and evaluate them for understanding of the process of assessing risk. Then discuss the students' ideas for managing the risk.

Content Standard G: Students should develop understanding of the nature of science and the history of science.

Environmental Hazards

At a Glance

Overview

Students use the knowledge they have gained from previous lessons to solve a problem depicted in a fictional scenario. In the scenario, students participate in a field trip to a natural history museum. Upon returning to the school, many participants complain of headache and nausea. Students consider the potential chemical exposures experienced by the field-trip participants and analyze who was exposed, how they were exposed, and how much exposure they experienced. Using fact sheets to learn about the specific hazards and health reactions attributable to certain chemicals, students solve the problem and recommend ways that the participants could have minimized or eliminated their exposure.

Major Concepts

People can use their understanding of the science of toxicology to identify potential sources of harm to human health from chemicals in the environment. They can use their knowledge to propose possible means to eliminate or reduce exposure to environmental toxic agents.

Objectives

After completing this lesson, students will

- be able to identify potential sources of harm to human health from chemicals in the environment;
- be able to apply their knowledge about dose, response, route of exposure, and individual susceptibility to situations involving potentially hazardous chemical exposures; and
- propose possible means to eliminate or reduce exposure to environmental toxic agents.

Background Information

Protecting Human Health

Decisions about chemical exposures occur at different levels. For example, a person can choose whether he or she wants to consume caffeine. In other cases, an individual is not able to control a chemical exposure simply by making a personal decision. For example, while a person might choose not to smoke in order to avoid exposure to the chemicals in tobacco smoke, he or she sometimes is unable to avoid secondhand smoke.

Sometimes there are larger social, economic, and political forces involved in hazardous exposure at a community level. As a result, organizations and agencies, including different levels of government, often become involved in prevention of chemical exposure and intervention when people suspect chemical exposure. For example, regulations made at a community level can minimize the exposure of members of the community to secondhand smoke in public places.

On a national level, many organizations are concerned with protecting and improving human health. The **Department of Health and Human Services** is the U.S. government's principal agency for protecting the health of all Americans. Within the Department of Health and Human Services operate many different divisions. The **National Institutes of Health** (NIH) is the world's premier medical research organization. Among its many institutes and centers is the **National Institute of Environmental Health Sciences** (NIEHS), whose mission is to reduce the burden of human illness and dysfunction from environmental causes by understanding how environmental factors, individual susceptibility, and age interrelate. The NIEHS achieves its mission through multidisciplinary biomedical research programs, prevention and intervention efforts, and communication strategies that encompass training, education, technology transfer, and community outreach.

The mission of the **Agency for Toxic Substances and Disease Registry** (ATSDR) is to prevent adverse effects on human health and diminished quality of life associated with exposure to hazardous substances from waste sites, unplanned releases, and other sources of pollution present in the environment. The ATSDR is directed by congressional mandate to perform specific functions concerning the effect on public health of hazardous substances in the environment. These functions include public health assessments of waste sites, health consultation concerning specific hazardous substances, health surveillance and registries, response to emergency releases of hazardous substances, applied research in support of public health assessments, information development and dissemination, and education and training concerning hazardous substances.

The **Food and Drug Administration** (FDA) ensures that the food we eat is safe and wholesome, the cosmetics we use don't hurt us, the medicines and medical devices we use are safe and effective, and radiation-emitting products such as microwave ovens won't harm us. Feed and drugs for pets and farm animals also come under FDA scrutiny. The FDA also sees that all of these products are labeled truthfully with the information that people need to use them properly. First and foremost, the FDA is a public health agency, charged with protecting American consumers by enforcing the Federal Food, Drug, and Cosmetic Act and several related public health laws. Investigators and inspectors visit more than 15,000 facilities a year, checking that products are made correctly and labeled truthfully. On average, 3,000 products a year are determined to be unfit for consumers and are withdrawn from the marketplace. In addition, about 30,000 import shipments a year are detained at the port of entry because the goods appear to be unsafe.

In addition to divisions of the Department of Health and Human Services, there are other government agencies for the communal protection of health. The mission of the **U.S. Environmental Protection Agency** (EPA) is to protect human health and to safeguard the natural environment—air, water, and land—upon which life depends. The EPA's purpose is to ensure that

- all Americans are protected from significant risks to human health and the environment where they live, learn, and work;
- national efforts to reduce environmental risk are based on the best available scientific information;
- federal laws protecting human health and the environment are enforced fairly and effectively;
- environmental protection is an integral consideration in U.S. policies concerning natural resources, human health, economic growth, energy, transportation, agriculture, industry, and international trade, and these factors are similarly considered in establishing environmental policy;
- all parts of society (communities, individuals, business, state and local governments, tribal governments) have access to accurate information sufficient to participate effectively in managing human health and environmental risks;
- environmental protection contributes to making our communities and ecosystems diverse, sustainable, and economically productive; and
- the United States plays a leadership role in working with other nations to protect the global environment.

Part of the U.S. Department of Labor is the **Occupational Safety and Health Administration** (OSHA). The mission of OSHA is to save lives, prevent injuries, and protect the health of America's workers. To accomplish this, federal and state governments work in partnership with the more than 100 million working men and women and their employers to comply with the Occupational Safety and Health Act of 1970. OSHA currently regulates exposure to approximately 400 substances present in the workplace that are capable of causing harm. Together with the **National Institute for Occupational Safety and Health** (NIOSH), which is part of the **Centers for Disease Control and Prevention** (CDC), OSHA provides guidelines about chemicals, including chemical and physical properties, health effects, exposure limits, and recommendations for medical monitoring. These guidelines summarize pertinent information about chemicals for workers and employers as well as for physicians, industrial hygienists, and other occupational safety and health professionals who may need such information to conduct effective occupational safety and health programs.

The **U.S. Department of Agriculture** (USDA) has agricultural toxicology regulatory authority, and the **Food and Nutrition Service** (FNS) participates with the CDC on food safety issues.

Notes about Lesson 6

In Lesson 6, students analyze a fictional situation in which members of a class are exposed to a chemical that makes them sick. While they investigate several scenarios in which individual behavior increased the risk of chemical exposure, students recognize that the actual cause of the sickness in the scenario is carbon monoxide poisoning caused by a faulty exhaust system in a school bus. Because the maintenance of the bus is a school district responsibility, and not an individual one, the exposure of students to carbon monoxide is not one over which the exposed students had control. Students see that there are various regulations, agencies, and organizations in place to protect them as citizens from chemical exposure over which they have little control. It is important, however, for students to recognize that they have the right, as citizens of their school, community, nation, and the world, to seek direct input into how to reduce the extent of chemical exposure on a communal level.

As the Evaluate lesson for the curriculum supplement, Lesson 6 offers students the opportunity to express their understanding of the concepts in the supplement in a new context. As students share and compare their ideas with those of others, they can refine and revise them. As you listen to them reasoning out loud, you can assess their individual understanding of human health and the environment.

This lesson is not the only opportunity you have had to assess your students' progress. As noted in each of the previous lessons, assessments have gone hand in hand with instruction throughout the supplement. Whenever individual students expressed themselves by talking, writing, or performing tasks, you have had an opportunity to assess their thinking and thus their learning. The assessment tasks are embedded within the lessons and offer you the opportunity to

- determine students' initial understanding of concepts to be learned,
- determine students' initial familiarity with processes and their ability to use them,
- monitor students' conceptual development and ability to use certain processes and skills, and
- collect information about students' achievement of the outcomes of each lesson and of the supplement as a whole.

(continued)

The approach to assessment in this supplement is congruent with the following recommendations in the *National Science Education Standards* (National Research Council, 1996).

- Assessment tasks are deliberately designed.
- Assessment tasks have explicitly stated purposes.
- Assessment data focus on the science content that is most important for students to learn.
- Assessment tasks are valid and authentic.
- Students have adequate opportunities to demonstrate their achievements.
- Assessment tasks are set in a variety of contexts.
- Assessment tasks include opportunities for students' self-assessment and reflection.

In Advance

Web-Based Activities

Activity 1 has a Web-based component.

Photocopies and Transparencies	Materials
1 copy of Master 6.1 **for each student** (print version only) 1 Choice Card from Master 6.2 **for each student** (print version only) 5 copies (at least) of Master 6.3 (print version only)	• computers • 1 red marker (print version only) • 1 coin for each student (print version only)

PREPARATION

Activity 1

Decide whether you will use the Web or print version of this activity. If you choose to use the Web version, which is preferred, arrange for students to have access to computers.

If you use the print version, gather the materials needed to conduct the activity. Duplicate Master 6.1, *Heads or Tails?*, 1 for each student. Copy Master 6.2, *Choice Cards*, and cut apart the cards, making enough for each student to have one card. Make at least five sets of the six fact sheets in Master 6.3, *Fact Sheets on Chemicals*. Fold each fact sheet in half. Label the outside of each sheet with the location from the scenario. Place the sets of fact sheets on a desk in the front of the room.

Activity 2

If you used the print version of Activity 1, students need their completed copy of Master 6.1, *Heads or Tails?*

Procedure

ACTIVITY 1: The Field Trip

Web Version

The following procedures describe how to conduct the Web version of this activity. Instructions for the print version follow after Step 4-w.

NSES

Content Standard A:
Students should develop abilities necessary to do scientific inquiry.

1-w. **Gather students in the computer lab and direct them to work with a partner for this Web-based activity.**

> WWW
>
> Have students go to the Web Portion of Student Activities page and choose Lesson 6 (*http://science.education.nih.gov/supplements/chemicals/student*). Then, have them click on *The Field Trip* and watch the video.

2-w. **Instruct students to work through the problem posed in the video using the available resources, records, and data.**

Circulate around the room, listening to students as they solve the problem presented on the Web site. Listen to see if students are using the language of toxicology: chemical, dose, response, individual susceptibility, and route of exposure.

3-w. **Once all teams have reached a conclusion about the cause of the illness on the field trip, conduct a class discussion during which teams present their conclusions and their supporting evidence.**

Because most students should reach the same conclusion (that a faulty exhaust system in the old yellow bus created carbon monoxide in high enough concentrations to poison some of the students), encourage teams to share one piece of evidence they used to come to their conclusion. Then, let other teams add to the picture of carbon monoxide poisoning, or share evidence for why another chemical exposure probably did not contribute to the illness of the students. In this way, all students have an opportunity to share new ideas.

4-w. **To complete the discussion of the field trip, go to Activity 2.**

Print Version

If you do not have access to the Web site, use the following print version of Activity 1.

NSES

Content Standard A:
Students should develop abilities necessary to do scientific inquiry.

1-p. **Tell students that today they are going to participate in a recreation of a field trip to a natural history museum. To let them know what the field trip was like, read to them the journal entry from one of the participants on the field trip (see page 113).**

2-p. **Distribute to each student one copy of Master 6.1, *Heads or Tails?* Tell students that they are going to determine their actions on the field trip based on a coin toss. For each action, if they get heads, they will check the box for the action on the left-hand side of the page. If they get tails, they will check the box for the action on the right-hand side of the page.**

Today, we went with our whole class to the Museum of Natural History. It was a cool trip! So much happened that I want to remember, so I am going to write it all down here. First, we all loaded up in the new blue passenger van—you know, the one that the school just bought. It was awesome. The seats are like airline seats and they even have seat belts. We didn't have to squish three into a seat like we do in the old bus. My friends and I rushed to get the back of the van—it's better there because we can have the most fun. We had to stop at the gas station to fuel up the van, so we stuck our heads out of the windows in the back and talked to the driver as he filled the tank. I guess we distracted him, because he overflowed the tank and some gas spilled on the ground. Oops! Gasoline sure stinks! Finally, we got back on the road. When we got to the museum, we got a special tour by a paleontologist. She showed us the lab where fossil exhibits are prepared. We stood outside the window and watched the scientists build a model of a dinosaur out of fiber glass and plywood. All the people in the lab wore respirators because I guess there are lots of chemicals in use in there—at least there was a sign on the door that said, "Caution! Chemicals in Use. Authorized Personnel Only." Then, without even reading the sign, a couple of kids from the class opened the door and went into the lab! Our guide seemed shocked. She pounded on the glass to get a scientist's attention. A scientist saw the students and hurried them back to the door. I think they got yelled at, but it was hard to tell what the scientist was saying through the respirator. Boy, did they get in trouble from the teacher!

When it was lunch time, we got to eat our sack lunches in the picnic area. It was a neat, big atrium with a really tall glass ceiling. A treat from the teachers was that each of us got to drink a soda that they brought in a big cooler. It was really too bad that they didn't have more root beer or lemon-lime soda because the new kid had to drink a caffeinated soda because that was all that was left—and she really isn't supposed to drink it because of some problem she has with caffeine. I would have shared mine with her, but I already took a sip from it.

After lunch they planned for us to go into the hands-on activity room. We got to paint plaster models of dinosaurs. What a mess we made. Some kids got paint all over their skin and needed to wash it off at the sink. We got sort of wild by the time we finished the project, and I think our teachers were ready to get us back to school.

When we went outside the museum, we saw the old yellow bus there to pick us up. My friends groaned—no more plush seats and clean windows. I never feel as safe in the old bus because there aren't seat belts, so I sat in the front of the bus going back to school, squished into a seat with two other people. I sure was glad to get to the school. The funny thing was that we weren't nearly as noisy going home as we were going to the museum. I guess we were tired. It was a fun day anyway.

3-p. Next, distribute one Choice Card (from Master 6.2) to each student. Tell students that they can use the Choice Card to overrule one of their coin flips if they would rather choose the opposite action.

4-p. Give each student one coin. Proceed as a class through the *Heads or Tails?* worksheet, one action at a time. Ask students to record the results of their coin toss by checking the appropriate box on the sheet. Remind students that they can use their Choice Card for one turn to choose the opposite action.

5-p. After all the students have completed the worksheet, announce that some of the members of the class got sick after the field trip and ended up going to the emergency room with their parents because they had severe headaches and nausea. Circulate around the room looking at all the students' sheets. With a red marker, write the words "Sick" or "Not Sick" on the top of each sheet.

Mark "Sick" on the worksheets if the student marked "you sat in the back of the yellow bus" (got heads in the coin toss for the last action). If the student marked "you sat in the front of the yellow bus" (got tails for the last action), then the student is not sick. Do not let the students know that you are looking only at the last action: Make it look like you are studying all the actions for the trip to decide if the student is sick.

Tip from the field test: To make the discussion more interesting and the problem harder and less obvious to solve, mark one or two students sick who did *not* sit at the back of the yellow bus. These students represent individuals who have higher susceptibility to carbon monoxide even though they did not sit in the back of the bus nearest to the faulty exhaust system. More-susceptible individuals would be affected by a lower concentration of carbon monoxide.

6-p. Discuss the problem of some students getting sick by asking these questions:

- **Why do you think some of the students got sick?**

Answers will vary, but try to get students to recognize that some students might have been exposed to chemicals during the field trip.

- **To what chemicals could students have been exposed during each of the parts of the field trip?**

Conduct a brainstorming session with students of possible chemical exposures:

- Ride in new van: "new car smell" from new carpet and seat fabrics, exhaust fumes
- Gas station: gasoline fumes
- Paleontology lab: fiber glass dust, plywood fumes
- Lunch: caffeine in soda, food poisoning from sack lunches
- Painting activity: paint on the skin, cleanup solvents
- Bus ride in the old bus: gasoline fumes, exhaust fumes



- **Why didn't all of the students get sick?**

Answers will vary. Some students might not have been exposed to chemicals because their actions were different. Some might not be susceptible to the chemicals that made other students sick.

- **How would you figure out what made some students sick while others remained healthy?**

Answers will vary. Accept possible strategies before moving to Step 7-p. Students might suggest comparing sick students' actions to the actions of students who did not get sick. Propose this strategy if students do not mention it.

7-p. **Ask each student who is sick to pair up with a student who is not sick.**

Statistically, you should end up with nearly an equal amount of sick and healthy students. If the numbers are not even, make a few groups of three students.

Tell students that you want them to figure out what made one student sick in each pair. Ask students to work with their partners to determine what actions and chemicals could have caused the sickness in their pair.

Students will realize that they can compare the actions each took on the field trip. If there are actions that the sick student did that the other student did not do, students might hypothesize that those actions put the sick student more at risk of exposure to certain chemicals.

8-p. Ask the students what information they need to solve the problem of what caused the sickness in some students.

Help students realize that they need more information about the kinds of chemicals to which students were exposed and the symptoms caused by each.

Show students the sets of fact sheets (Master 6.3) at the front of the room. Tell the students that each fact sheet contains information about chemicals to which some students were exposed at specific locations during the field trip. Instruct students to go to the front of the room and select one fact sheet the pair would like to study based on their determination from Step 7-p of what actions and chemical exposures might have caused the sickness. They can return that fact sheet and select another if time allows.

Direct students to read the information on the fact sheet, discuss it with their partner, and decide whether the chemical in the location could have caused the sickness.

Students should consider the chemical, the route of exposure, the dose, and the symptoms that a person exposed to the chemical exhibits. When they read the fact sheet, they may determine that the chemicals to which they were exposed in a certain location could not have caused the illness because there was not enough chemical there, the dose they might have received was too little, or the symptoms of the sick people do not match those produced by exposure to the chemicals.

Students will probably have more than one possible location of chemical exposure to check. They will need to study all the possible locations and chemicals to determine which one might have caused the sickness. It is possible that they may not be able to decide between two possibilities until the class meets together and compares notes.

9-p. Once students have come to some conclusions about the possible cause of sickness, discuss their solutions with the whole class.

There are two ways to figure out why some students became sick. The first is by the process of elimination. Help students narrow the possible chemicals that caused illness by determining how many of the sick students were exposed to chemicals at each location. Compare the total number of sick students with those sick students who were involved in actions at the various locations. For example, if the total number of sick students was 15, but only 6 sick students drank caffeine, what conclusions can students draw?

From the discussion, students can see that all the students who sat at the back of the yellow bus became sick, while students who took part in each of the other actions were not universally sick. Ask the sick students how many were *not* sitting at the back of the yellow bus. Only those few students you purposely marked sick (if you chose to) should reply. Explain their illness in the context of individual susceptibility to chemical exposure.

The second way to figure out what made the students sick is to study the fact sheets. In all cases except carbon monoxide, the exposure the students received to the chemicals in each location is insignificant. Students can see that, even though there might be chemicals present in various locations or associated with various activities, their health is not at risk when they are exposed at the levels that were present on the field trip. Being able to recognize that an exposure to a chemical is not at a level that causes harm is an important part of the risk-assessment process.

Students will make the correlation between sitting in the back of the yellow bus and carbon monoxide poisoning by referring to the fact sheets. They will reach the conclusion that the sick students were suffering from carbon monoxide poisoning, which was caused by a faulty exhaust system in the old yellow bus. Those in the back of the bus were exposed to more carbon monoxide than those in the front of the bus. Those who got sick who were sitting in places other than the back of the bus must be more sensitive to carbon monoxide than average.

To assess your students' understanding of individual susceptibility, ask them to explain what could have happened to those few students who did not sit at the back of the bus but were sick anyway.

10-p. To complete the discussion of the field trip, go to Activity 2.

ACTIVITY 2: What Can I Do?

1. **Ask students whether some of the students on the field trip made choices that either limited or increased their exposure to chemicals on the museum field trip. Discuss how the choices the students on the field trip made are similar to decisions that they make in their own lives.**

   Students who did the Web version of the activity can refer to the records online to find out how exposure to the chemicals present at the field trip locations can be avoided.

   If students did the print version of Activity 1, ask them how their use of the Choice Cards simulated decisions they make in their own lives that influence their exposure to chemicals.

   Informed citizens can make decisions to limit or eliminate their exposure to environmental hazards. They can alter their lifestyles, their work, their use of materials that are made of hazardous chemicals, and so on.

NSES

Content Standard F: Students should develop understanding of personal health, natural hazards, and risks and benefits.

2. **Discuss with students that the cause of the sickness in some of the field-trip students was related to a situation over which the students had no control. Ask students what they think they would be able to do about the faulty exhaust system in the bus. Go one step further and ask students what they think they can do about chemical exposure on a community level.**

   Some choices are not left to the individual because the decisions are made at a community or national level. For example, people could be at risk of exposure to radiation when they live near a nuclear power plant even if they do not support the decision to use nuclear energy to produce power. In the scenario in this activity, students did not know that the yellow bus had a faulty exhaust system, so they were unable to decide to limit their exposure to carbon monoxide. In response to the situation with the bus, students could write letters to their superintendent, petition the school for stricter safety standards, or raise money to support a better maintenance program. Share with students information about the various organizations and agencies whose mission it is to protect human health (see *Background Information*). Encourage students to investigate the organizations by logging onto the following Web sites:

   - U.S. Department of Health and Human Services
     http://www.hhs.gov
   - National Institutes of Health
     http://www.nih.gov
   - National Institute of Environmental Health Sciences
     http://www.niehs.nih.gov
   - Agency for Toxic Substances and Disease Registry
     http://www.atsdr.cdc.gov
   - U.S. Food and Drug Administration
     http://www.fda.gov
   - U.S. Environmental Protection Agency
     http://www.epa.gov
   - U.S. Occupational Safety and Health Administration
     http://www.osha.gov
   - National Institute for Occupational Safety and Health
     http://www.cdc.gov/niosh
   - Centers for Disease Control and Prevention
     http://www.cdc.gov
   - U.S. Department of Agriculture and Food and Nutrition Service
     http://www.usda.gov

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Lesson 1
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Additional Resources for Teachers

The following resources may provide additional background information for you and your students about chemicals in the environment and human health.

Agency for Toxic Substances and Disease Registry

http://www.atsdr.cdc.gov
This site includes ToxFAQs™, summaries about hazardous substances with easy-to-understand information about exposure to hazardous substances and effects on human health (*http//:www.atsdr.cdc.gov/toxfaq.html*). The site also includes a kids' page (*http://www.cdc.gov/family/kidsites/index.htm*) with facts about toxic chemicals and the environment.

Centers for Disease Control and Prevention

http://www.cdc.gov/
Offers information on a range of topics including diseases and conditions (*http://www.cdc.gov/DiseasesConditions/*) like ADHD, autism, cancer, HIV/AIDS; environmental health (*http://www.cdc.gov/Environmental/*) issues like air quality, asthma, climate change, natural disasters; life stages and populations (*http://www.cdc.gov/LifeStages/*) covering pregnancy, children, women, older adults; healthy living (*http://www.cdc.gov/HealthyLiving/*) covering topics like aging, mental health, genetics and genomics, and obesity.

Environmental Health Perspectives

http://www.ehponline.org
A monthly journal of peer-reviewed research and news published by the NIEHS. The *EHP* Science Education Program promotes environmental health science as an integrative context for learning to promote students' use and understanding of scientific literature. We do this by using current, credible environmental health information to teach students about the interconnection between their health and the world around them.

International Food Information Council

http://www.foodinsight.org
Read the article titled "Caffeine and health: Clarifying the controversies." The site includes information for educators on food and food risks.

National Environmental Education Foundation

http://www.neefusa.org
NEEF provides credible resources to solve everyday environmental problems.

National Institute of Environmental Health Sciences

http://www.niehs.nih.gov
This site provides current and authoritative information about the work of the National Institute of Environmental Health Sciences and about the institute's latest research projects. The site includes links to NIEHS curricula, resources for science teachers, and fact sheets about environmental health topics (*http://www.niehs.gov/health/scied/index.cfm*).

National Toxicology Program

http://ntp-server.niehs.nih.gov
Headquartered at the National Institute of Environmental Health Sciences, the National Toxicology Program coordinates toxicology research and testing activities within the Department of Health and Human Services. This site includes factsheets on chemicals, reports on carcinogens, and links to other sites, such as the Interagency Coordinating Committee on the Validation of Alternative Methods (ICCVAM) regarding toxicology testing (*http://iccvam.niehs.nih.gov/*).

Resource Guide on Children's Environmental Health

http://www.cehn.org/cehn/resources/resource_guide
This site, provided by the Children's Environmental Health Network, includes a keyword index so students can search specific toxicants (*http://www.cehn.org/resources/resource_guide_keyword_index*).

Society of Toxicology (SOT)

http://www.toxicology.org
A professional and scholarly organization of scientists who practice toxicology in the U.S. and abroad. SOT provides teachers with extensive resources to teach toxicology-related topics in the classroom and to familiarize students with the study of toxicology (*http://www.toxicology.org/teachers/curriculum.asp*).

Toxlearn

http://toxlearn.nlm.nih.gov/
A joint project of NLM and SOT is another extensive selection of databases and other toxicology related information resources.

U.S. Environmental Protection Agency

http://www.epa.gov/kids
This site has teacher and student resources for learning about the environment and the connection between the environment and human health.

U.S. National Library of Medicine (NLM)

http://www.nlm.nih.gov
The U.S. National Library of Medicine is the world's largest medical library. This site includes the Toxicology and Environmental Health Information Program, which provides information on toxicology, hazardous chemicals, and toxicological effects of drugs, among other topics (*http://sis.nlm.nih.gov/enviro.html*). For a listing of educational resources, go to *http://sis.nlm.nih.gov/enviro/edcotox.html#a4*. ToxTown for Teachers is at *http://toxtown.nlm.nih.gov/text_version/teachers.php*, and ToxMap Resources for Teachers are at *http://toxmap.nlm.nih.gov/toxmap/home/forTeachers.jsp*.

Other Helpful Sites

AAAS Educational Resources on ScienceNetLinks
- Toxicology: *http://www.sciencenetlinks.com/lessons.php?DocID=429*
- Endocrine Disruptors: *http://www.sciencenetlinks.com/lessons.php?DocID=407*

A Small Dose of Toxicology
- Learn about the effects of common chemicals: *http://www.asmalldoseof.org/toxicology/index.php*

Baylor College of Medicine Teacher Resources
- BioEd Online: *http://www.bioedonline.org/*
- K8 Science: *http://www.k8science.org/*

Canadian Network of Toxicology Centers
- Toxicology: *http://www.uoguelph.ca/cntc/educat/guide/guide_index.shtml*

EPA Teaching Center
- Teaching Resources: *http://www.epa.gov/teachers/teachresources.htm*

LessonPlanet
- Toxicology: *http://www.lessonplanet.com/search?media=lesson&keywords=toxicology&grade=All+Grades&rating=3*

Maryland Public Television: Thinkport
- EnviroHealth Connections: *http://www.thinkport.org/classroom/connections/default.tp*

Minimata Disease Resources
- Minimata Disease History: *http://www.env.go.jp/en/chemi/hs/minamata2002/index.html*
- National Institute for Minimata Disease: *http://www.nimd.go.jp/english/index.html*

NIEHS Science Mentor Idea
- For toxicologists: *http://www.toxexpo.com/AI/FA/Tipsheet1Toxic_eMay%202303.pdf*
- Oregon State University Environmental Health Sciences Center Educational Resources: *http://www.ehsc.orst.edu/teachers*
- Podcasts: *http://ehsc.science.oregonstate.edu/podcasts*

Southwest Environmental Health Sciences Center COEP

- Basic Toxicology Lab Stations: *http://coep.pharmacy.arizona.edu/curriculum/basictoxlab/index.html*
- Chemicals and Human Health: *http://coep.pharmacy.arizona.edu/curriculum/chh/index.html*

WGBH Boston Public Television

- PBS Teachers Domain: *http://www.teachersdomain.org/*
- Environmental Public Health Collection: *http://www.teachersdomain.org/special/enh/*

Chemical Hygiene Plan: 5.0 Toxic Chemicals. Radford, VA: Radford University. Retrieved February 17, 2010, at *http://www.radford.edu/fpc/Safety/ChemHyg/chp5.htm*.

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Glossary

Definitions for the following terms were gathered from a variety of sources, which are listed in the Reference section.

absorption: The process of taking in, as when a sponge takes up water. Chemicals can be absorbed through the skin into the blood stream and then transported to other organs. Chemicals also can be absorbed into the blood after they are breathed in or swallowed.

acetaminophen: A synthetic chemical used as an analgesic and as an antipyretic.

acute exposure: A single exposure to a toxic substance that results in a severe response or death. Acute exposures are characterized as lasting no longer than a day, as compared to longer, continuing chronic exposure over a period of time.

Ames test: Mutagenic assay (a measure of mutagenic ability) that involves specially engineered strains of bacteria. Because of the relationship between mutagenicity and carcinogenicity, the test is used as a rapid and relatively inexpensive first screening of untested chemicals that are suspected of being carcinogens.

benzene: A clear, colorless liquid with a sweet odor that burns readily. Benzene is obtained from crude petroleum. Small amounts may be found in products such as paints, glues, pesticides, and gasoline.

caffeine: A bitter crystalline alkaloid found in coffee, tea, kola nuts, and cacao pods; it is a heart and central nervous system stimulant.

carbon monoxide: A colorless, odorless poison gas produced by incomplete combustion of organic matter. Carbon monoxide may be produced in lethal quantities in automobile exhaust, faulty home heating systems, improperly used portable gas stoves and heaters, improperly vented wood stoves and fireplaces, and in many industrial situations.

carcinogenic: Any substance that may produce cancer.

chemical: Any substance having a defined molecular composition.

chronic exposure: Exposure to toxic chemicals occurring over a long period of time (months to over one year).

collagen matrix barrier: An artificial "skin" used to test whether a chemical is likely to irritate, corrode, or burn human skin.

concentration: The amount of one substance dissolved or contained in a given amount of another. For example, sea water contains a higher concentration of salt than an equal amount of fresh water does.

dimethylmercury: The same as methylmercury, but containing two methyl radicals, $(CH_3)_2$.

dosage: The amount of a toxicant, drug, or other chemical administered to, or taken by, an organism and expressed as some function of the organism and of time (mg/kg body weight/day).

dose: The total amount of a toxicant, drug, or other chemical that is administered to, or taken by, an organism.

dose response: How an organism's response to a toxic substance quantitatively shifts as its overall exposure to the substance increases (e.g., a small dose of carbon monoxide may cause drowsiness; a large dose can be fatal).

EC_{50}: Effective concentration; the dosage at which the desired response is present for 50 percent of the population.

element: A form of matter that cannot be broken down into simpler substances. Elements exist in nature as solids, liquids, or gases.

environment: The interdependent system of living and nonliving things.

experimental control: A group of experimental subjects that is not exposed to a chemical or treatment being investigated so that it can be compared with experimental groups that are exposed to the chemical or treatment.

exposure: Contact with a chemical by swallowing, breathing, or touching (such as with the skin or eyes). Exposure may be short term (acute) or long term (chronic).

fiber glass: Fine-spun filaments of glass. Fiber glass is often made into yarn that is woven into textiles, used in woolly masses as insulation, or pressed and molded as plastic material.

formaldehyde: A colorless, pungent gas used in solution as a strong disinfectant and preservative, and in the manufacture of synthetic resins and dyes.

genetic: Inherited; having to do with information that is passed from parents to children through DNA in the genes.

germinate: To sprout from a seed.

hazard: A source of risk. A hazard produces risk only if organisms are exposed to it and if exposure creates the possibility of harm.

hazardous waste: Byproducts of society that can pose a substantial or potential hazard to human health or the environment when improperly managed. Possesses at least one of four characteristics (ignitability, corrosivity, reactivity, or toxicity), or appears on special EPA lists.

heart rate: The number of pulses of the heart in one minute.

herbicide: Chemicals developed to kill plants or regulate plant growth.

individual susceptibility: Differences in reactions between people after exposure to the same amount of a hazardous substance. A person's body size, age, gender, genetics, and health status can affect individual susceptibility.

ingestion: Swallowing (such as eating or drinking). One route of exposure to chemicals. After ingestion, chemicals can be absorbed into the blood and distributed throughout the body.

inhalation: Breathing. One route of exposure to chemicals. During inhalation, chemicals can be deposited in the lungs, taken into the blood, or both.

insecticide: A chemical specifically used to kill or prevent the growth of insects.

irritant: A substance that can cause irritation of the skin, eyes, or respiratory system.

kilogram: A basic unit of mass; abbreviated kg.

LD_{50}: The dosage of chemicals needed to produce death in 50 percent of treated organisms. LD_{50}s are usually expressed as the weight of the chemical per unit of body weight (mg/kg). Chemicals may be fed (oral LD_{50}), applied to the skin (dermal LD_{50}), or administered in the form of vapors (inhalation LD_{50}).

lead: A heavy metal that is hazardous to human health if it is breathed or swallowed.

meniscus: Curved surface of a liquid in a graduated cylinder.

mercury: A heavy metal that can accumulate in tissue of organisms in the environment and is highly toxic if breathed or swallowed.

metabolism: All the chemical reactions that enable the body to function. For example, food is metabolized (chemically changed) to supply the body with energy. Chemicals can be metabolized by the body and made either more or less harmful.

methylisocyanate: A toxic chemical used in pesticide production.

methylmercury: A human-made molecule, synthesized for commercial purposes (to kill mold), and a naturally occurring compound made by certain bacteria. Methylmercury penetrates the brain and is a potent neurotoxin. Methylmercury also crosses the placenta and, as a result, a large number of women who were exposed during pregnancy in past methylmercury epidemics gave birth to severely brain-damaged children.

mg/kg: Milligrams per kilogram.

microgram (µg): One millionth of a gram.

milligram (mg): One thousandth of a gram.

Minamata disease: A neurological disease first identified in Minamata, Japan, as a result of mercury poisoning.

molecule: The smallest part of a compound that has all the properties of the compound; made up of two or more atoms chemically bonded.

mutagen: An agent that causes a permanent genetic change in a cell other than what occurs during normal genetic recombination. Mutagenicity is the capacity of a chemical or physical agent to cause such permanent alteration.

natural: Produced or existing in nature; not artificial or manufactured.

nervous system: Includes the brain and all the nerves.

neurotoxin: Any substance that is capable of destroying or adversely affecting nerve tissue.

National Institute of Environmental Health Sciences (NIEHS): One of the National Institutes of Health (NIH) research institutes. The mission of NIEHS is to reduce the burden of human illness and dysfunction from environmental causes by understanding how environmental factors, individual susceptibility, and age interrelate.

National Institutes of Health (NIH): One of eight health agencies of the Public Health Service (the Public Health Service is part of the U.S. Department of Health and Human Services). Composed of 24 separate institutes, centers, and divisions, NIH is the largest biomedical research facility in the world.

nontoxic: Not harmful or poisonous.

organism: The highest level of cell organization. All organisms carry out life processes.

overdose: Too large a dose; a dose to excess.

Paracelsus: A 16th-century physician (1493–1541) who saw the need for scientific experimentation in toxicology and thus gave toxicology a scientific basis. He recognized that chemicals often have both therapeutic and toxic properties based on dose. His observations laid the foundation for the concept of the dose-response relationship.

parathion: An organophosphate that is used as an insecticide; it is absorbed through the skin, eaten, or inhaled; it is toxic because it acts on the nervous system.

pesticide: Chemicals developed to control a wide variety of pests in primarily agricultural and forest environments.

pollution: The undesirable presence of matter or energy that can cause harmful environmental effects.

population: A group of individuals of the same species living in a particular area.

potency: The measure of a chemical's effectiveness as a medicine or a poison. The more potent the chemical, the less it takes to exert its effect.

response: The variety of reactions to exposure to chemicals that might occur in an organism.

risk assessment: Qualitative and quantitative evaluation of the risk posed to human health and/ or the environment by exposure to a chemical.

risk management: The process by which risk is reduced or controlled. Risk assessment information is used, along with other information, such as values, cost, and feasibility, to arrive at a risk management decision.

route of exposure: The way in which a person may contact a chemical substance. For example, a person may ingest a chemical, inhale a chemical, or absorb a chemical through the skin.

solvent: A substance (usually a liquid) capable of dissolving or dispersing one or more other substances. Water is a solvent. Organic solvents include alcohols, aldehydes, benzene, toluene, glycol ethers, trichloroethylene (TCE), formaldehyde, and carbon tetrachloride. Drinking water is an important source of solvent exposure; solvents also pass rapidly through the skin and produce high levels in the bloodstream within minutes after skin exposure. Nearly all solvents (other than water) can cause acute and chronic injury to the central nervous system. Many solvents are associated with development of kidney failure and chronic kidney disease, and others can cause acute toxic damage to the liver.

subacute exposure: Repeated exposure to a chemical for one month or less.

synthetic: Made by forming a compound by combining two or more simpler compounds, elements, or radicals; human-made, not from nature.

threshold: The lowest dose of a chemical at which a certain measurable effect is observed and below which it is not observed.

toxic: Harmful; poisonous.

toxicant: Any chemical or mixture of chemicals that presents a risk of death, disease, injury, or birth defects in organisms that ingest or absorb it.

toxicity: The capacity or property of a substance to cause adverse effects.

toxicologist: A scientist trained to examine the nature of the adverse effects of chemicals on living organisms and assess the probability of their occurrence.

toxicology: The multidisciplinary science that examines the adverse effects of chemicals on organisms.

toxin: A naturally occurring substance or agent that may injure an organism exposed to it.

Masters

Lesson 5, *What Is the Risk?*

Activity 1: People at Risk

Master 5.1, *Risk Assessment and Management* .... transparency
Master 5.2, *Minamata Disease* .... student copies

Lesson 6, *Environmental Hazards*

Activity 1: The Field Trip

Master 6.1, *Heads or Tails?* .... student copies (*print* version only)
Master 6.2, *Choice Cards* .... classroom set (*print* version only)
Master 6.3, *Fact Sheets on Chemicals* .... classroom sets (*print* version only)

Item Cards

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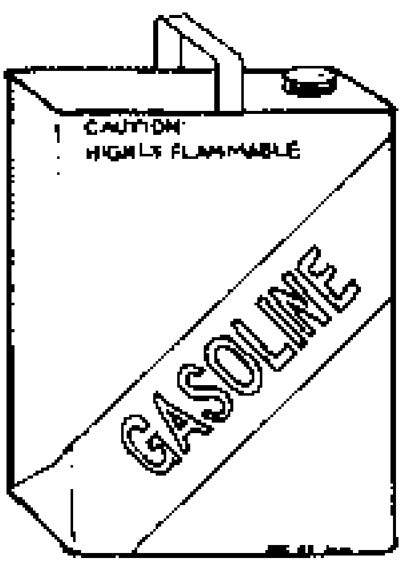
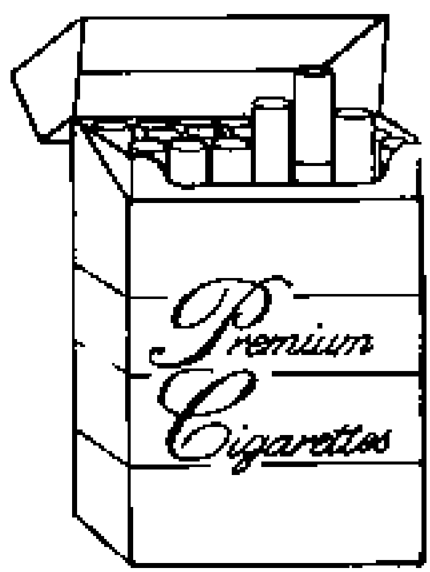
Gasoline



Tobacco



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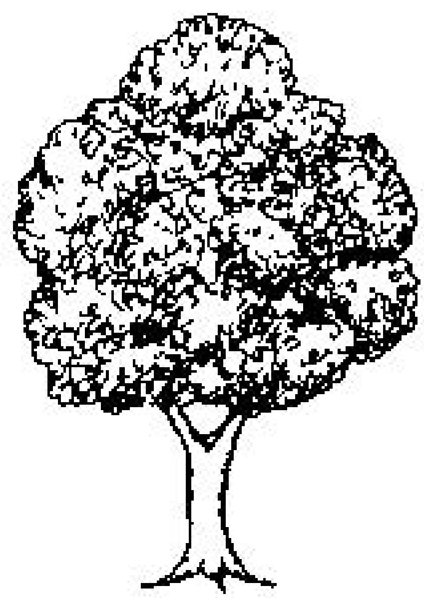
Alcohol

Tree



Master 1.1b (page 2 of 4)

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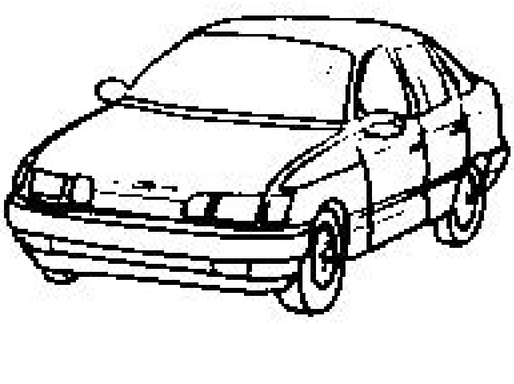
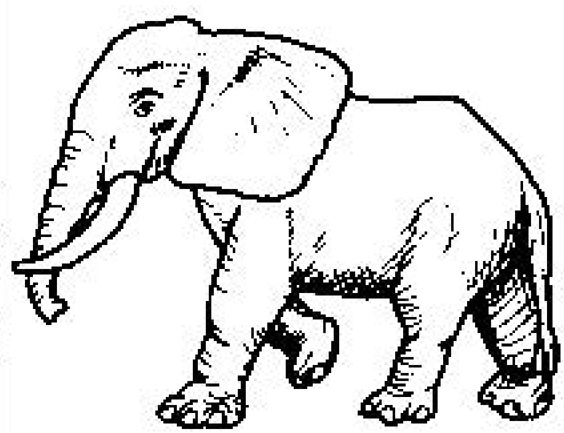
Car



Elephant



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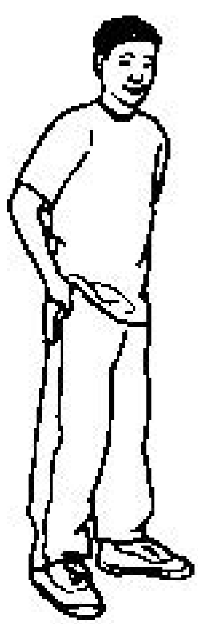
fold

Human



Poison

Periodic Table of Elements

Periodic Table of the Elements

Key: Symbol

H																		He
Li	Be													B	C	N	O	F	Ne
Na	Mg													Al	Si	P	S	Cl	Ar
K	Ca		Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr		Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	*	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	**	Lr	Rf	Db	Sg	Bh	Hs	Mt	110 Uun Ununnilium	111 Uuu Unununium	112 Uub Ununbium		114 Uuq Ununquadium		116 Uuh Ununhexium		118 Uuo Ununoctium

*	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
**	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No

Elemental Composition of the Human Body

Element	% of Human Body
oxygen	65.00
carbon	18.00
hydrogen	10.00
nitrogen	3.00
calcium	2.00
phosphorus	1.10
potassium	0.35
sulfur	0.25
chlorine	0.15
sodium	0.15
iodine	0.10
trace elements	under 0.10

Source: DiSpezio, M., et al. 1996. *Science insights: Exploring living things*. (Teacher's Edition) Menlo Park, CA: Addison-Wesley Publishing Company, p. 57.`

Questions for Case Studies

1. **What happened? Where did it happen? When did it happen?**

2. **What chemical was involved?**

3. **What was the route of exposure?**

4. **What were the symptoms of toxicity?**

5. **How could a person have prevented his or her exposure to the chemical?**

6. **Have any changes occurred since the incident? Describe them.**

Case Studies of Routes of Exposure

CASE STUDY #1

Dr. Karen Wetterhahn, a Dartmouth College scientist and leading researcher on the impact of toxic metals on living organisms, died in June of 1997 of a lethal dose of dimethylmercury (die-METH-ul-MER-kyoo-ree). She was studying how mercury prevents cells from repairing themselves, a characteristic commonly seen in cancer cells.

Ten months earlier, Dr. Wetterhahn had an accident in her laboratory. A drop of the toxic compound spilled and seeped through her latex gloves. Dr. Wetterhahn followed all the known safety procedures when working with a toxic chemical: She used a hood to protect her from fumes and wore a face shield and gloves. Tests in an independent laboratory after the accident, however, showed that dimethlymercury can pass through latex gloves in 15 seconds or less, usually without damage to the gloves. It came as a surprise to the chemistry department at Dartmouth and to the doctor's research colleagues that the gloves she was wearing at the time of the spill were not sufficient protection. Since the accident, researchers working with dimethylmercury are urged to wear neoprene gloves with long cuffs or two pairs of gloves, one of them laminated and one of them heavy duty.

Dimethylmercury is a thick, colorless liquid with a sweet odor. It is not the same kind of mercury found in thermometers. Instead, it looks like water but is three times as dense. It is attracted to the oil in human skin and is readily absorbed by the body. It can cause permanent nervous system damage or death. Dr. Wetterhahn sought medical attention when she felt numbness in her fingers, was unsteady while walking, had difficulty speaking, had blurred vision, and had problems hearing. Within three weeks of diagnosis of mercury poisoning, she went into a coma that lasted until her death four months later.

Poisoning from dimethylmercury is a rare event. According to Dartmouth officials, only one other researcher has died of dimethylmercury poisoning in this century: a Czechoslovakian scientist in 1971. Before that, two people died from exposure to the chemical when it was first made in the laboratory in the mid-1800s.

Sources: Associated Press. 1997, March 28. Hanover, NH; Associated Press. 1997, June 11. Hanover, NH; Haworth, K. 1997, April 1. Mercury poisoning from lab work puts Dartmouth chemist in hospital. *The Chronicle of Higher Education*; Holden, C. (Ed.). 1997, June 20. Random samples: Death from lab poisoning. *Science* 276, 1797.

CASE STUDY #2

Early in the morning of December 3, 1984, a young autorickshaw (taxi) driver finally finished his day of work in Bhopal (boh-PAWL), India. As he drove home to his family, he began to notice that the air felt hot even though it was a winter's night. There was smoke in the air that made his eyes burn.

He arrived at his house and went in, calling to his wife and two children.

"What is going on?" he said.

"We don't know," replied his wife, coughing. "But, we have noticed the smell, too. It is making us feel very sick."

Just then, the young man noticed thick smoke coming in under the door. Outside he heard screaming and shouting. Suddenly, there was a knock on the door. The next-door neighbor shouted through the door, "Run, run away from here. Gas has leaked from the Union Carbide plant and people are collapsing in the streets!"

The man and his wife looked at each other, frightened. "Why was there no siren or warning?" they asked each other.

It was then that the children started crying. They coughed as if they were choking and then vomited, over and over again. The young man covered his mouth with a wet muffler and picked up his children. He and his wife got into the taxi to begin to drive away from the cloud of gas.

Everywhere in the streets were people running, vomiting, wearing only pajamas. Many people tried stopping the taxi and begged for space, but there was no room for more people. The gas cloud was so thick that the streetlights looked like dim candles burning. Corpses lay in the streets, some bloated to twice their usual size. Police vans were roaming the city, blaring through their loudspeakers, "Evacuation!" The young man drove on, leaving the city and the terror behind.

The next day, news came that the pesticide plant in Bhopal had leaked the chemical methylisocyanate (METH-ul-IE-soh-SIE-uh-nate). The workers and people living around the plant were exposed to a deadly gas. By the end of the week, at least 6,000 people were dead. When the young man and his family returned to the city, it was like a graveyard.

During the next two months, the man and his family suffered, too. Unable to find medical care, one of the children died a slow, painful death. The man's wife was no longer able to do her chores because she felt so weak and her lungs always burned. The man worked from dawn to dusk to bring in money for the family and to take care of his wife and child.

Today, thousands of people in Bhopal, India, are still seriously ill. Many people who were exposed to the cloud of gas continue to suffer from diseases related to their exposure to the chemical. They have problems with their lungs, less control over their limb movements, nervous system diseases, and damaged immune systems.

(continued)

When an investigation into the disaster in Bhopal was completed, Union Carbide was accused of having poor safety and maintenance standards. Defects in the methylisocyanate unit were found in various places: the gauges measuring temperature and pressure were unreliable and ignored; the refrigeration unit had been shut off; the gas scrubber, designed to neutralize any escaping chemical, had been shut off for maintenance; the flare tower, designed to burn off any escaping chemical, was undersized and turned off; the water curtain, designed to neutralize any remaining gas, was too short to reach the tower where the gas was billowing; the alarm on the storage tank did not signal the increase in temperature; and there were inadequate storage tanks for excess chemical. Officials from Union Carbide believed that the leak was the result of sabotage by a disgruntled employee, but the company has never brought charges against anyone.

In February 1989, the Supreme Court of India ordered Union Carbide Corporation (United States) and Union Carbide India Limited, the owner and operator of the chemical plant, to pay $470 million in settlement of all claims arising out of the chemical leak. In addition, the companies were ordered to build a hospital in Bhopal and set up a charitable trust in England to support it. In 1994, Union Carbide Corporation completed the sale of its interest in Union Carbide India Limited to a company in Calcutta. Part of the proceeds from the sale went to the hospital and clinics in Bhopal.

Source: Testimony of Bhopal Gas Victims. Retrieved August 9, 2000, from *http://www.bhopal.org/testimony/jewan_shinde.html*.

CASE STUDY #3

A two-year-old girl named Jane ended up in the emergency room after her mother began to worry about her illness. Jane complained of abdominal pain, she had lost her appetite, she was vomiting, she was constipated and, lately, she seemed very tired.

The doctor in the emergency room asked Jane's mother where the family lived. He recognized the area as an inner-city neighborhood of old homes, many in poor repair, with peeling and chipping paint. He asked that a blood sample be taken and tested for the level of lead in it. He discovered that Jane's blood lead level was 100 micrograms of lead per deciliter (1 deciliter = 100 mL) of blood. Because any amount of lead above 10 micrograms per deciliter of blood is dangerous, Jane was at risk of major seizures and cardiac arrest. The doctor told Jane's mother that Jane was suffering from lead poisoning, but that she would feel better within a short time if she began drug therapy immediately. The drug was easy for Jane to take by mouth, and she could continue her treatment at home.

The cause of Jane's illness was the lead in the dust, paint, or soil around her home. The doctor told Jane's mother that the long-term effects of lead in a child can be severe. They include learning disabilities, decreased growth, hyperactivity, impaired hearing, and even brain damage. If caught early, however, these effects can be limited by medical treatment and by reducing exposure to lead.

Jane's mother wondered why she and her husband were not sick. The doctor explained it this way. Children swallow lead or breathe lead-contaminated dust when they play in dust or dirt and then put their fingers or toys in their mouths. Often, children eat without washing their hands first. They tend to chew on window ledges and cribs and get lead paint in their mouths. All of these behaviors would be unusual for an adult, so adults are not at as high a risk of exposure. In addition, adults' organ systems are not affected by lead the way children's organs are.

When Jane's mother asked the doctor what she should do to minimize the family's exposure to lead, the doctor had several suggestions. First, test children living in older homes once a year for high lead levels in their blood. Second, keep areas where children play as clean as possible. Wash things that have fallen on the floor, like bottles and pacifiers. Mop floors and windowsills twice a week. Third, make sure children wash their hands before meals, naptime, and bedtime because these are times when they tend to put their hands in their mouths. Fourth, get professional help to remove lead paint that is peeling or chipping. Paint over lead paint in good condition to seal it in. Fifth, give children milk with their diet. The calcium in the milk will be absorbed by the body instead of the lead. Children with poor nutrition are more likely to have elevated blood lead levels. Finally, the doctor told Jane to check with her local health department and housing authority for help with her task of minimizing lead exposure. Many government programs and agencies can help educate people about lead poisoning and prevention.

CASE STUDY #4

The news spread through the school like a wildfire in the spring of 1999. A boy in the eighth grade, Jimmy Green, had died. He had tried for the first time sniffing gasoline from a plastic bag in his garage. He had a heart attack within minutes of breathing the fumes.

Mr. Cobb, the biology teacher, gathered students and their parents for a meeting. He told them that Jimmy Green died because he inhaled a deadly chemical. He told them that inhaling chemicals, especially ones like gasoline that are made up of so many different chemicals, can be very damaging to the body. Mr. Cobb reminded students that the lungs can deliver the toxic chemicals that students sniff directly to vital tissues in the body in high concentrations. The results can be short-term memory loss, hearing loss, arm and leg spasms, permanent brain damage, liver and kidney damage, and death.

Mr. Cobb let the families know that Jimmy Green died of “sudden sniffing death syndrome.” In some people, breathing toxic fumes from gasoline can interrupt the normal rhythm of the heart and result in a heart attack. It is impossible to know who might die from sniffing, but 3 out of 10 people who die from sniffing do so during their first use, as Jimmy did. Besides dying from sudden sniffing death syndrome, people who inhale toxic chemicals also die of asphyxia, or suffocation, because of the plastic bags they use; from choking on vomit; and from accidents, fires, and suicides that result from poor decisions made while intoxicated.

Mr. Cobb told the parents that the commercial products that students sniff are easy to get because many people have these products in their homes. In this way, starting a habit of abuse with these chemicals is less expensive than with other substances, such as marijuana or cocaine.

Treatment for people who abuse inhalants is similar to that for people who abuse drugs. It is very difficult to stop using inhalants. Many people who go through rehabilitation to help them stop sniffing need to repeat the program after relapsing back into inhalant use.

Parents and students left the meeting knowing that they did not want to intentionally expose themselves to the dangers of sniffing toxic chemicals. Losing Jimmy Green was enough.

CASE STUDY #5

In December of 1971, an epidemic occurred in Iraq. More than 6,500 people in many parts of the country became ill with nervous system disorders. They had numbness and tingling around their mouths, lips, fingers, and toes. They had a clumsy, stumbling walk and a feeling of weakness. Some had difficulty swallowing and pronouncing words. Many had vision and hearing loss. In all, 459 people fell into a coma and died.

It took considerable detective work to determine the source of the widespread illness. Finally, it became apparent that a shipment of seed grain from Mexico, which was intended only for planting, was used to make bread instead. The seed had been treated before shipment with a fungicide containing methylmercury (METH-ul-MER-kyoo-ree). The warning about the fungicide and instructions for the seed use were not written in Iraqi, so the people at the southern port of Basra, in Iraq, did not realize the seed should not be eaten. The seed was distributed to households around the country. The women in the country ground the seed to make flour and used it in their baking. The result was mass mercury poisoning from a very unusual source: homemade bread.

Opening Questions

As a team, think of a chemical that you would like to be exposed to because it makes you healthier. Think of a chemical that you would try to avoid because it harms you in some way. Record these two chemicals in your science notebook.

Use complete sentences to answer the following questions about each of the chemicals:

- Where do you find the chemical?
- How does the chemical enter your body?
- How does it make you healthier or harm you?
- How much chemical do you need to be exposed to for it to help you or harm you?

Making Solutions for Toxicity Testing

Materials for Each Team

6 50-mL beakers, clean and empty
1 50-mL graduated cylinder
1 10-mL graduated cylinder
1 100-mL beaker with 50 mL of chemical
100 mL of water in a beaker
1 tray
eyedropper
masking tape
permanent marker
safety glasses
latex gloves

Procedure

1. Put on the latex gloves and safety glasses.

2. Use the masking tape and marker to label each of the six empty 50-mL beakers with information from the following table.

Beaker #	Amount of Water	Amount of Chemical	Total Volume of Liquid	% Concentration of Chemical
1	20.00 mL	0.00 mL	20 mL	0%
2	18.75 mL	1.25 mL	20 mL	6.25%
3	17.50 mL	2.50 mL	20 mL	12.5%
4	15.00 mL	5.00 mL	20 mL	25%
5	10.00 mL	10.00 mL	20 mL	50%
6	0.00 mL	20.00 mL	20mL	100%

3. Use the 50-mL and the 10-mL graduated cylinders to measure the correct amount of water. Pour the water into each of the labeled beakers according to the above table. Use the eyedropper for small corrections.

4. Use the 50-mL and the 10-mL graduated cylinders to measure the correct amount of chemical. Pour the chemical into each of the labeled beakers of water according to the above table. Use the eyedropper for small corrections.

5. When you have finished, check that all the beakers contain 20 mL of chemical solution. If a beaker contains more or less than 20 mL, consult the above table and repeat the procedure for that beaker. Place the beakers in order on the tray, with 0 percent concentration on the left and 100 percent concentration on the right.

6. Return any unused chemical to your teacher. Wash all other containers and put them away.

Toxicity Testing on Seeds

Materials for Each Team

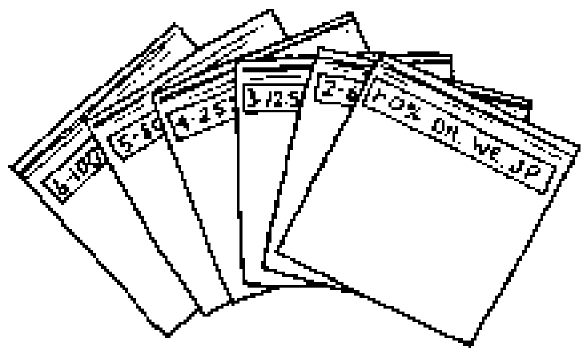
6 resealable plastic sandwich bags
12 paper napkins
6 beakers of chemical solution, ranging from 0% to 100% concentration
1 bag of seeds (approximately 60 seeds in a bag)
1 permanent marker
latex gloves
safety glasses
1 tray

Procedure

1. Label all six bags with your team members' initials and a number and a percent concentration of chemical, like this:

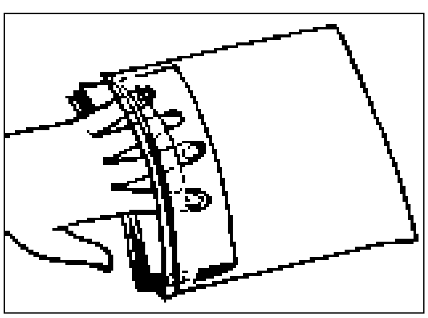
#1	0% (control)
#2	6.25%
#3	12.5%
#4	25%
#5	50%
#6	100%

Step 1

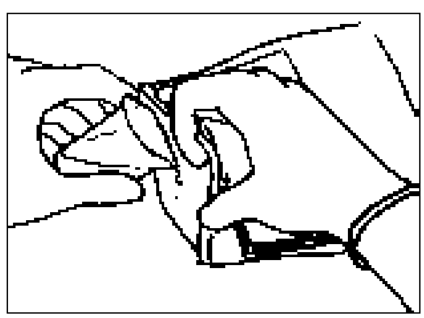


2. Put two napkins together and fold them in half so that they fit into the plastic bag. Fill each bag with two folded paper napkins.

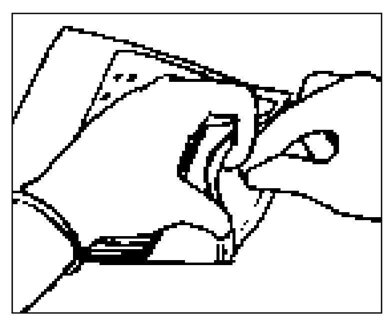
Step 2



Step 3



Step 4



3. Put on the safety glasses and latex gloves. Carefully pour the chemical solutions into the bags, making sure to match the numbers and concentration percentages of the bag and the chemical. Each bag now will contain 20 mL of chemical solution that is absorbed by the paper napkins.

4. Count out 10 seeds. Carefully place the seeds on the moist paper napkins in the control bag (#1), making sure to space them evenly (do not clump them in one spot). Seal the plastic bag, pushing out the air as you go.

5. Repeat Step 4 for the remaining bags.

6. Observe the seeds and fill in the following data table with information you know at this time.

Data table for toxicity testing.

Bag #, Dose (% concentration)	Day 1: # of seeds germinated	Day 1: # of seeds not germinated	Day 2: # of seeds germinated	Day 2: # of seeds not germinated	Day 3: # of seeds germinated	Day 3: # of seeds not germinated
1 (control), 0%						
2, 6.25%						
3, 12.5%						
4, 25%						
5, 50%						
6, 100%						

7. Place the seed bags in a stack, lying flat with the seeds up, on the tray. Put the tray of seeds in the spot designated by your teacher. Put this worksheet in your science notebook.

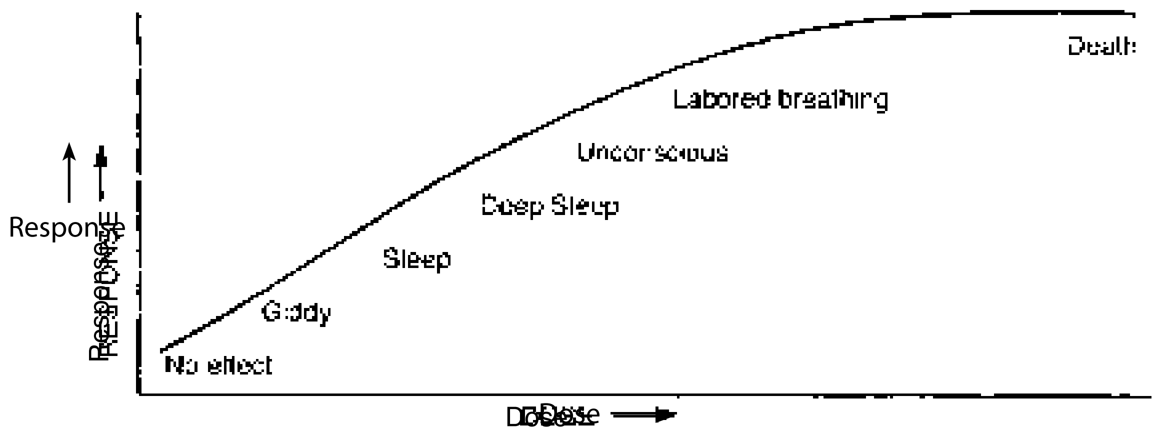
Questions

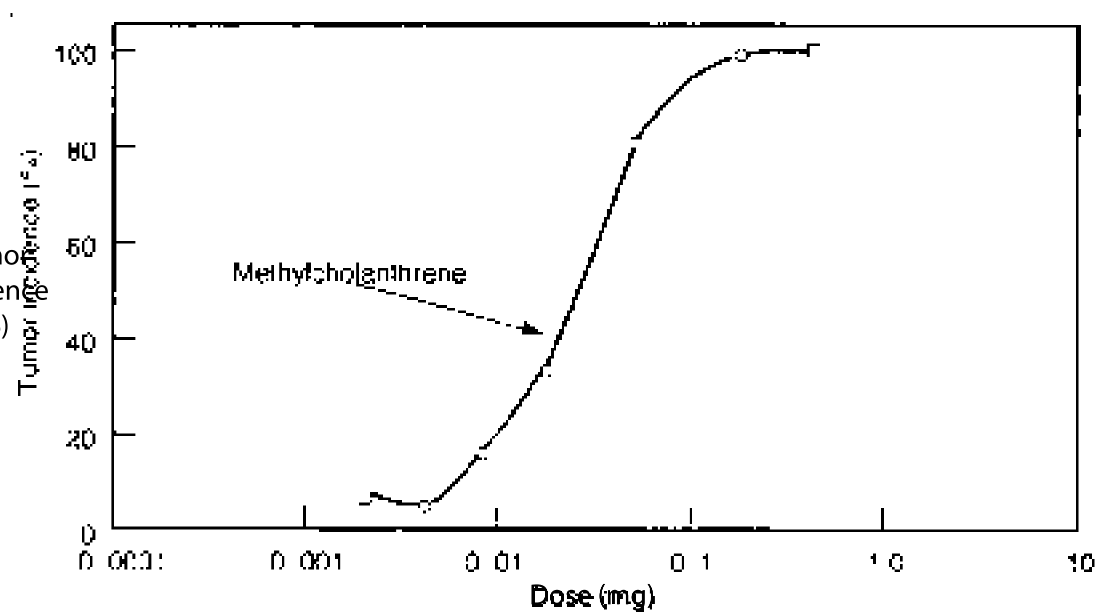
1. What is your chemical? Describe what you know about the chemical. (Do you consider it harmful, beneficial, or neither? What is it used for? How would a human be exposed to this chemical?)

2. In which bag is the dose of chemical the highest? In which bag is the concentration of chemical in the solution the highest? Describe how you know.

3. Do you think you will see a difference in the effect on seeds of a small dose of chemical compared with the effect of a larger dose? Predict what you think will happen to the seeds in each bag.

Dose-Response Curves





Master 3.1

Graph Paper

Name ___________________________________

Date ___________________________________

Class ___________________________________

Directions: Plot dose-response data for your chemical on graph A and for two other teams' chemicals on graphs B and C.

Chemical A _______________________________

Chemical B ____

Chemical C ____

Acetaminophen Dosage Chart

Children's Chewable Acetaminophen Dosage (80 mg/tablet)

Weight (lb)	Weight (kg)	Age (yr)	Dose
under 24	under 11	under 2	consult doctor
24–35	11–16	2–3	2 tablets
36–47	17–21	4–5	3 tablets
48–59	22–27	6–8	4 tablets
60–71	28–32	9–10	5 tablets
72–95	33–43	11	6 tablets

Warning: Take no more than five doses per day.

A Poisonous Dose? The Case History

Date: February 25

Patient: Andy Brown

Age: 2 years old

Weight: 26.5 lbs (12 Kilograms)

Symptoms: stomach upset, nausea, vomiting, fever

Current medicines: 1 teaspoon liquid acetaminophen 4 times a day

Action taken: Admit Andy to hospital (February 25). blood work ordered

Notes: Andy was sick with a fever when his mother was called out of town on business. Andy went to stay with his aunt. The mother left some Children's Suspension Liquid Acetaminophen to use for Andy's fever, but it ran out. On February 24, the aunt began to use her own Infants' Concentrated Drops, giving Andy 1 teaspoon every 4 hours, just like she did with the Children's acetaminophen. In total, the aunt gave Andy 4 doses of infants' drops.

Lab Results: High levels of acetaminophen found in the blood

Diagnosis: Acetaminophen overdose and poisoning, which can lead to liver damage and death (an overdose of acetaminophen is 150 milligrams per Kilogram of body weight. Andy weighs 12 Kilograms, so 1,800 milligrams of acetaminophen is an overdose)

Treatment: Within 8 to 12 hours, administer antidote (Done: February 25)

Prognosis: Good (Feb. 25)
Updated to excellent (Feb. 26)

Follow-Up: Talk to Andy's aunt and mother: Infants' Concentrated Suspension Drops is more than three times stronger than Children's Suspension Liquid even though the two formulas look similar. Parents and caregivers should always read the dosage chart on the medicine bottle to ensure that they are giving the proper dosage. It is also important never to use a different unit of measurement than the one indicated on the dosage chart (such as a teaspoon instead of a dropper) to administer medicine.

A Poisonous Dose? The Problem

Your teacher will display a transparency of a doctor's chart. Read the first page of the doctor's chart that describes Andy Brown's case. Then use information provided on the transparency and on this worksheet to answer the following questions.

Part I

How much Infants' Concentrated Suspension Drops did Andy receive from his aunt?

a. 1 teaspoon
b. 1 teaspoon 4 times in 1 day
c. 3 teaspoons
d. 4 teaspoons
e. b and d
f. none of the above

Use the dosage chart below to calculate how much acetaminophen, in milligrams (mg), Andy's aunt gave him in one day. Remember, Andy's aunt gave Andy his medicine in a teaspoon. To use the dosage chart, you need to know that each teaspoon contains 6.25 dropperfuls of medicine.

$$4 \text{ teaspoons} \times \frac{6.25 \text{ dropperfuls}}{1 \text{ teaspoon}} \times \frac{\square \text{ milligrams}}{1 \text{ dropperful}} = \square \text{ milligrams of acetaminophen}$$

Infants Concentrated Suspension Drops (80 mg/dropper)

Weight (lb)	Weight (kg)	Age (yr)	Dose
under 24	under 11	under 2	consult doctor
24–35	11–16	2–3	2 dropperfuls

Warning: Take no more than five doses per day.

The warning on the dosage chart says that a child should take no more than five doses of Infants' Concentrated Suspension Drops in one day. How many milligrams of acetaminophen would there be in five doses for a child Andy's size?

$$5 \text{ doses} = 10 \text{ dropperfuls} \times \frac{\square \text{ milligrams}}{1 \text{ dropperful}} = \square \text{ milligrams of acetaminophen}$$

Conclusion to Part I

What do you think is making Andy sick?

Part II

When Andy's mother gives him a pain reliever, she usually gives him Children's Suspension Liquid. Use the chart below to calculate how many milligrams of acetaminophen a boy Andy's size would get in four doses of Children's Suspension Liquid.

$$4 \text{ doses} = 4 \text{ teaspoons} \times \frac{\square \text{ milligrams}}{1 \text{ teaspoon}} = \square \text{ milligrams of acetaminophen}$$

Children's Suspension Liquid (160 mg/teaspoon)

Weight (lb)	Weight (kg)	Age (yr)	Dose
under 24	under 11	under 2	consult doctor
24–35	11–16	2–3	1 tsp.
36–47	17–21	4–5	1 1/2 tsp.
48–59	22–27	6–8	2 tsp.
60–71	28–32	9–10	2 1/2 tsp.
72–95	33–43	11	3 tsp.

Warning: Take no more than five doses per day.

What did Andy's mother use to measure a dose of Children's Suspension Liquid? (Circle one.)

a teaspoon a dropper

What did Andy's aunt use to measure Andy's doses of Infants' Concentrated Suspension Drops?

a teaspoon a dropper

What does the dosage chart for infants' drops say should be used to measure the medicine?

a teaspoon a dropper

Conclusion to Part II

Andy received an accidental overdose of acetaminophen. On a separate piece of paper, describe how you think the mistake happened.

Parent Letter

Dear Parents,

Next week in science class we will be investigating individual responses to caffeine. Each student will need to bring in a 12-ounce can of ______________________________ . Please provide a can and label it with your child's name and class period.

During the investigation, students will consume 12 ounces of the caffeinated soft drink and measure what effect it has, if any, on their heart rates.

Students are not to bring in any soft drink other than the one specified. Students who do not bring in a drink, or those without permission to drink a soft drink during science class, will be the "control" in the investigation and will drink 12 ounces of water. In this way, everyone can take part in the investigation.

Thank you for your continued support.

____

Teacher's Signature

– –

______ My child, __________________________, has permission to participate in the caffeine investigation in science class and will bring in a 12-ounce can of __________________________________ to consume as part of the activity.

______ My child, __________________________, will not participate by consuming a 12-ounce soft drink, but will participate in the activity as a control by drinking the same amount of water.

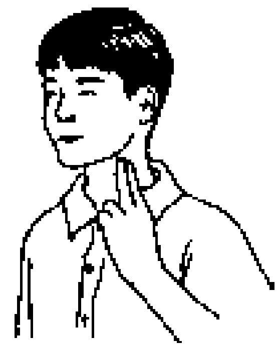
____________________________________ ______________________

Parent's or Guardian's Signature Date

The Chemical Caffeine: How Do You Respond?

Materials for Each Team

2 cans of caffeinated soft drink (1 for each student)
1 watch or classroom clock with a second hand
data table (provided with these instructions)
pencils



Procedure

Do Steps 1–3 with your teacher.

1. When your teacher directs you to do so, find your pulse. You can find it most easily by pressing two fingers against the artery in your neck or on the inside of your wrist. Practice counting the beats.

2. When your teacher directs you to start, count the number of beats you feel in 15 seconds. Your teacher will tell you when to stop. Record the number in the first column of the data table on the next page.

3. Multiply the number of beats you counted in 15 seconds by four to calculate the number of beats you would have counted in one minute. This number is your resting heart rate. Record your resting heart rate on the data table.

With your partner, complete the rest of this investigation.

4. What do you think might happen to your heart rate after you drink a caffeinated soft drink? Write your prediction here:

____

____

5. Together, at the same time, drink the cans of soft drink. For best results, try to drink them quickly, taking no more than 10 minutes to finish the can. Write the name of the soft drink above your data table.

6. Sit at rest for about 5 minutes. You can talk to your partner, but keep your body still so that you do not elevate your heart rate with activity. If your teacher instructs you to do so, read quietly at your seat.

7. One partner at a time, measure your heart rate for 15 seconds. To do this, have one partner be the counter and find his or her pulse. Have the other partner be the timer and watch the second hand on a watch or on the classroom clock. Have the timer say "Start" and "Stop" at the beginning and end of 15 seconds while the counter counts his or her beats. Record the number of beats in your data table in the first column of row 1. Repeat the procedure so that the other partner can count his or her heartbeats in 15 seconds.

8. Once every two minutes, repeat Step 7, until you have measured the number of heartbeats in 15 seconds at least 10 times. Record each measurement in the first column in your data table.

9. From each of your measurements, calculate your heart rate after drinking caffeine by multiplying the number of beats you counted by four. Record your heart rate for each measurement in the final column of your data table.

10. Using the highest number you calculated for heart rate after drinking a soft drink, determine the difference between your resting heart rate and your heart rate after drinking a caffeinated soda. Record that number below the data table. Then, calculate the number of minutes it took after finishing the drink for your heart rate to reach its peak. Record the number below the data table.

Name of soft drink: ________________________________

Data table for caffeine experiment.

Heartbeats counted in 15 seconds	Multiply by 4	Heart rate per minute
Resting:	x 4	
1	x 4	
2	x 4	
3	x 4	
4	x 4	
5	x 4	
6	x 4	
7	x 4	
8	x 4	
9	x 4	
10	x 4	

Difference between resting heart rate and highest heart rate after caffeine: ____

Number of minutes after finishing the drink for the heart rate to reach its peak: ____

11. How accurate was your prediction? Did your heart rate go up, down, or stay the same after you drank a caffeinated soft drink?

Extension Question

Could sugar have been the ingredient in soda that affected your heart rate, rather than caffeine? How could you find out?

Risk Assessment and Management

Risk Assessment

Step 1

- Is a new health problem present?
- What are the symptoms?
- What do the affected individuals have in common?

Step 2

- What is causing the problem?
- What is the source of the problem?

Step 3

- What are the sources of exposure to the chemical?
- How much exposure are people in the area receiving?
- Is the exposure acute or chronic? (Is it likely to happen only once or often over the course of time?)

Conclusion: How great is the risk to people?

Risk Management

- How do the people involved perceive the risk? Are their perceptions accurate?
- Who is responsible for the harmful substance and its presence in the environment? What role does the responsible party have in any cleanup?
- What are the benefits and tradeoffs that a person must weigh when making a decision about the risk?

Conclusion: What action should people take to minimize their risk? Can the risk be managed by individuals, the community, and/or governments?

Minamata Disease

Part I

In the city of Minamata, along the western coast of Japan, unusual things began to happen in the 1950s. First, dead fish began to float in the bay. Then, cats began to fall into the sea and die in what people in the town called "cat suicide." At the same time, birds began to drop dead from the sky.

Soon, people began to act strangely, too. They stumbled while walking, were unable to write, and had trouble buttoning their buttons. In only a few years, the illness seemed to be an epidemic. Fishermen seemed the most severely afflicted. Men who were once strong suddenly had trouble keeping their balance. They could not stay afloat if they fell into the sea from their fishing boats. They had convulsions and had to be tied to their beds, where many of them died. Sadly, other members of their families also had the strange disease, which came to be known as Minamata disease.

Doctors believed that the mysterious symptoms were caused by poisoning. They tried to find a food source that birds, cats, fish, and people had in common. Finally, they realized that it was the fish that were contaminated, and the birds, cats, and people were eating the fish. What was contaminating the fish?

Part II

Although Minamata used to be a poor fishing village, it prospered when the Chisso Corporation built a manufacturing plant in the city. For 20 years, the plant had been making a chemical called acetaldehyde (a-seh-TAL-deh-hide), which is used to make plastics, drugs, and perfume. As part of its normal operations, the Chisso Corporation dumped waste products into Minamata Bay. Fishermen complained that the dumping was killing the fish. The company paid the fishermen money to help them since there were fewer fish to catch and sell. This arrangement seemed to work well for everyone until people started getting sick.

Mercury is one ingredient that is used to manufacture acetaldehyde. When mercury is dumped into water, the bacteria in the water convert it into organic mercury. When the bacteria are eaten by small fish, which are in turn eaten by larger fish, the mercury becomes concentrated in the tissue of the fish. What made this contamination of the fish so dangerous to humans?

Part III

Mercury is a strong toxin that causes damage to the brain. Most people are exposed to mercury by eating contaminated fish. The U.S. Environmental Protection Agency has estimated that people who eat more than 30 pounds of fish in a year are at higher risk of experiencing toxic effects from mercury. In Minamata, fishermen and their families often ate contaminated fish for every meal. It was this exposure to small amounts of mercury over long periods of time that caused the Minamata disease. In all, more than 12,000 people have suffered from the disease.

Part IV

Many people, devastated by the disease, moved away from Minamata to make their living elsewhere: The city now has only 70 percent of the number of people it once had. The Chisso Corporation no longer uses mercury in its manufacturing or dumps waste into the bay. It has paid more than $2 billion to victims of Minamata disease. The bay was dredged, and 1.5 million cubic meters of contaminated sludge was removed from it. Finally, 40 years later, the water in the bay is safe for swimming and fishing.

Heads or Tails?

If you get heads

_____ you sat in the front of the blue van

_____ you leaned out the window

_____ you watched from outside the lab

_____ you drank soda with caffeine

_____ you got paint on your skin

_____ you sat in the back of the yellow

If you get tails

____ you sat in the back of the blue van

____ you stayed inside the van

____ you sneaked inside the lab

____ you drank soda without caffeine

____ you painted neatly

____ you sat in the front of the yellow bus bus

Choice Cards

CHOICE CARD	CHOICE CARD
CHOICE CARD	CHOICE CARD
CHOICE CARD	CHOICE CARD
CHOICE CARD	CHOICE CARD
CHOICE CARD	CHOICE CARD

Fact Sheets on Chemicals

Fact Sheet #1
Chemicals in the Blue Passenger Van

Sometimes, when people are exposed to new products such as carpet or furniture in their homes or new automobiles, they experience a variety of symptoms such as headaches, itchy eyes, and difficulty breathing. Scientists are not always able to determine whether the chemicals emitted by the new products are responsible, but they are aware that chemicals used in building materials can harm humans. When these products are inside small areas, such as rooms in houses, in mobile homes, or in vehicles, the gases they emit can produce an odor.

Formaldehyde
Formaldehyde is a chemical used in the manufacturing of pressed wood products, as a component of glues and adhesives, and for adding permanent-press qualities to fabrics. Formaldehyde is released as gas into the air from new products that are made with it, such as carpet, carpet adhesives, fabrics, and plywood. This “outgassing” is greatest when the product is new and gradually decreases as the product ages until it no longer occurs. High heat and humidity increase the rate at which formaldehyde is released and shorten the time during which the odor of formaldehyde gas is noticeable.

A person exposed to high levels of formaldehyde in the air can have watery eyes, burning sensations in the eyes and throat, nausea, and difficulty breathing. High concentrations sometimes trigger attacks in people with asthma. New products made for homes, autos, and buses do not release high levels of formaldehyde.

To minimize exposure to formaldehyde, people can ventilate areas that contain new products that emit formaldehyde. They can choose to use wood products that are not pressed wood but should weigh their worry about formaldehyde against the fact that the use of pressed wood conserves more natural resources. They can request low-emitting adhesives for carpets.

The blue van, although new to the students, was built four years ago with materials containing chemicals including formaldehyde. The van previously was owned by a touring company in Florida and was bought by the school district in August of the current year.

Fact Sheet #2
Chemicals at the Gas Station

Benzene in Gasoline
Gasoline is a mixture of chemicals, including benzene. Benzene is a colorless liquid with a sweet odor. It evaporates into the air very quickly when you pump gas into your car or when gasoline is accidentally spilled onto surfaces at a gas station. The concentration of benzene in gasoline is low.

Outdoor air contains low levels of benzene from tobacco smoke, gas stations, exhaust from motor vehicles, and industrial emissions. The air around gas stations contains slightly higher levels of benzene than air in other places.

Breathing benzene vapor in small amounts occasionally causes headache, euphoria (a "high"), a light-headed feeling, dizziness, drowsiness, or nausea. Higher levels of benzene exposure can result in drowsiness, dizziness, rapid heart rate, headaches, tremors, confusion, and unconsciousness. Fifteen to 20 breaths of concentrated gasoline vapor can produce a response for five to six hours, ranging from dizziness and confusion to restlessness and hallucinations. Very high doses of benzene can result in death.

Benzene vapors are mildly irritating to the skin, eyes, and lungs. If liquid benzene splashes into the eyes or onto the skin, it can cause burning pain and damage the cornea of the eyes.

No long-term effects are likely from a single, small exposure to benzene. Repeated small exposures (for more than 365 days) can cause blood disorders and cancer of blood-forming cells. Benzene can cause harmful effects in bone marrow and a decrease in red blood cells, leading to anemia. It also can cause excessive bleeding and affect the immune system, increasing the chance for infection.

Many states require gas stations to install vapor-return barriers that cover gas pump nozzles. These barriers help prevent air pollution from gasoline fumes and protect people who are pumping gas from gasoline fumes. In addition, overflow shut-off valves help keep people from accidentally spilling gasoline onto the ground.

The Environmental Protection Agency's annual inspection of the gas station where the school van stopped for gas indicated that the overflow shut-off valve on the gas pump needed adjusting and people using it often spilled a small amount of gasoline.

Fact Sheet #3
Chemicals in the Paleontology Lab

In the paleontology lab, scientists, artists, and technicians work to create models of dinosaurs and their environments out of plaster, fiber glass, plywood, and fiberboard.

Fiber Glass
Fine particles in the air can cause health problems. In areas where materials are cut, ground, or sanded, the particulate matter that becomes airborne is a source of air pollution. The health effects of breathing in the particles can include eye, nose, and throat irritation; respiratory infections and bronchitis; and lung cancer.

The use of fiber glass in building materials creates fiber glass dust, fine glass fibers that can be breathed into the lungs. Manufacturers of materials made with fiber glass suggest that people working with the material, like those in the paleontology lab, use a mask over their nose and mouth to protect themselves from airborne glass fibers. The Occupational Safety and Health Administration's report on the paleontology lab states that the work place complies with regulations; the level of particles in the air requires that scientists in the lab wear respirators, which they do.

Formaldehyde
Pressed-wood board is made with adhesives that contain urea-formaldehyde resins. Some examples of pressed board that are commonly used as building materials are particle board, plywood, and fiberboard. The higher the resin-to-wood ratio, the more formaldehyde there is in the product.

Pressed-wood products emit formaldehyde gas, and the air in rooms where pressed-wood products are used can have elevated levels of formaldehyde. If the heat and humidity are high in a room, the emission of formaldehyde can increase. As the product made with formaldehyde ages, the emissions of formaldehyde decrease until they are no longer measurable.

Most people will notice the pungent odor of formaldehyde if they are exposed to it. They will experience a burning sensation in their eyes, nose, and throat when they breathe the gas, even in small amounts for short periods of time. Breathing in the gas over a longer time or at higher doses can cause coughing or choking. Very high exposures can cause death from throat swelling or from chemical burns to the lungs. People working for long periods of time in areas with formaldehyde gas wear respirators or work in a room with good ventilation.

People are surrounded by pressed-wood products in their everyday life. The use of pressed-wood products in the paleontology lab does not pose an increased health hazard to the workers. Because they use respirators, the workers' exposure to formaldehyde is minimal.

Fact Sheet #4
Chemicals at Lunch

Caffeine
Caffeine is a naturally occurring substance found in the leaves, seeds, or fruits of more than 60 plants. Coffee and cocoa beans, kola nuts, and tea leaves contain caffeine and are used to make beverages such as coffee, tea, cola drinks, and chocolate.

The U.S. Food and Drug Administration and the American Medical Association have conducted extensive research into the health aspects of caffeine. They agree that moderate consumption of tea, coffee, and other caffeinated drinks does not cause health problems. Moderate caffeine consumption is defined as about 300 milligrams a day, which is equal to three cups of coffee or between four and eight cans of a caffeinated soft drink.

People differ greatly in their sensitivity to caffeine. Some people can drink many cups of coffee, tea, or soft drinks a day and feel no effect, while others feel stimulating effects after one cup. When trying to lessen their intake of caffeine, some sensitive individuals might experience mild, temporary symptoms of withdrawal, including headaches, restlessness, and irritability.

Caffeine can increase alertness in tired individuals and help people stay alert when they work or study. There is no difference in the way children and adults handle caffeine, and caffeinated beverages do not affect hyperactivity or the attention span of children.

Caffeine can cause a temporary rise in blood pressure, less than that normally experienced when climbing stairs and not lasting more than several hours. However, individuals with high blood pressure should consult their physicians about caffeine consumption.

The students on the field trip each brought their own lunch. As a treat, the teachers brought soft drinks for the students. Some of the soft drinks contained caffeine, some did not.

Fact Sheet #5
Chemicals in the Art Room

Solvents
Solvents are substances that dissolve other substances. Water is one example of a solvent. Some solvents smell like kerosene and are used as paint thinner and cleaner. The chemicals that make up some solvents can be harmful to human health.

Exposure to the harmful chemicals occurs when people use products such as paint thinner and breathe the vapors or get the vapors in their eyes. Exposure to these substances can affect the nervous system and cause dizziness, headache, or a prolonged reaction time. Exposure also can cause eye, skin, or throat irritation.

Children attending school and participating in arts and crafts might use art supplies that contain small amounts of solvents, such as rubber cement, permanent felt tip markers, pottery glazes, enamels, and spray fixatives.

The use of glue-containing solvents in a small room with no fresh air can cause headaches, which can signal central nervous system problems. Large doses, such as those experienced during intentional glue sniffing, can cause loss of coordination, nausea, and even death.

Chronic exposure in poorly ventilated areas to hobby materials containing solvents can result in chronic health effects that are hard to trace to their cause. These include skin disease, liver damage, and nervous system damage.

Most schools use only nonhazardous art materials. The selection of materials is based on fulfilling the following conditions:

- no dust or powders;
- no harmful solvents or solvent-containing products;
- no aerosol spray cans or air brushes;
- nothing that stains the skin or cannot be washed out of clothing;
- no acids, alkalis, bleaches, or other corrosive chemicals;
- no lead, cadmium, or other metal products (these can be found in glazes, metal work, and stained-glass products)
- no donated or found materials, unless ingredients are known;
- no old materials purchased before 1990 (when the new labeling standard of the American Society of Testing and Materials (ASTM) became effective);
- only use products that meet the ASTM standard and are labeled "conforms to ASTM D-4236."

[Source: Environmental and Occupational Health Sciences Institute. 1997. Infosheet: Children's Art Supplies.]

The dinosaur model painting the students did used tempera paint, which is a brilliant, opaque, nontoxic watercolor. Its solvent is water; it can be thinned with water and cleans up with water. The coloring agents in the paint are nontoxic.

Fact Sheet #6
Chemicals in the Yellow Bus

Carbon Monoxide

Carbon monoxide is an odorless, colorless, poisonous gas released from the incomplete burning of fossil fuels, such as gasoline, propane, natural gas, oil, wood, and coal. Burning tobacco also produces carbon monoxide, one of the gases in cigarette smoke.

When people breathe in carbon monoxide, the carbon monoxide molecules compete with oxygen molecules for the same binding sites on hemoglobin. The hemoglobin molecule cannot tell the difference between carbon monoxide and oxygen, so it carries carbon monoxide in the blood instead of oxygen. When tissues become starved of oxygen, people begin to experience fatigue. As the concentration of carbon monoxide increases, people experience headaches, weakness, nausea, dizziness, dim vision, and changes in heart rhythm. If carbon monoxide is present at very high concentrations, it can lead to unconsciousness, coma, convulsions, and death. According to the Mayo Clinic, approximately 10,000 people are poisoned by carbon monoxide in the United States each year. Fetuses, infants, elderly people, and people with anemia or a history of heart or respiratory disease are especially sensitive to carbon monoxide exposures.

About two-thirds of all deaths from carbon monoxide poisoning occur in cars. Automobile exhaust contains up to 9 percent carbon monoxide, although catalytic converters substantially reduce carbon monoxide levels to below 1 percent. Because of lack of ventilation, automobile exhaust can leak into the car and slowly overcome the passengers.

People can reduce their exposure to carbon monoxide. They can use carbon monoxide detectors to warn them of any carbon monoxide in their home or workplace. They can keep gas appliances in their homes properly adjusted. They can install and use vents and exhaust fans for their gas stoves, space heaters, and fireplaces. They can make sure that their furnaces are working properly and are not leaking. They can make sure they never idle their car in the garage or breathe the fumes from other idling vehicles. Finally, they can keep their automobile in good condition, paying particular attention to the exhaust system. A state vehicle emissions report made the day after the field trip indicated that the yellow bus the students rode home in from the field trip had a faulty exhaust system.