How Your Brain Understands What Your Ear Hears

Under a Contract from the
National Institutes of Health

National Institute on
Deafness and Other Communication Disorders

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This material is based on work supported by the National Institutes of Health under Contract No. 263-99-C-0031. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the funding agency.

NIH Publication No. 04-4990

ISBN: 1-929614-10-1

Contents

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. The NIH Office of Science Education (OSE) is dedicated to promoting science education and scientific literacy.

We designed this curriculum supplement to complement existing life science curricula at both the state and local levels and to be consistent with *National Science Education Standards*.[1] It was developed and tested by a team composed of teachers from across the country, scientists, medical experts, other professionals with relevant subject-area expertise from institutes and medical schools across the country, representatives from the NIH National Institute on Deafness and Other Communication Disorders (NIDCD), and curriculum-design experts from Biological Sciences Curriculum Study (BSCS), SAIC, and Edge Interactive. 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.

The structure of this module enables teachers to effectively facilitate learning and stimulate student interest by applying scientific concepts to real-life scenarios. Design elements include a conceptual flow of lessons based on BSCS's 5E Instructional Model of Learning, multi-subject integration emphasizing 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.

Each curriculum supplement comes with a complete set of materials for both teachers and students, including printed materials, extensive background and resource information, and a Web site with interactive activities. These supplements are distributed at no cost to teachers across the United States. All materials may be copied for classroom use, but may not be sold. We welcome feedback from our users. For a complete list of curriculum supplements, updates, and availability and ordering information, or to submit feedback, please visit our Web site at *http://science.education.nih.gov* or write to

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We appreciate the valuable contributions of the talented staff at BSCS, SAIC, and Edge Interactive. 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 supplements are both engaging and effective. I hope you find our series a valuable addition to your classroom and wish you a productive school year.

Bruce A. Fuchs, Ph.D.
Director
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National Institutes of Health

1 In 1996, the National Academy of Sciences released the *National Science Education Standards*, which outlines what all citizens should understand about science by the time they graduate from high school. The *Standards* encourages teachers to select major science concepts that empower students to use information to solve problems rather than stressing memorization of unrelated information.

About the National Institutes of Health

Founded in 1887, the National Institutes of Health (NIH) today is the federal focal point for medical research in the United States. Composed of separate institutes and centers, NIH is one of eight health agencies of the Public Health Service within the U.S. Department of Health and Human Services. The NIH mission is to uncover new knowledge about the prevention, detection, diagnosis, and treatment of disease and disability, from the rarest genetic disorder to the common cold. It does this through

- *Research.* Enhancing research outcomes across the medical research continuum by supporting research in NIH's own intramural laboratories as well as the research of nonfederal scientists working in universities, medical schools, hospitals, and research institutions throughout the country and abroad; communicating scientific results; promoting the efficient transfer of new drugs and other technologies; and providing effective research leadership and administration.
- *Research Training and Career Development Program*. Supporting research training and outreach designed to ensure a continuing supply of well-trained scientists.
- *Research Facilities Program*. Modernizing and improving intramural and extramural research facilities to ensure that the nation's scientists have adequate facilities in which to conduct their work.

Science education efforts by NIH and its institutes and centers are critical in 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 the scientific results so that they can make informed decisions about their own health as well as the health of the public.

This curriculum supplement is one such science education effort, done through the partnership of the NIH National Institute on Deafness and Other Communication Disorders, the NIH Office of Science Education, and Biological Sciences Curriculum Study (BSCS).

About the National Institute on Deafness and Other Communication Disorders

James F. Battey, Jr., M.D., Ph.D.

What We Do

Fundamental processes of hearing, balance, smell, taste, voice, speech, and language allow humans to interact and to experience and manipulate their environment. NIH's primary research institute devoted to human communication research is the National Institute on Deafness and Other Communication Disorders (NIDCD). The NIDCD supports research across the 50 states. Some of that research may be going on right now in your state. For more information on the NIDCD, consult the section *More About the NIDCD and Its Research*, page 145, or visit us on the Web at *http://www.nidcd.nih.gov*.

Your Young Scientists

The NIDCD is committed to encouraging young people who have an interest in science to delve into it further. It also is working to improve public understanding about how normal and diseased processes work so that individuals can make well-informed decisions about their health over a lifetime. Please let us know about your experience with the module, or let us answer any questions you have about any aspect of the material presented or the research of the NIDCD.

As director of the NIDCD, I am indebted to you for your work with these young people, and as the father of two middle schoolers, I appreciate the challenges you will face! Thank you for your interest in human communication research.

Jim Battey, M.D., Ph.D., Director NIDCD
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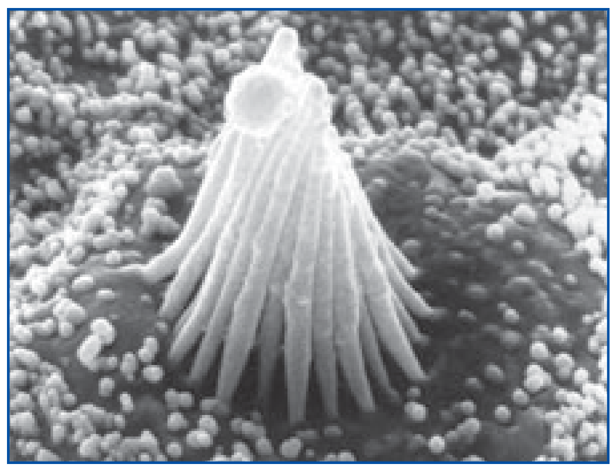


Electron micrograph of a healthy hair cell.

Introduction to *How Your Brain Understands What Your Ear Hears*

Human communication depends on taking in information from the environment through the five senses and processing that information in the brain. The sense of hearing is critical to this process. Other mental abilities such as attention and memory are also important.

Because human communication is a complex process, it may be impaired in a variety of ways. About one in six Americans must cope with some form of communication disorder, such as

- not being able to hear at all or having a hearing impairment,
- dizziness or balance problems,
- stuttering,
- ringing in the ears (tinnitus),
- not being able to speak (laryngeal cancer, aphasia), or
- autism.

Research has helped us better understand communication disorders and what causes them. Already, research has led to the development of vaccines for diseases such as measles, mumps, meningitis, and rubella—diseases that previously caused hearing loss for many people. Technologies to assist individuals with communication disorders have also been developed. Current and future research will help us better detect, diagnose, intervene, rehabilitate, or treat newborns with hearing loss; understand the genetic contributions to hearing and communication; and apply appropriate technologies to assist those who have communication disorders.

What Are the Objectives of the Module?

How Your Brain Understands What Your Ear Hears has four objectives. The first is to help students understand the interrelationship of hearing, language, and human communication. It also helps students develop healthy hearing habits so they avoid noise-induced hearing loss.

The second objective is to use hearing and communication as a way of understanding important scientific concepts. Lessons in this module help students sharpen their skills in observation, critical thinking, experimental design, and data analysis. They also make connections to other disciplines such as English, mathematics, and social science.

The third objective is to convey to students the purpose of scientific research. Ongoing research affects how we understand the world around us and gives us a foundation for improving our choices about personal health and the health of our community. In this module, students experience how science provides evidence that hearing is key to language acquisition, that human communication is multisensory, and that excessive exposure to loud noise can lead to hearing loss. The lessons in this module encourage students to think about the relationships among knowledge, choice, behavior, and human health in this way:

Knowledge (what is known and not known) + Choice = Power

Power + Behavior = Enhanced Human Health

The final 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 life science classes offer an ideal setting for integrating many areas of student interest. In this module, students participate in activities that integrate inquiry science, human health, mathematics, and the interweaving of science, technology, and society. The real-life context of the module's classroom lessons is engaging, and the knowledge gained can be applied immediately to students' lives.

"Nice reflection on self-issues of hearing. Many students are amazed at how many times they might be causing damage." – Field-Test Teacher

"I learned a lot about how hearing works and what you can do to keep it working well." – Field-Test Student

What's in It for the Teacher?

How Your Brain Understands What Your Ear Hears meets many of the criteria by which teachers and their programs are assessed.

- 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**.
- It is an **integrated** module, drawing most heavily from the subjects of science, social science, mathematics, and health.
- The module has a Web-based **technology component** on which there are sound clips, video, and interactive animations.
- The module includes built-in **assessment tools**, which are noted in each of the lessons with an assessment icon.

In addition, the module provides a means for **professional development**. Teachers can engage in new and different teaching practices such as those described in this module without completely overhauling their entire program. In *Designing Professional Development for Teachers of Science and Mathematics*, the authors write that supplements such as this one "offer a window through which teachers get a glimpse of what new teaching strategies look like in action."[6] By experiencing a short-term unit, 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 supplemental unit such as this module can encourage reflection and discussion, and stimulate teachers to improve their practices by focusing on student learning through inquiry.

The following table correlates topics often included in a biology curriculum with the major concepts presented in this module. This information is presented to help teachers make decisions about incorporating this material into the curriculum.

Correlation of *How Your Brain Understands What Your Ear Hears* to Middle School Life Science Topics

Topic	Lesson 1	Lesson 2	Lesson 3	Lesson 4	Lesson 5
Organisms sense and respond to environmental stimuli.	✔	✔	✔	✔	✔
Sound is a form of energy.	✔	✔	✔	✔	
Energy can change from one form to another.				✔	
Human health and medicine			✔	✔	✔
Risk assessment and management					✔
Relationship of science, technology, and society					✔

Implementing the Module

The five lessons in this module are designed to be taught in sequence for one to two weeks (as a supplement to 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?

How Your Brain Understands What Your Ear Hears is designed to help students achieve the following major goals associated with scientific literacy:

- to understand a set of basic scientific principles related to hearing and communication and their relationship to human health;
- 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?

The lessons are organized into a conceptual framework that allows students to move from what they already know about hearing, some of which may be incorrect, to gaining a scientific perspective on the nature of hearing and communication. Students learn about hearing and human communication by investigating the diversity of languages and their acquisition (*Getting the Message*). Students then explore the multisensory nature of communication and classify the types of sounds in their environment (*Sound Communication*). Students proceed to learn how sound is studied by scientists. They are introduced to the concepts of loudness and pitch, and they learn how these concepts relate to hearing and hearing loss in humans (*Do You Hear What I Hear?*). Students are then introduced to the hearing pathway and the concept of transduction in *A Black Box Problem: How Do I Hear?* In the final lesson, students evaluate the risk of noise-induced hearing loss for fictitious individuals. They also consider whether their own lifestyle places them at risk (*Too Loud, Too Close, Too Long*). The table on pages 8 and 9 illustrates the scientific content and conceptual flow of the five lessons.

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

NSES

How Your Brain Understands What Your Ear Hears 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 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. The Content Standards chart on pages 6 and 7 lists the specific content standards that this module addresses.

Teaching Standards

The suggested teaching strategies in all of the lessons support teachers as they work to meet the teaching standards outlined in the *National Science Education Standards*. This 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 Science Content and Conceptual Flow of the Lessons table and the Suggested Timeline for teaching the module. Teachers can use this mod-

Content Standards: Grades 5–8

Standard A: As a result of their activities in grades 5–8, all students should develop	**Correlation to *How Your Brain Understands What Your Ear Hears***
Abilities necessary to do scientific inquiry	
• Identify questions that can be answered through scientific investigations.	Lesson 4
• Use appropriate tools and techniques to gather, analyze, and interpret data.	Lesson 3
• Develop descriptions, explanations, predictions, and models using evidence.	Lessons 3, 4
• Think critically and logically to make the relationships between evidence and explanations.	Lessons 3, 4, 5
• Recognize and analyze alternative explanations and predictions.	Lessons 1, 2, 3, 4
• Communicate scientific procedures and explanations.	Lessons 2, 4, 5
• Use mathematics in all aspects of scientific inquiry.	Lessons 3, 5
Understandings about scientific inquiry	
• Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects; and some involve making models.	All Lessons
• Mathematics is important in all aspects of scientific inquiry.	Lessons 3, 5
Standard B: As a result of their activities in grades 5–8, all students should develop an understanding of	
Transfer of energy	
• Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.	Lesson 4
Standard C: As a result of their activities in grades 5–8, all students should develop an understanding of	
Structure and function in living systems	
• Living systems at all levels of organization demonstrate the complementary nature of structure and function. Important levels of organization for structure and function include cells, organs, tissues, organ systems, whole organisms, and ecosystems.	Lesson 4
• Specialized cells perform specialized functions in multicellular organisms. Groups of specialized cells cooperate to form a tissue, such as muscle. Different tissues are in turn grouped together to form larger functional units, called organs. Each type of cell, tissue, and organ has a distinct structure and set of functions that serve the organism as a whole.	Lesson 4

• Disease is a breakdown in structures or functions of an organism. Some diseases are the result of intrinsic failures of the system. Others are the result of damage by infection by other organisms.	Lessons 3, 4, 5
Regulation and behavior	
• Behavior is one kind of response an organism can make to an internal or environmental stimulus.	Lessons 1, 2, 5
Standard E: As a result of their activities in grades 5–8, all students should develop	
Understandings about science and technology	
• Science and technology are reciprocal. Science helps drive technology. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable.	Lessons 3, 4, 5
• Technological solutions have intended benefits and unintended consequences.	Lesson 5
Standard F: As a result of their activities in grades 5–8, all students should develop an understanding of	
Personal health	
• The potential for accidents and the existence of hazards imposes the need for injury prevention. Safe living involves the development and use of safety precautions and the recognition of risk in personal decisions.	Lesson 5
Risks and benefits	
• Risk analysis considers the type of hazard and estimates the number of people who might be exposed and the number likely to suffer consequences. The results are used to determine the options for reducing or eliminating risks.	Lesson 5
• Important personal and social decisions are made based on perceptions of benefits and risks.	Lesson 5
Science and technology in society	
• Technology influences society through its products and processes. Technology influences the quality of life and the ways people act and interact.	Lessons 4, 5
Standard G: As a result of their activities in grades 5–8, all students should develop an understanding of	
Science as a human endeavor	
• Science requires different abilities, depending on such factors as the field of study and type of inquiry. Science is very much a human endeavor, and the work of science relies on basic human qualities, such as reasoning, insight, energy, skills, and creativity.	All Lessons
Nature of science	
• Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.	Lessons 3, 4

Science Content and Conceptual Flow of the Lessons

Lesson and Learning Focus*	Topics Covered and Major Concepts
1: *Getting the Message* ***Engage:*** Students become engaged in the study of hearing, communication, and understanding.	***Distinguishing between hearing and communication.*** • Hearing involves sound, while understanding involves the brain. ***Relating the concept of critical period to language acquisition.*** • There is a critical period during which language acquisition takes place.
2: *Sound Communication* ***Explore:*** Students watch and listen to human speech. They explore the multisensory nature of human communication. The Explore phase gives students a common set of experiences upon which to begin building their understanding.	***Communication is multisensory.*** • The most effective communication is multisensory. • Sound is a powerful and important means of communication. ***Sounds can be environmental, voiced, and musical.*** • There are three types of sound: environmental, voiced, and musical.
3: *Do You Hear What I Hear?* ***Explore/Explain:*** Students generate a hearing-response curve. They also listen to recordings that simulate hearing loss. Students express their understanding of the relationships among loudness, pitch, and hearing.	***Characteristics of loudness and pitch.*** • Loudness and pitch are distinct properties of sound. • Loudness is related to the amplitude of the sound wave; pitch is related to its frequency. ***The human hearing response and hearing loss.*** • Humans do not hear all pitches equally well. • The loudness of very-low- and very-high-pitched sounds must be increased for them to be detected. • A healthy sense of hearing is characterized by the recognition of a wide spectrum of pitches. • Hearing loss may involve failure to detect specific pitches.
4: *A Black Box Problem: How Do I Hear?* ***Elaborate:*** Students deepen their understanding of hearing by investigating the parts of the hearing pathway and their functions.	***The components of the hearing pathway and their functions.*** • The hearing pathway processes sound in a series of steps that involve different structures within the ear. • Hearing requires the passage of vibrational energy from one medium to another, as well as its conversion to electrical energy (in the form of nerve impulses). • Damage to specific parts of the hearing pathway results in predictable changes in hearing. ***The process of transduction.*** • Transduction is the conversion of vibrational energy into electrical energy that occurs in the cochlea.

5: ***Too Loud, Too Close, Too Long*** ***Elaborate/Evaluate:*** Students reflect on what they learned in the module in the context of noise-induced hearing loss (NIHL). They evaluate risks for NIHL for several fictitious individuals as well as for themselves and recommend ways to reduce these risks.	***Understanding occurs in the brain.*** • Understanding what one hears occurs in the brain. • Damage to specific parts of the hearing pathway results in predictable changes in hearing. ***Characteristics, causes, and prevention of noise-induced hearing loss.*** • Noise-induced hearing loss leads to an inability to hear and understand speech and other sounds at normal loudness levels. • Noise-induced hearing loss can be temporary or permanent. • Noise-induced hearing loss can result from a one-time exposure to extremely loud sound, repeated or long-term exposure to loud sound, or extended exposure to moderate sound. • Noise-induced hearing loss can happen to people of all ages. • The best way to protect one's hearing is to avoid loud noise whenever possible.

*See How Does the 5E Instructional Model Promote Active, Collaborative, Inquiry-Based Learning? on pages 9 to 11.

ule 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 of 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 can encourage and model the skills of scientific inquiry, as well as foster curiosity, openness to new ideas and data, and skepticism, which characterize the study of 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 to tasks that students will engage in outside the classroom or to practices 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 by way 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 understanding. 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 when they work alone in a competitive environment. When active, collaborative learning is directed toward scientific inquiry, students succeed in making their own discoveries. They ask questions, observe, analyze, explain, draw conclusions, and ask new questions. These inquiry-based experiences include both those that involve students in direct experimentation and those in which students develop explanations through critical and logical thinking.

The viewpoint that students are active thinkers who construct their own understanding from 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 5E model sequences the learning experiences so that students have the opportunity to construct their understanding of a concept over time. The model leads students through five phases of learning that are easily described using words that begin with the letter *E*: Engage, Explore, Explain, Elaborate, and Evaluate. The following paragraphs illustrate how the five Es 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 think they know about the topic and concepts to be covered.

The Engage lesson in this module, Lesson 1: *Getting the Message*, is designed to

- pique students' curiosity and generate interest;
- determine students' current understanding about hearing and communication;
- invite students to raise their own questions about hearing and its relationship to human communication;
- encourage students to compare their ideas with those of others; and
- enable 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: *Sound Communication*, and Lesson 3: *Do You Hear What I Hear?*, students investigate the multisensory nature of human communication and communicating by way of sounds in their environment. Students also investigate the characteristics of sound, such as loudness and pitch. These lessons provide a common set of experiences within which students can begin to construct their understanding. Students

- interact with materials and ideas through classroom demonstrations and simulations;
- 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 sound, hearing, and communication.

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. The Explain lesson for this module, Lesson 3: *Do You Hear What I Hear?*, encourages students to

- explain concepts and ideas (in their own words) about sound in terms of loudness and pitch;

- listen to and compare the explanations of others 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; and
- compare their current thinking with what they previously thought.

Elaborate

In Elaborate lessons, students apply or extend previously introduced concepts in new situations and relate their previous experiences to new ones. In the Elaborate lesson in this module, Lesson 4: *A Black Box Problem: How Do I Hear?*, students

- make conceptual connections between new and former experiences, connecting the structure of the ear with their concepts of sound and communication;
- connect ideas, solve problems, and apply their understanding to a new situation;
- 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 instructional 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 5: *Too Loud, Too Close, Too Long,* provides an opportunity for students to

- demonstrate what they understand about the ear and hearing and how well they can apply their knowledge to solve a problem, namely reducing risk for noise-induced hearing loss;
- share their current thinking with others;
- assess their own progress by comparing their current understanding with their prior knowledge; and
- ask questions that take them deeper into a concept.

To review the relationship of the 5E Instructional Model to the concepts presented in the module, see the table titled Science Content and Conceptual Flow of the Lessons, on pages 8 and 9.

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 learn in ways that are different from those experienced in a traditional classroom. The following charts, What the Teacher Does and What the Students Do, outline these differences.

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 the curriculum, the most appropriate mechanism for assessing student learning is one that occurs informally at various points within the lessons, rather than just once at the end of the module. Accordingly, integrated within the lessons in the module are specific assessment components. These "embedded" assessment opportunities include one or more of the following strategies:

- performance-based activities, such as developing graphs or participating in a discussion about risk assessment;
- oral presentations to the class, such as reporting experimental results; and

What the Teacher Does

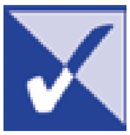
Stage	That is *consistent* with the 5E Instructional Model	That is *inconsistent* with the 5E Instructional Model
Engage	• Piques students' curiosity and generates interest • Determines students' current understanding (prior knowledge) of a concept or idea • Invites students to express what they think • 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 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 students that they are wrong • Gives information and facts that solve the problem • Leads 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 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

What the Students Do

Stage	That is *consistent* with the 5E Instructional Model	That is *inconsistent* with the 5E Instructional 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 • 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 • Demonstrate what they understand about the concept(s) and how well they can implement a skill	• Ignore previous information or evidence • Draw conclusions from "thin air" • Use terminology inappropriately and without understanding
Evaluate	• 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

- written assignments, such as 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 that teachers can assess appear in the margin beside each step in which 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; teachers 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 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 assure that the infraction will not occur a second time.
- Set a good example by observing all safety practices. This includes wearing eye protection during all investigations when eye protection is required for the 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, verbally alert the students to the potential hazards 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 upon 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 are given a variety of opportunities to discuss, interpret, and evaluate basic science and health issues, some in light of their values and ethics. As students encounter issues about which they feel strongly, some discussions might become controversial. The degree of controversy will depend on many factors, such as how similar the students are with respect to socioeconomic status, perspectives, value systems, and religious preferences. In addition, the language and attitude of the teacher factor into the flow of ideas and the quality of exchange among the students.

The following guidelines may help teachers facilitate discussions that balance factual information with feelings.

- Remain neutral. Neutrality may be the single most important characteristic of a successful discussion facilitator.
- Encourage 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 to enter the discussion.
- Emphasize that everyone must be open to hearing and considering diverse views.
- Use unbiased questioning to help the 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.
- 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 upon a nonhostile environment in the classroom. Remind students to respond to ideas instead of to the individuals presenting those ideas.
- Respect silence. Reflective discussions often are slow. If a teacher breaks the silence, students may allow the teacher to dominate the discussion.
- At the end of the discussion, ask the students to summarize the points that they and their classmates have made. Respect students regardless of their opinion about any controversial issue.

Using the Student Lessons

The heart of this module is the set of five classroom lessons. These lessons are the vehicles that will carry important concepts related to hearing and communication to your students. To review the concepts in detail, refer to the chart Science Content and Conceptual Flow of the Lessons, on pages 8 and 9.

Format of the Lessons

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

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

- The **Overview** provides a short summary of student activities.
- The **Major Concepts** section states the central idea(s) the lesson is designed to convey.
- **Objectives** lists specific understandings or abilities students should have after completing the lesson.
- **Teacher Background** specifies which portions of the background section titled *Information about Hearing, Communication, and Understanding* relate directly to the student lesson. This reading material provides the teacher with the science content that underlies the key concepts covered in the lesson. The information provided is *not* intended to form the basis of lectures to students. Instead, it enhances the teacher's understanding of the content so that he or she can more accurately facilitate class discussions, answer student questions, and provide additional examples.

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

- **Web-Based Activities** tells the teacher which of the lesson's activities use the *How Your Brain Understands What Your Ear Hears* Web site as the basis for instruction.
- **Photocopies** lists the paper copies and transparencies that need to be made from masters, which follow the student lesson.
- **Materials** lists all the materials other than photocopies needed for each of the activities in the lesson.
- **Preparation** outlines tasks the teacher needs to perform prior to the lesson.

Procedure outlines the steps in each activity of the lesson. It provides implementation hints and answers to discussion questions.

Within the procedure, annotations provide additional commentary.

- **Assessment** provides strategies for assessing student progress throughout the module, and is identified by an assessment icon (see page 18).
- **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 strategy. Instructions tell the teacher how to access the Web site and the relevant activity. Information about using the Web site can be found in *Using the Web Site* (see pages 21–24). A print-based alternative to Web activities is provided in the event that computers with Internet access are not available.

identifies a print-based alternative to a Web-based activity to be used when computers are not available.

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

The Lesson Organizer provides a brief summary of the lesson. It outlines procedural steps for each activity and includes icons that denote where in each activity masters, transparencies, and the Web site are used. The lesson organizer is intended to be a memory aid for you to use only after you become familiar with the detailed procedures for the activities. It can be a handy resource during lesson preparation as well as during classroom instruction.

Suggested Timeline

Timeline	Activity
3 weeks ahead	Reserve computers Verify ability to access Internet and to download required plug-ins
1 week ahead	Copy masters Make transparencies Gather materials
Day 1 Monday	**Lesson 1** Activity 1: *What Did You Say?* Activity 2: *When the Time Is Right*
Day 2 Tuesday	**Lesson 2** Activity 1: *How Do We Understand?* Activity 2: *Sound Safari*
Day 3 Wednesday	**Lesson 3** Activity 1: *Measuring Intensity*
Day 4 Thursday	Activity 2: *Pitch Me a Curve*
Day 5 Friday	**Lesson 4** Activity 1: *The Mysterious Black Box*
Day 6 Monday	Activity 2: *Understanding Form and Function*
Day 7 Tuesday	**Lesson 5** Activity 1: *It's Too Loud!* Activity 2: *Assessing Risk for Hearing Loss*
Day 8 Wednesday	Activity 3: *Sound Advice*

The **Masters** required to teach the activities are located at the end of each lesson.

Timeline for the Module

The timeline (on page 18) outlines the optimal plan for completing the five lessons in this module. This schedule assumes that you will teach the activities on consecutive days. If your class requires more time for completing the procedures, for discussion of issues raised in this module, or for completing activities on the Web site, adjust your timeline accordingly.

Using the Web Site

The *How Your Brain Understands What Your Ear Hears* Web site is a tool, like an overhead projector or a textbook, that can help you organize your use of the module, engage student interest in learning, and orchestrate and individualize instruction. The Web site features sound clips, video clips, and animations that complement three of the module lessons.

Hardware/Software Requirements

The Web site can be accessed from Apple Macintosh and IBM-compatible personal computers. Links to download the Macromedia Flash and QuickTime Player plug-ins are provided on the Web site main page. The minimum hardware and software requirements for using the Web site are listed in the following table.

To access the Web site, type the following URL into your browser: *http://science.education.nih.gov/supplements/hearing/teacher.*

Getting the Most out of the Web Site

Before you use the Web site, or any other piece of instructional software in your classroom, it may be valuable to identify some of the benefits you

Minimum Hardware/Software Requirements for Using the Web Site

CPU/Processor (PC Intel, Mac)	Pentium 333 MHz, Power PC or faster
Operating system (DOS/Windows, Mac OS)	Windows 95/98/2000 or Mac OS 7
System memory (RAM)	64 MB or more
Screen display	800 x 600, 16 bit (65K colors)
Browser	Microsoft Internet Explorer 5.5 or Netscape Communicator 4.75 and higher
Browser settings	JavaScript enabled
Free hard drive space	10 MB
Connection speed	56 kbps
Plug-ins	Macromedia Flash Player (version 6 and higher) and QuickTime Player (version 5 and higher)
Audio	Sound card with speakers

expect the software to provide. Well-designed instructional multimedia software can

- motivate students by helping them enjoy learning and want to learn more because it enlivens content that students otherwise might find uninteresting;
- offer unique instructional capabilities that allow students to explore topics in greater depth and in ways that are closer to actual real-life experience than print-based resources can offer;
- provide teachers with support for experimenting with new instructional approaches that allow students to work independently or in small teams and that give teachers increased credibility among today's technology-literate students; and
- increase teacher productivity by helping teachers with assessment, record keeping, and classroom planning and management.

The ideal use of the Web site requires one computer for each student team. However, if you have only one computer available in the classroom, you can still use the Web site (for example, by using a suitable device for projecting the screen image, or by rotating student teams through the computer station). If you do not have the facilities for using the Web site with your students, the print-based alternatives are provided for those lessons.

Collaborative Groups

Many of the activities in the lessons are designed to be completed by teams of students working together. Although individual students working alone can complete these activities, this strategy will not stimulate the types of student-student interactions that are part of active, collaborative, inquiry-based learning. Therefore, we recommend that you organize collaborative teams of two to four 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 this type of arrangement can be efficient, it means that some students will not have the opportunity to experience the in-depth discovery and analysis that the Web site was designed to stimulate.

We recommend that you keep your students in the same collaborative teams for all of the activities in the lessons. This will allow each team to develop a shared experience with the Web site 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 four students to one computer, then 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 way 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 that you have assigned.

A second way to structure the lessons if you have only one computer available is to use a projection system to display the desktop screen for the whole class to view. Giving selected students in the class the opportunity to manipulate the Web activities in response to suggestions from the class can give students some of the same autonomy in their learning they would have gained from working in small teams.

Web Activities for Students with Disabilities

The Office of Science Education (OSE) is committed to providing access to the Curriculum Supplement Series for individuals with disabilities, including members of the public and federal employees. To meet this commitment, we will comply with the requirements of Section 508 of the Rehabilitation Act. Section 508 requires that individuals with disabilities who are members of the public seeking these materials will have access to and use of information and data that are comparable to those provided to members of the public who are not individuals with disabilities. The online versions of this series have been prepared to comply with Section 508.

If you use assistive technology (such as a Braille reader or a screen reader) and the format of any material on our Web sites interferes with your ability to access the information, please let us know. To enable us to respond in a manner most helpful to you, please indicate the nature of your accessibility problem, the format in which you would prefer to receive the material, the Web address of the requested material, and your contact information.

Contact us at

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National Institutes of Health
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Bethesda, MD 20892-7984
ose@science.education.nih.gov

How Your Brain Understands What Your Ear Hears 508-Compliant Web Activities

Lesson, activity	For students with hearing impairment	For students with sight impairment
Lesson 1, Activity 1: *What Did You Say?*	Students may click on the closed-captioning icon to view the captioning for Tracks 1–6.  The closed-captioning icon is located in the top left corner of the activity, within the rounded gray rectangle. The text appears below the track listing and animation.	There is a text description within the activity that is read by screen readers. It describes the format of the activity and indicates what software is required for optimal performance. Tracks 1–6 are accessible via the keyboard. When using a screen reader, Track 4 includes a descriptive narration.
Lesson 3, Activity 2: *Pitch Me a Curve*	Students may click on the closed-captioning icon to view the captioning for the Introduction and Filtered Sound sections.  The closed-captioning icon is located in the top left corner of the activity, within the rounded gray rectangle. The text appears below the animation.	There is a text description within the activity that is read by screen readers. It describes the format of the activity and indicates what software is required for optimal performance. The Introduction screen includes a text description of the oscilloscope tracings. When using a screen reader, the hearing-response graph begins with an audio description and instructions for the activity. Students may navigate between pitches with the Tab key

	Throughout the activity, an oscilloscope provides a visual representation of the sounds that occur.	and increase/decrease the loudness with the +/– keys. When using a screen reader, the Filtered Sound section begins with an audio description and instructions for the activity. The audio describes the differences between each track. Students may navigate to the three track buttons using the Tab key. Supervision is recommended.
Lesson 4, Activity 1: *The Mysterious Black Box*	Introduction, Animation, Sequencing Activity Students may click on the closed-captioning icon to view the captioning for the Introduction and Animation sections. The final animation at the end of the Sequencing Activity also has captioning available.  The icon is located in the top left corner of the activity, within the rounded gray rectangle. The text appears below the animations.	There is a text description within the activity that is read by screen readers. It describes the different sections of the activity and indicates what software is required for optimal performance. When using a screen reader, the Introduction includes a descriptive narration that explains the animation. A second descriptive narration explains the Black Box Animation. When using a screen reader, students will encounter an accessible version of the Sequencing Activity. This includes text instructions and audio feedback during the game. Students are instructed to complete the sequence by putting the components of the hearing pathway in their correct order. Once they have placed the components in order, they can review and test the sequence. Once the Sequencing Activity has been completed successfully, students move on to the final animation. A descriptive narration explains the animation of the hearing pathway. Supervision is recommended.
Lesson 5, Activity 1: *How Small Is a Hair Cell?*	No special considerations are required.	An equivalent description of the video has been provided. It is located directly beneath the video and is accessible via a screen reader.

Information about Hearing, Communication, and Understanding

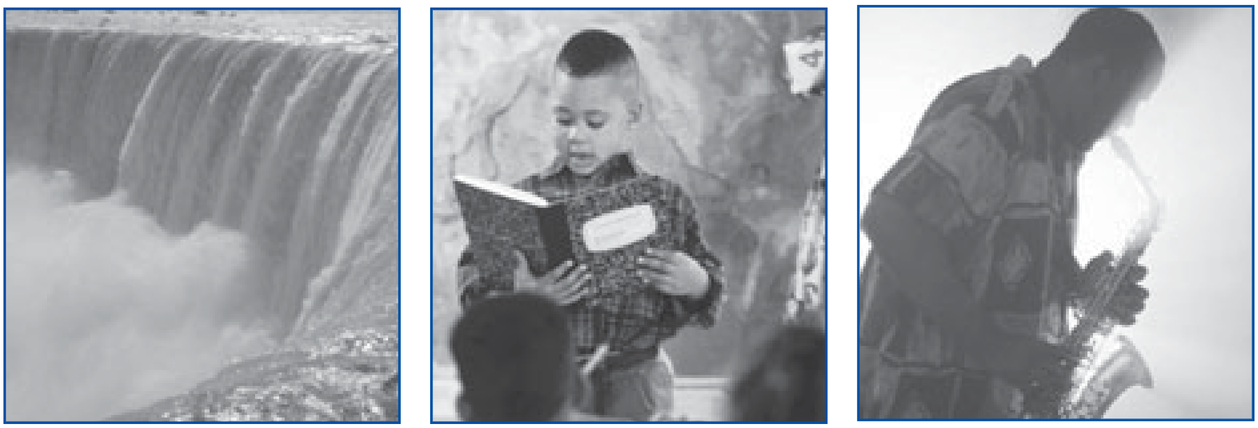

Figure 1. Sounds may be classified as environmental, voiced, or musical.

1 Introduction

Sound offers us a powerful means of communication. Our sense of hearing enables us to experience the world around us through sound. Because our sense of hearing allows us to gather, process, and interpret sounds continuously and without conscious effort, we may take this special sense of communication for granted. But, did you know that

- Human communication is multisensory, involving visual, tactile, and sound cues?
- The range of human hearing, from just audible to painful, is over 100-trillion-fold?
- Tiny specialized cells in the inner ear, known as hair cells, are responsible for converting the vibrational waves of sound into electrical signals that can be interpreted by the brain?
- Tinnitus, commonly known as "ringing in the ears," is actually a problem that originates in the brain?
- A recent study showed that men who hunt experience an increased risk of high-pitched hearing loss of 7 percent for every five years that they hunt? Nearly all (95 percent) of these same hunters report that they do not use hearing protection while hunting.[11]

Contemporary hearing research is guided by lessons learned from sensory research, namely that specialized nerve cells respond to different forms of energy—mechanical, chemical, or electromagnetic—and convert this energy into electrochemical impulses that can be processed by the brain. The brain then works as the central processor of sensory impulses. It perceives and interprets them using a "computational" approach that involves several regions of the brain interacting all at once. This notion is different from the long-held view that the brain processes information one step at a time in a single brain region. Over the past decade, scientists have begun to understand the intricate mechanisms that enable the ear to convert the mechanical vibrations of sound to electrical energy, thereby allowing the brain to process and interpret these signals.

Scientific understanding of the role of genes in hearing is also increasing at an impressive rate. The first gene associated with hearing was isolated in 1993. By the end of 2000, more than 60 genes related to hearing were identified.[15] In addition, scientists have pinpointed over 100 chromosomal regions believed to harbor genes affecting the hearing pathway. Many genes were first isolated in the mouse, and from this, the human genes were identified. Completion of the Mouse and Human Genome Projects is helping scientists isolate these genes.

The rapid growth in our understanding is of more than academic interest. In a practical sense, sharing this information with young people can enable them to adopt a lifestyle that promotes the long-term health of their sense of hearing. With this in mind, this supplement will address several key issues, including

- What is the nature of sound?
- What mechanism allows us to process sounds with great precision—from the softest whisper to the roar of a jet engine, from a high-pitched whistle to a low rumble?
- What are the roles of hearing, processing, and speaking in human communication?
- What happens when the hearing mechanism is altered or damaged? How does sound processing change?
- What can be done to prevent or accommodate damage to our sense of hearing?

2 Misconceptions Related to Sensory Perception and Hearing

In presenting the material contained within this supplement, you may have to deal with students' incomplete understanding about hearing. Some of the likely misconceptions about hearing that students have follow:

Misconception 1: Our senses provide a complete and accurate picture of the world.

Younger students are often unaware of the limitations of their senses. They may believe that what they perceive is all that there is. Most students would be quite surprised to learn that their ears produce measurable sounds of their own that are normally inaudible to the brain. Also, they might not be aware that some animals use sound frequencies that are out of our hearing range. For example, whales communicate using low-frequency sounds that are inaudible to humans and can carry across vast expanses of ocean. This module will make students aware that our senses react to only a limited range of the energy inputs available. Much sensory information exists beyond our ability to experience it. Our level of awareness is influenced by our individual abilities, our genes, our environment, and our previous experiences, as well as the interactions among them. Learning about the limitations of our senses can help students interpret their environment more accurately.

Your ears produce sounds of their own that are normally inaudible to the brain.

Misconception 2: Our senses function independently of one another.

Students may believe that because each sense is specialized for a particular type of sensation, senses function by themselves and do not interact with one another or with the rest of the body. Research, however, reveals many interactions between the senses.[7] During this module, students will learn about the sensory integration that takes place in the brain.

Misconception 3: As we age, our brain networks become fixed and cannot be changed.

Scientific research has shown that the brain never stops changing and adjusting to its environment.[1] This ability is important for acquiring new knowledge and for compensating for deficiencies that result from age or injury. The ability of the brain

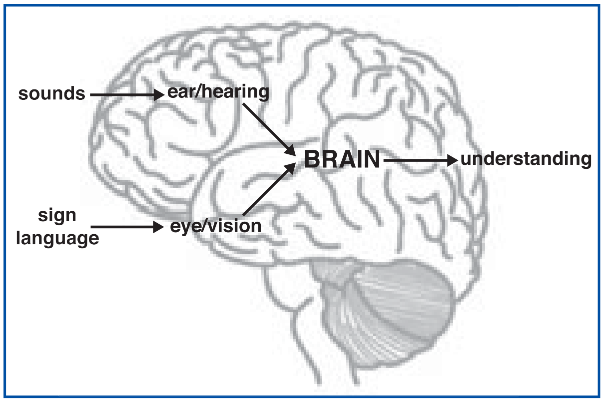

Figure 2. Regardless of the senses used, understanding occurs in the brain.

to "reprogram" itself is called plasticity. Special brain exercises, or training techniques, exploit brain plasticity to help people cope with specific language and reading problems.

Misconception 4: Our senses do not really require any preventive maintenance.

Students may believe that because our senses function without any conscious input, always being "on," their function and health are not influenced by what we do. The module will make students aware that the overall health of their senses, like all other bodily systems, is affected by the lifelong demands placed on them. Students will learn about biological mechanisms in which potentially harmful input can lead to both short-term and long-term hearing impairments, and they will learn about simple, effective ways to minimize harmful stimuli.

3 Major Concepts Related to Hearing and Communication

Research into hearing and communication is providing a scientific foundation for understanding the anatomy, physiology, and genetics of the hearing pathway, as well as the social and cultural aspects of human communication. The following discussion is designed to introduce you to some major concepts about hearing and communication.

3.1 Communication is multisensory

Although some people might define communication as an interaction between two or more living creatures, it involves much more than this. For example, we are constantly receiving information from, and changing our relationship with, our environment. This communication is received through our senses of smell, taste, touch, vision, and hearing. Communication with others makes use of vision (making eye contact or assessing body language) and sound (using speech or other sounds, such as laughing and crying). When a group of people shares a need or desire to communicate, language is born. The most common human language is the language of words. Words may be communicated in various ways. Although they are usually spoken, they also may be written, fingerspelled, or expressed through sign language.

Figure 3. Words may be communicated by writing, speaking, and signing.

Communication with others makes use of sound and vision.

3.2 Language acquisition: imprinting and critical periods

Since the time of Plato, there has been debate over the nature of language. Some believe that language is inborn and purposeful, while others believe it to be artificial and arbitrary. Some consider language to be an evolutionary product, while others do not. It appears that words are not "built into" the brain, because language is a relatively recent evolutionary development and also because languages differ substantially from one another. Language and communication are made possible by specialized structures. We have evolved a sophisticated apparatus for both speech and hearing. Our brains have specific regions devoted to speech, hearing, and language functions. Still, the mechanisms by which children acquire language are only partially understood.

Our brains have specific regions devoted to speech, hearing, and language functions.

There are two concepts important to the acquisition of language. One is imprinting, which refers to the ability of some animals to learn rapidly at a very early age and during a well-defined period in their development. Imprinting generally refers to the ability of offspring to acquire the behaviors characteristic of their parents. This process, once it occurs, is not reversible. A famous example of imprinting was described by Nobel laureate Konrad Lorenz in the 1930s.[5] Lorenz observed that newly hatched goslings would follow him, rather than the mother goose, if they saw him first. The period of imprintability may be very short, just hours for some species.

A second concept, related to imprinting, is **critical periods**. A nonhuman example of a critical period is the limited time frame within which a male bird must acquire his song.[8] For instance, a male white-crowned sparrow usually begins singing its full song between 100 and 200 days of age. Proper song acquisition is needed for mating and for marking territory. However, to learn his song, the young bird must be exposed to an adult bird's song consistently and frequently between one week and two months after hatching (its critical period for song acquisition). If the male sparrow hears the song only before or after its critical period, then he will not be able to learn the song correctly.

***Figure 4.** Konrad Lorenz with young goslings that imprinted to him.*

These examples demonstrate the brain's flexibility—its ability to be changed or to adapt to its environment. They demonstrate that an animal may alter its behavior or acquire a behavior that helps improve its chances for survival. Do animals have anything to teach us about our own acquisition of language? The answer seems to be yes. Consider the following: Scientists have reported that seal pups learn to recognize their mothers' voices within a few days of being born.[2] This is important because the mother seals must leave their pups after roughly a week to go hunting. Upon returning, mother seals vocalize and wait for their pups to respond. By playing recordings of various females, the investigators determined that for the first few hours after birth, seal pups will respond to the voice of any adult female. However, after two to five days, the pups learn to respond only to their mother's voice.

Very soon after birth, human infants learn to distinguish speech sounds from other types of sound. Within the next month or two, the infant learns to distinguish between different speech sounds.[4, 14] An 18-month-old toddler can recognize and use the sounds (called **phonemes**) of his or her language and can construct two-word phrases. A 3½-year-old child can construct nearly all of the possible sentence types. From this point on, vocabulary and language continue to expand and be refined.[12]

Communication is truly a multisensory experience. For most individuals, the pathway from creating sound (speaking) to receiving, processing, and interpreting sound (hearing) is critical.

The parameters of language development and developmental phases are under rigorous study. For ethical reasons, investigators cannot explore such questions through human experimentation that would deprive infants of language intentionally. Occasionally, however, unusual circumstances provide us with a glimpse of how humans acquire or do not acquire spoken language. There are examples of individuals who were not exposed to spoken language from birth but who had normal hearing. These individuals never developed normal language or speech. Although such examples have been put forth as justification for the critical-period hypothesis for language development, there are confounding issues. The possibility exists that these individuals had some type of brain abnormality that was responsible for their not acquiring spoken language. Nonetheless, the importance of sound as a stimulus for the hearing apparatus and its need to be processed by the brain for understanding is unquestioned.

Communication is truly a multisensory experience. For most individuals, the pathway from creating sound (speaking) to receiving, processing, and interpreting sound (hearing) is critical. This module focuses on the key issues of how sound is processed so that communication is achieved.

3.3 Sound has a physical basis

Sound represents vibrational energy. It is created when a medium such as air, wood, metal, or a person's vocal cords vibrate. Sounds carried as energy are transferred from one molecule to the next in the vibrating medium. To understand sound, consider the analogy in which a stone is dropped into a body of water. This action produces ripples that will spread out in all directions from the point where the stone contacted the water. The ripples become weaker (decrease in intensity) as they get farther away from the origin. So it is with sound. The vibration through a medium proceeds in waves. However, unlike ripples on water, sound waves move away from their point of origin in three dimensions, not just two.

Sound waves possess specific characteristics. **Frequency** represents the number of complete wave cycles per unit of time, usually one second (see Figure 5). Frequency is expressed in **hertz (Hz)**, which means cycles per second. Low-frequency sounds are those that vibrate only a few times per second, while high-frequency sounds vibrate many more times per second. The term used to distinguish your perception of higher-frequency sounds from lower-frequency sounds is **pitch**.

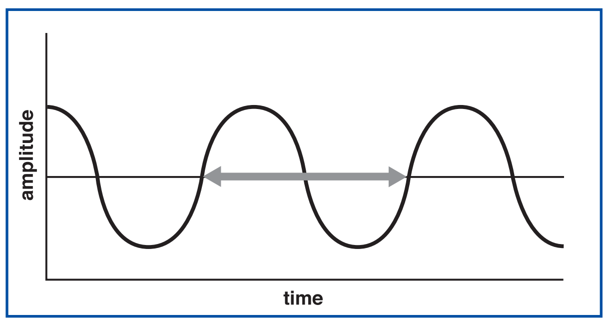

Figure 5. *Representation of frequency. The arrow indicates one cycle of the sound wave.*

The speed of sound is constant for all frequencies, although it does vary with the medium through which it travels. In air, sound travels at a speed of roughly 340 meters per second. Sound travels fastest through metals because the molecules of that medium are packed very closely together. Similarly, sound travels about four times faster in water than in air. It follows that sound travels faster in humid air than dry air; in addition, humid air absorbs more high frequencies than low frequencies, leading to differences in the perception of sound heard through the two media. Finally, temperature can affect the speed of sound in any medium. For instance, the speed of sound in air increases by about 0.6 meters per second for each degree Celsius increase in temperature.

The human ear responds to frequencies in the range of 20 Hz to 20,000 Hz (20 kHz),[18] although most speech frequencies lie between 100 and 4,000 Hz. Frequencies above 20,000 Hz are referred to as **ultrasonic**. Though ultrasonic frequencies are outside the range of human perception, many animals can hear these sounds. For instance, dogs can hear sounds at frequencies as high as 50,000 Hz, and bats can hear sounds as high as 100,000 Hz. Other sounds, such as some produced by earthquakes and volcanoes, have frequencies of less than 20 Hz. These sounds, referred to as **infrasonic** or **subsonic**, are also outside the range of human hearing.

We all know that sounds can be louder or softer, but what does this mean? Sound is energy, and this energy, when traveling through air, displaces, or vibrates, air molecules. For example, the softest sound humans can hear is a sound that displaces particles of air by one-billionth of a centimeter.[13] The extent to which air particles move from their original resting point determines the **amplitude** of the sound wave (see Figure 7). The greater the amplitude of the sound wave, the greater the intensity, or pressure, of the sound. **Intensity** refers to the overall amplitude of a sound. This distinction in terms is necessary, since nearly all sounds to which we are exposed are complex sounds made up of a combination of sound waves. **Loudness** is our perception of the intensity, frequency, and duration of a sound.

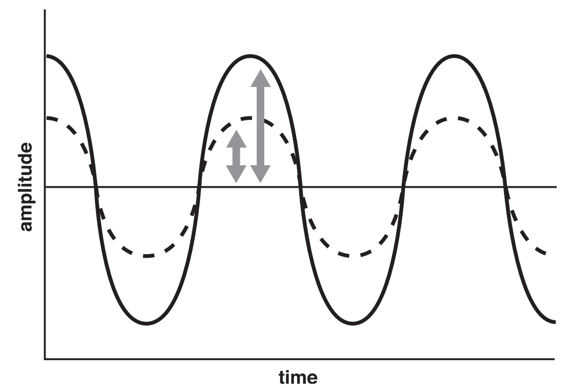

Figure 7. Representation of amplitudes of a wave. The dashed line has a lower amplitude than the solid line.

Sound intensity is measured in relation to an accepted reference point. One such reference is the threshold at which a sound can be heard. How the intensity of any given sound compares with this standard reference level is given in units known as decibels (dB). The **decibel** is one-tenth of a bel, a unit named after the inventor Alexander Graham Bell. The decibel scale is not a linear one, but rather represents the ratio of

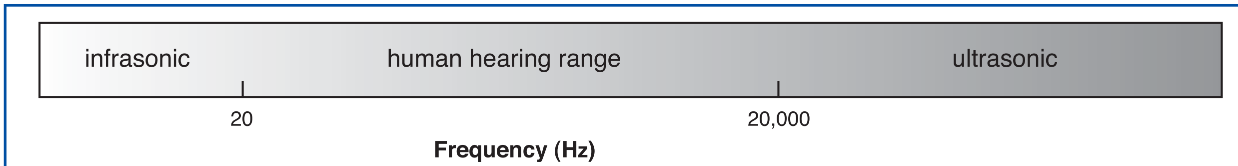

Figure 6. The sound spectrum.

the sound to the reference standard. To understand why ratios are necessary, consider the tremendous range of sound intensities we are capable of hearing. Scientists estimate that the human ear is sensitive to about 100,000,000,000,000 (10^{14}) units of intensity. Also consider that a shout is about 1,000,000 (10^6) times more powerful than a whisper. Because dealing with such large numbers is cumbersome, the decibel scale is used to simplify comparisons (see Table 1). Every 10-dB increase in sound intensity represents a 10-fold increase in sound intensity and a perceived doubling in loudness. Therefore, a sound at 60 dB is 100 times as intense as a sound at 40 dB but is only perceived as four times as loud. In this way, the predominant range of human hearing is represented on a scale from 0 to 140 dB. The average intensities of some everyday sounds are presented in Table 2.

Every 10-dB increase in sound intensity represents a 10-fold increase in sound intensity and a perceived doubling in loudness.

Individuals are often unaware of the damage loud noise does to their hearing. Even common noises, such as highly amplified music and gas-engine mowers or leaf blowers, can damage human hearing with prolonged exposure. Sporting events can also expose individuals to hazardous decibel levels as defined by the Occupational Health and Safety Administration (OSHA). Under OSHA guidelines, the limit of continuous noise exposure for an eight-hour day in an industrial setting is 90 dB. OSHA also prohibits workplace **impact noise** (short bursts of sound) greater than 140 dB. By increasing our awareness of decibel levels of common environmental noises, we can better limit our exposure to hazardous noise levels or take measures to protect our ears.

Table 1. The Decibel System

Intensity Ratio	Intensity Difference (dB)
1:1	0
2:1	3
4:1	6
8:1	9
10:1	10
16:1	12
20:1	13
100:1	20
400:1	26
800:1	29
1,000:1	30
2,000:1	33
8,000:1	39
10,000:1	40
100,000:1	50
1,000,000:1	60
10,000,000:1	70
100,000,000:1	80
1,000,000,000:1	90
10,000,000,000:1	100
100,000,000,000:1	110
1,000,000,000,000:1	120
10,000,000,000,000:1	130
100,000,000,000,000:1	140

Even common noises, such as highly amplified music and gas-engine mowers or leaf blowers, can damage human hearing with prolonged exposure.

Table 2. Average Intensities of Everyday Sounds

Sound	dB Level
hearing threshold	0
breathing	10
rustling leaves	20
whispering	25
library	30
refrigerator	45
average home	50
normal conversation	60
clothes dryer	60
washing machine	65
car	70
vacuum cleaner	70
busy traffic	75
noisy restaurant	80
outboard motor	80
inside car in city traffic	85
electric shaver	85
screaming child	90
passing motorcycle	90
convertible ride on freeway	95
table saw	95
hand drill	100
tractor	100
diesel truck	100
circular saw	100
jackhammer	100
gas engine mower	105
helicopter	105
chain saw	110
amplified rock concert	90–130
shout into ear at 20 cm	120
car horn	120
siren	120
threshold of pain	120–140
gunshot	140
jet engine	140
12-gauge shotgun	165
rocket launching	180
loudest audible tone	194

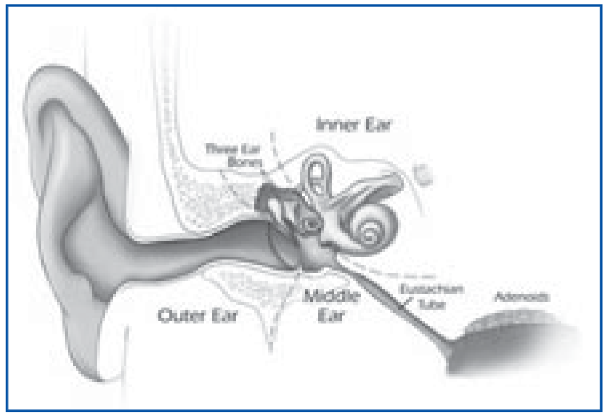

Figure 8. Anatomy of the human ear.

3.4 Perception of sound has a biological basis

When sound, as vibrational energy, arrives at the ear, it is processed in a complex but distinct series of steps. These steps reflect the anatomical division of the ear into the outer ear, middle ear, and inner ear (see Figure 8).

The pathway from the outer ear to the inner ear is remarkable in its ability to precisely process sounds from the very softest to the very loudest and to distinguish very small changes in the frequency of sound (pitch). Humans can discern a difference in frequency of just 0.1 percent. This means that humans can tell the difference between sounds at frequencies of 1,000 Hz and 1,001 Hz.

The outer ear. The outer ear is composed of two parts. The **pinna** is the outside portion of the ear and is composed of skin and cartilage. The second part is called the **ear canal** (also called the external auditory canal). The pinna, with its twists and folds, serves to enhance high-frequency sounds and to focus sound waves into the middle and inner portions of the ear. The pinna also helps us determine the direction from which a sound originates. However, the greatest asset in judging the location of a sound is having two ears. Because one ear is closer to the source of a sound than the other, the brain detects slight differences in the times and intensities of the arriving signals. This allows the brain to approximate the sound's location. Interestingly, the position and orientation of the pinna, at the side of the head, help reduce sounds that originate behind us. This helps us hear sounds that originate in the direction we are looking and reduces distracting background noises.

Some students (and adults) may believe that the size of the ear is an indication of the organism's hearing ability—that is, the larger the ear, the better the ability to hear. This misperception doesn't take into account the internal structures of the ear that process sound vibrations. A large pinna may serve a function that is unrelated to hearing. For example, the external ear of the African elephant is filled with small blood vessels that help the animal dissipate excess heat. The external ear may be specialized in other ways, as well. Cat owners, for example, have undoubtedly observed the rather dramatic movement of their pet's pinnae as the animal attempts to locate the source of a sound.

The ear canal is about 2.5 cm (1 inch) long and leads to the **tympanic membrane** (eardrum) of the middle ear. The outer two-thirds of the canal contains glands that secrete a wax-like substance. This earwax, along with hairs that are present, serves to keep dust, insects, and other foreign material from going deeper into the ear. It also helps maintain a constant humidity and temperature for the middle ear. Individuals should not attempt to remove earwax, since this secretion will work itself out of the canal naturally in most cases. To avoid damage, it should be removed by a medical professional. Hearing researchers strongly concur with the truth of the adage: *Put nothing smaller than your elbow into your ear.* In addition to its protective function, the ear canal acts as an amplifier for sound frequencies between 3,000 and 4,000 Hz.

The ear canal acts as an amplifier for sound frequencies between 3,000 and 4,000 Hz.

The elegance of the middle ear system lies in its ability to greatly amplify sound vibrations before they enter the inner ear.

The middle ear. The tympanic membrane (eardrum) separates the outer ear from the middle ear. It is a continuously growing structure, which means that damage to the membrane can generally be repaired. The membrane is circular in shape. The elastic properties of the tympanic membrane allow it to vibrate in response to sound waves. Vibrations from the tympanic membrane tend to focus near the center of the structure. From there, the vibrations are transferred to the **malleus**, the first of the three bones of the middle ear. The three bones of the middle ear are collectively called the **ossicles**. The second bone of the middle ear is the **incus**, which is connected to the malleus and vibrates in concert with it. A third bone, the **stapes**, is connected to the incus, and also vibrates. The stapes sits in an opening in the bony wall, called the **oval window**, that separates the middle ear from the inner ear. The elegance of the middle ear system lies in its ability to greatly amplify sound vibrations before they enter the inner ear. Amplification occurs in part because the tympanic membrane is 15–30 times larger than the oval window. This size difference allows the force from the initial movement of the tympanic membrane to be concentrated as this energy transfers to the inner ear. The ossicles are the smallest bones in the body. The three bones are smaller than an orange seed. The malleus reaches an average length of about 8 mm, the incus 9 mm, and the stapes, only 3 mm. These bones also are referred to informally as the hammer, anvil, and stirrup, respectively.

The middle ear is an air-filled space. It is connected to the back of the throat by a small tube called the **eustachian tube**, which allows the air in the middle ear space to be refreshed periodically. The eustachian tube can become blocked by infection, and fluid may fill the middle ear space.

Changes in air pressure can also affect the tympanic membrane, resulting in the ear-popping phenomenon experienced by people who fly in airplanes or drive over mountain roads. The membrane may bend in response to altered air pressure and then "pop" back to its original position when the eustachian tube opens and internal and external air pressures are equalized.

The process of converting the vibrational energy of sound into nerve impulses is called transduction.

The inner ear. Two interconnected parts that form a system of small cavities and passageways make up the inner ear. One part is the **vestibular system**, which is responsible for helping maintain balance. The second part is the **cochlea**, a coiled cavity about 35 mm long. The human cochlea makes about two turns. It is shaped like a spiral seashell or snail shell and is the hearing portion of the inner ear. It is responsible for converting the vibrational energy produced by the middle ear into nerve impulses (electrical energy) that will travel to the brain. The process of converting energy from one form into another is called **transduction**. Because the brain is incapable of interpreting the information in the vibrational energy of a sound source, transduction is a critical process, providing information to the brain in a form that it can process.

The cochlea is divided into an upper chamber, called the **scala vestibuli** or **vestibular canal**, and a lower chamber, called the **scala tympani** or **tympanic canal**. These are seen most easily if the cochlea is represented as uncoiled, as in Figure 9.

Both the upper and lower chambers are filled with a fluid, called **perilymph**, which is nearly identical to spinal fluid. The stapes vibrates against the oval window, creating fluid vibrations that are transmitted as pressure waves all the way through the cochlea. As represented by the arrows in Figure 10, these waves move from the upper chamber to the lower chamber, to the round window. The **round window** allows the release of the hydraulic pressure caused by vibration of the stapes in the oval window. Additionally, the diameter of the chambers decreases from base (closest to the windows) to apex.

The upper and lower chambers are separated from one another by the **cochlear duct**. The cochlear duct is separated from the lower chamber by the **basilar membrane** and is filled with **endolymph**, a fluid similar to that found within cells. Sitting on the basilar membrane is the highly sensitive organ

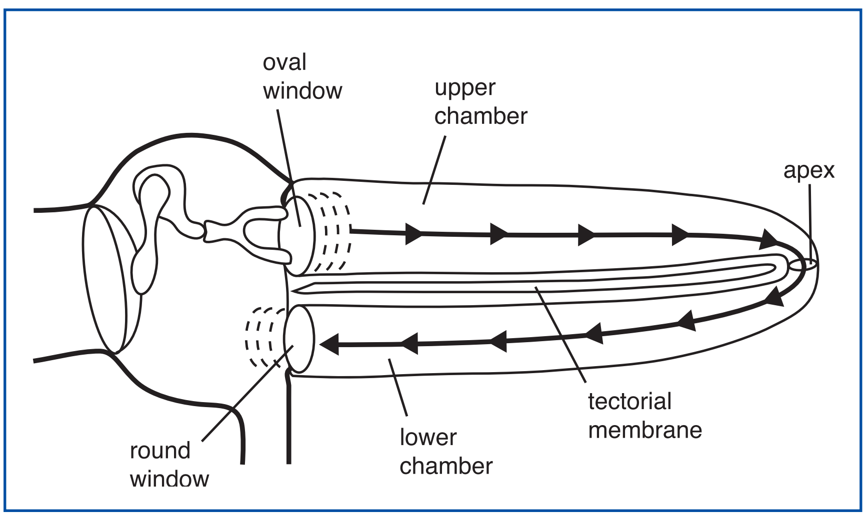

Figure 9. *An uncoiled cochlea, to the right of the oval and round windows.*

of hearing called the **organ of Corti**, named after Alfonso Corti, the Italian anatomist who discovered it in the late 1800s. The relationships between the basilar membrane and the organ of Corti are depicted in Figure 11.

Hair cells of the organ of Corti are the specialized receptor cells of hearing. Under a microscope, these cells appear as elongated ovals with hairlike extensions, the **stereocilia**, waving at one end. Like microphones, hair cells ultimately translate, or transduce, mechanical vibrations occurring in the outer, middle, and inner ear into electrical impulses. These nerve impulses are then relayed to the brain via the auditory nerve. There are actually two types of hair cells. The inner hair cells are arranged in a single row along the full length of the organ of Corti. There are about 3,500 of them in total. The outer hair cells run the full length of the organ of Corti but are arranged in three parallel rows. There are nearly four times more outer hair cells than inner hair cells (about 12,000 per ear). The inner hair cells contact nearly all of the nerve fibers of the auditory nerve that transmits information to the brain. The outer hair cells primarily contact nerve fibers that carry information from the brain. Hair cells are quite sensitive to stimulation by slight sounds and also are extremely rapid in their responses and communication with auditory neurons. Hair cells, for example, respond 1,000 times faster to stimulation than do visual receptor cells. The key to their sensitivity lies in part with their structure. The membrane-bound hairlike structures that give hair cells their name, stereocilia, extend from the cell tops and are embedded in an overhanging sheet of cells called

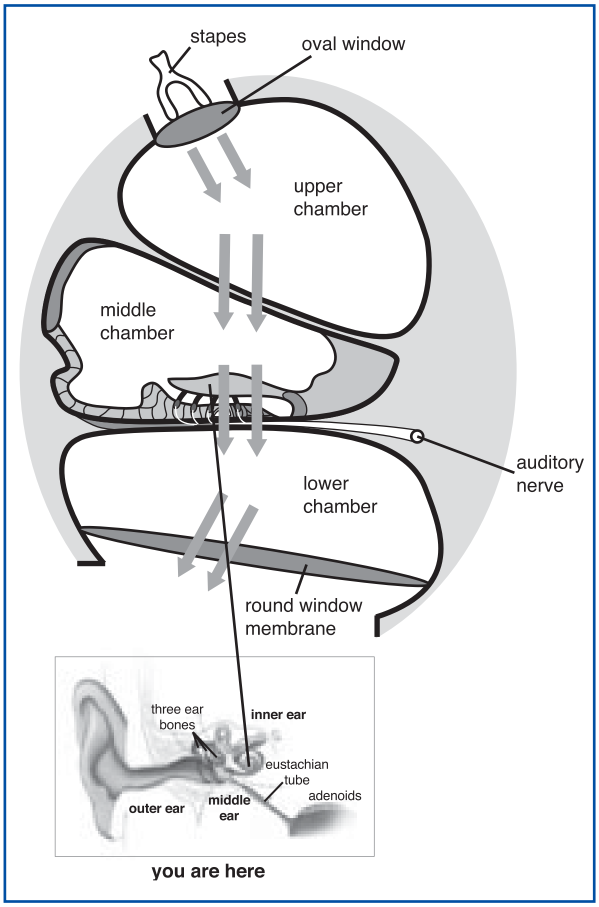

Figure 10. Diagrammatic representation of the movement of vibrational energy through the cochlea.

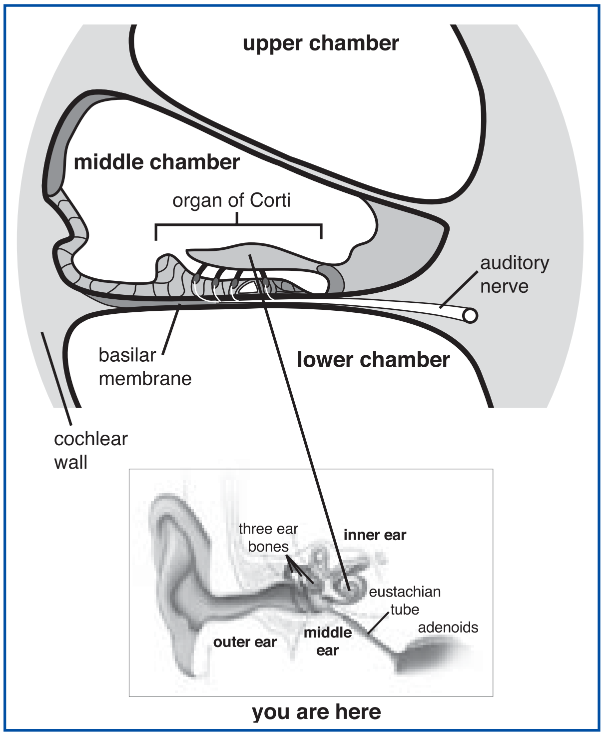

Figure 11. Details inside a coil of the cochlea showing the organ of Corti.

the **tectorial membrane** (see Figure 12). Each hair cell may have about 100 stereocilia. In a resting state, the stereocilia lean on one another and have the overall appearance of a conical bundle.

Hair cells ultimately translate, or transduce, mechanical phenomena occurring in the outer, middle, and inner ear into electrical impulses.

To understand how hair cells function to transduce the mechanical vibrations of sound, consider Figures 10 and 12.

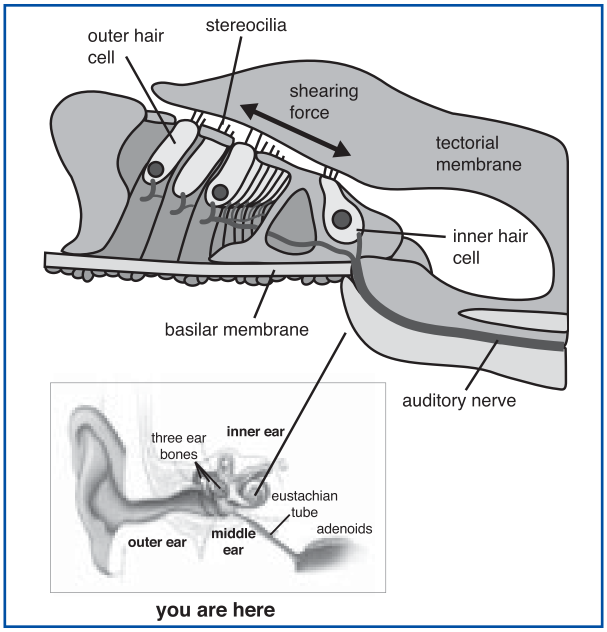

Figure 12. Details of the organ of Corti showing hair cells and the relationship of the stereocilia (hair bundles) to the adjacent membrane.

The bodies of hair cells sit on top of the basilar membrane (see Figure 12). The stereocilia of hair cells connect the body of the cell with the tectorial membrane. Pressure waves in the cochlea (see Figure 10) move the basilar membrane and cause the stereocilia to move. This movement initiates biochemical events in the cells that result in the generation of electrical signals.

Sound is mapped to different parts of the cochlea according to frequency. Figure 13 shows where tones of different frequencies cause vibrations of maximum amplitude along the length of the cochlea. The base, close to the stapes, is stiff and narrow and responds more to high-frequency (high-pitched) sounds. The apex, far from the stapes, is broad and responds more to low-frequency sounds.

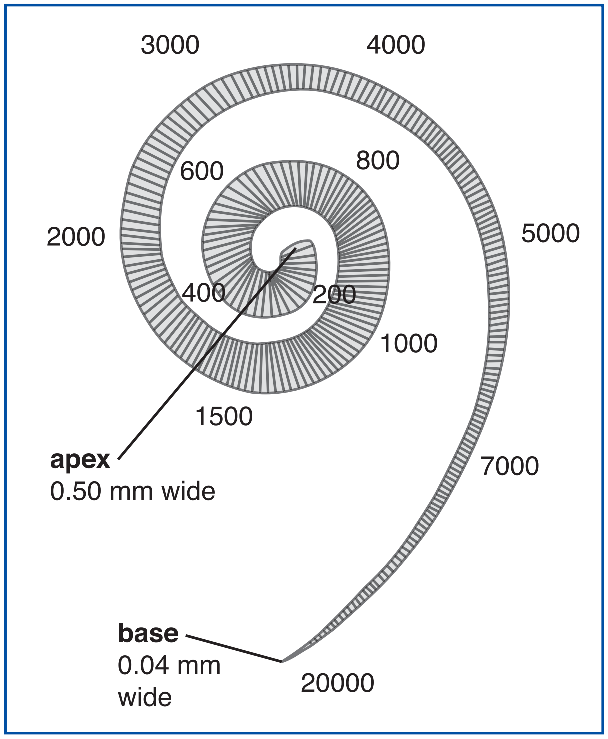

Figure 13. Specific frequencies cause vibrations of maximum amplitude at different points along the cochlea. The numbers in the diagram represent frequency in hertz.

Transmission to the brain. Extending from the organ of Corti are 30,000–40,000 nerve fibers that form the **auditory nerve**. The number of fibers required to carry a sound signal may give the brain a measure of the sound's intensity. The fibers of the auditory nerve proceed a short distance to the **brainstem**. From there, fibers extend to the **midbrain** and then to the **auditory cortex**, which is located in the **temporal lobe** of the brain (see

Figure 14). Through mechanisms that remain unknown, the brain interprets the electrochemical information it receives, thus allowing us to perceive sounds as having varying loudness and pitch.

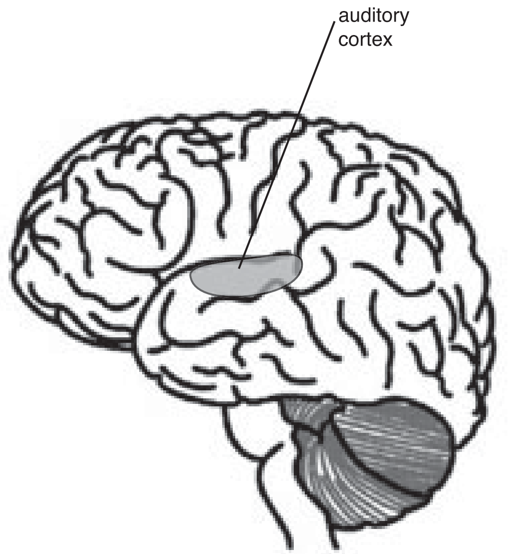

Figure 14. The location of the auditory cortex in the human brain.

The brain recognizes and interprets sound in our environment through a sequence of events called auditory processing. A disorder, known as **auditory processing disorder (APD)**, came to prominence in the 1970s.[3, 9] In APD, something interferes with the brain's ability to process or interpret information about sound, although hearing seems to be normal. Children with APD typically have normal hearing and intelligence. Symptoms of APD are having difficulty paying attention and remembering information presented orally; poor listening skills; difficulty carrying out multistep directions; poor spelling, vocabulary, and reading comprehension skills; difficulty processing information; low academic performance; behavioral problems; language difficulty (tendency to confuse syllable sequences); and difficulty developing vocabulary and understanding language. APD is sometimes called "word-deafness" because children with the disorder may not recognize the subtle differences between sounds in words. For example, children with APD may hear the sentence "Tell me how a couch and a chair are alike" as "Tell me how a cow and a hair are alike."

What causes this apparent deficiency or slowing in the brain's ability to process auditory information? Researchers do not know. Auditory processing is a learned function, and if something interferes with the brain's training, the result may be a deficit in the capacity to process sound.

Sound direction is localized by virtue of our having two ears and our ability to use different parts of the auditory system to process distinct aspects of incoming directional information.

Sound direction is localized by virtue of our having two ears and our ability to use different parts of the auditory system to process distinct aspects of incoming directional information. Certain cells in the brainstem compare the intensities of sound coming into each ear and then relay a computed signal to the auditory cortex to estimate the sound's direction. Another group of brainstem cells contributes to the interpretation of sound direction by specifically comparing the time lag between the sound reaching them from the right ear versus the left ear.

Nerve fibers coming from the brain may carry information back to the ear. This is the brain's way of filtering out signals that are unimportant, and concentrating only on important signals. Other nerve fibers proceed from the brain to the middle ear, where they control muscles that help protect against the effects of dangerously loud sounds.

Not only does the inner ear process the sound vibrations it receives, it also creates its own sound vibrations. When hair cells respond to vibration, their movement in the fluid environment of the cochlear duct produces friction, and this results in a loss of energy. However, a group of hair cells replaces the lost sound energy by creating their own. Some of this sound energy leaks back out of the ear and can be detected using a computer-based sound analyzer and a probe inserted into the outer third of the ear canal. This ability of hair cells to respond to sound by producing their own sound is the basis of one type of hearing test performed on infants and young children.

4 Hearing Loss

The auditory pathway is capable of providing a lifetime of useful service. It is, however, fragile and subject to damage from a variety of sources. Hearing loss and deafness can result from sound exposure, heredity, ototoxic drugs (chemicals that damage auditory tissues), accidents, and disease or infection. **Conductive hearing loss** results from damage to the outer or middle ear, and **sensorineural hearing loss** results from damage to the inner ear.

Hearing loss and deafness can result from sound exposure, heredity, ototoxic drugs, accidents, and disease or infection.

Damage associated with conductive hearing loss interferes with the efficient transfer of sound to the inner ear. Conductive hearing loss is characterized by a loss in sound intensity. Voices may sound muffled, while at the same time the individual's own voice may seem quite loud. It can be caused by anything that interferes with the vibration of the eardrum or with the movement of the bones of the middle ear. Even a buildup of earwax can lead to conductive hearing loss.

A number of treatment options exist for conductive hearing loss. The appropriate response depends upon the cause of the problem. For example, an ear doctor can simply remove a buildup of earwax. It should be pointed out, however, that you should never try to remove wax from your own ears. You can too easily push the wax further into the ear canal and even damage your eardrum. A common cause of conductive hearing loss in children is ear infections. Other causes of conductive hearing loss are a punctured eardrum or otosclerosis (a buildup of spongy tissue around the middle ear). These can be treated through surgery.

Sensorineural hearing loss is generally associated with damage to the hair cells in the inner ear. Such damage is the most common cause of hearing loss and can result from a number of factors working alone or in combination.

4.1 Noise exposure

When hair cells are damaged, their ability to participate in sound transduction is compromised. If your hair cells are completely destroyed, you will be unable to hear any sounds, no matter how loud they are. If the hair cells are damaged, you may still hear sounds, but the sounds will be distorted. Recall that different hair cells respond to different pitches. The pattern of hair-cell damage determines which pitches are preferentially lost. Typically, hair cells that respond to higher pitches are lost first. One reason is that the basilar membrane vibrates more vigorously in response to higher pitches. These vibrations can cause the delicate stereocilia of the hair cells to be sheared off (see Figure 15). One consequence of this damage is that it becomes more difficult to understand the higher-pitched voices of women and children. It also becomes more difficult to distinguish a person's speaking voice from background noise. The effects of noise-induced hearing loss may be temporary or permanent, depending on the intensity and duration of the exposure. Although a person's hearing may recover from temporary, slight damage to the hair cells, the complete loss of hair cells is irreversible in humans. Reptiles and birds are able to regenerate hair cells, however, so scientists are currently exploring ways to encourage regeneration of hair cells in humans.

The effects of noise-induced hearing loss may be temporary or permanent, depending on the intensity and duration of the exposure.

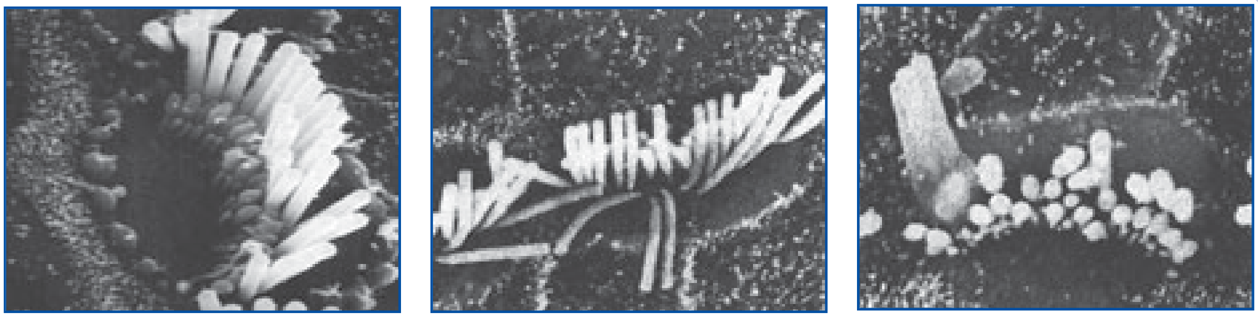

Figure 15. The left panel shows normal stereocilia (or hair bundles) associated with inner hair cells in the cochlea. The middle and right panels show noise-induced damage to hair cells. Note the bent-over stereocilia in the middle panel. The right panel shows missing and fused stereocilia.

The phrase "too loud, too long, too close" (see the WISE EARS! Web site, *http://www.nidcd.nih.gov/health/wise/index.asp*) summarizes the causes of noise-induced hearing loss. The intensity, duration, and proximity of sound to the listener determine whether or not damage occurs and if that damage is reversible or permanent. Hearing loss can result from a single loud noise, such as an explosion, but more commonly results from repeated exposure to less intense sounds that are close by.

The phrase "too loud, too long, too close" summarizes the causes of noise-induced hearing loss.

4.2 Aging

Damage to hair cells is associated with aging, though it is not inevitable. Such damage can result from a combination of factors, such as noise exposure, injury, heredity, illness, and circulation problems. Some of these factors, such as noise exposure, can take many years before their damaging effects are noticeable. Hearing loss often begins when a person is in his or her 20s, though it may not be noticed until the person is in his or her 50s. Not surprisingly, the greater the noise exposure over a lifetime, the greater the hearing loss. Because the hair cells at the base of the cochlea "wear out" before those at the apex, the higher pitches are lost first, followed by the lower ones.

4.3 Ototoxic drugs

Medications and chemicals that are poisonous to auditory structures are called **ototoxic**. Certain antibiotics can selectively destroy hair cells, enabling scientists to better understand hair-cell function in normal and abnormal hearing. Other types of drugs can be used to selectively destroy other tissues of the auditory pathway. A few common medications can produce the unwanted side effect of **tinnitus**, or ringing in the ears. One such drug is aspirin. Arthritis sufferers, who may consume large amounts of aspirin, sometimes experience tinnitus and hearing loss as a side effect of their aspirin use. Fortunately, the effect is temporary and the tinnitus tends to disappear when aspirin use is discontinued.

4.4 Disease and infections

A variety of diseases and infections can lead to hearing loss. Children are especially prone to the ear infection called **otitis media** from viruses or bacteria. Children are more susceptible to infection than adults are, partly because the location of their eustachian tube in relation to the middle ear allows easier access to bacteria from the nasal passages. These infections cause pain and may result in a buildup of fluid, which can lead to hearing loss. Usually, the bacterial infections can be controlled by antibiotics. Antibiotics are ineffective against viruses, however. The over-prescription of antibiotics to treat viral forms of otitis media has led to a rise in bacteria that are resistant to antibiotics. If allowed to progress untreated, ear infections can lead to a much more serious condition called meningitis. Young children who experience ear infections accompanied by hearing loss for prolonged periods also may exhibit delayed speech development. The reason for this is that the first three years of life are a critical period for acquiring language, which depends upon a child's ability to hear spoken words.

Young children who experience ear infections accompanied by hearing loss for prolonged periods also may exhibit delayed speech development.

Otosclerosis refers to a condition in which the bones of the middle ear are damaged by the buildup of spongy or bone-like tissue. The impaired function of the ossicles (the malleus, incus, and stapes) can reduce the sound reaching the ear by as much as 30 to 60 dB. This condition may be treated by surgically replacing all or part of the ossicular chain with an artificial one.

Ménière's disease affects the inner ear and vestibular system, the system that helps us maintain our balance. In this disorder, the organ of Corti becomes swollen, leading to a loss of hearing that comes and goes. Other symptoms include tinnitus, episodes of vertigo (dizziness), and imbalance. The disease can exist in mild or severe forms. Unfortunately, the cause of the disease is not well understood and effective treatments are lacking.

4.5 Heredity

The Mouse and Human Genome Projects are setting the stage for identifying the genetic contributions to hearing. Though deciphering the genetics underlying any developmental pathway is complex, identifying genes involved in the hearing pathway can greatly aid our understanding of the hearing process. Genes associated with a number of hereditary conditions that cause deafness, such as Usher syndrome[16] and Waardenburg syndrome,[17] already have been isolated. The identification of hearing-related genes has moved at an incredibly fast pace in the past decade. The first genetic mutation affecting hearing was isolated in 1993; by the end of 2000, the number of identified auditory genes was over 60. Scientists have also pinpointed over 100 chromosomal regions believed to harbor genes affecting the hearing pathway.

An important technology for investigating the roles that genes play in hearing is the production of transgenic and "knockout" mice, which result when scientists insert a foreign gene into (transgenic) or delete a targeted gene from (knockout) the mouse genome. The hearing responses of transgenic or knockout mice are compared with their unaltered counterparts. If differences are detected, they are presumed to be caused by the specific gene that was inserted or deleted. Eventually, scientists hope to use their understanding of the genetic basis of hearing to develop treatments for hereditary hearing loss and deafness.

The Mouse and Human Genome Projects are setting the stage for identifying the genetic contributions to hearing.

4.6 Cochlear implants

A **cochlear implant** (see Figure 16) is a hearing device designed to bypass absent or damaged hair cells. The cochlear implant is a small, complex, electronic device that can help provide an interpretable stimulus to a person who is profoundly deaf or severely hard-of-hearing. The implant is surgically placed under the skin behind the ear, and consists of four basic parts:

- a microphone that picks up sound from the environment;
- a speech processor, which selects and arranges sounds picked up by the microphone;
- a transmitter and receiver/stimulator that receives signals from the speech processor and converts them into electric impulses; and
- electrodes that collect the impulses from the stimulator and send them to the brain.

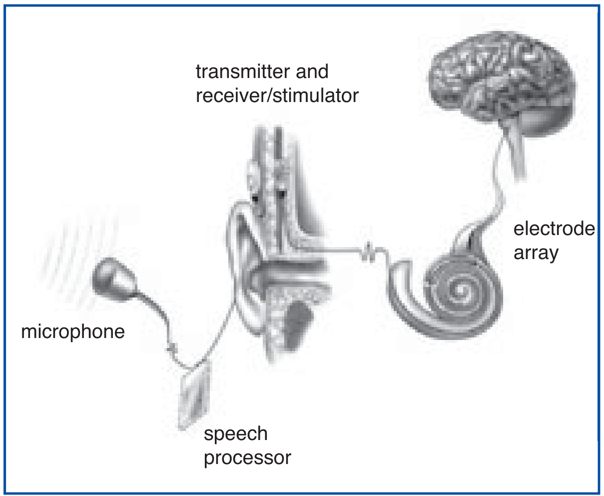

Figure 16. Diagram of a typical cochlear-implant system.

A cochlear implant does not restore or create normal hearing. Instead, under the appropriate conditions, it can give a deaf or severely hard-of-hearing person a useful auditory understanding of the environment, including sirens and alarms. A cochlear implant is very different from a hearing aid. Whereas hearing aids amplify sound and change the acoustical signal to match the degree of hearing loss, cochlear implants compensate for damaged or nonworking parts of the inner ear by bypassing them altogether. When hearing is functioning normally, complex processes in the inner ear convert sound waves in the air into electrical impulses. These impulses are then sent to the brain, where a hearing person recognizes them as sound. A cochlear implant works in a similar manner: it electronically transforms sounds and then sends them to the brain. Hearing through an implant sounds different from normal hearing, but it allows many people with severe hearing problems to participate fully in oral communication.

Outcomes for patients with cochlear implants vary. For many, the implant provides sound cues that help them better understand speech. Many are helped to such an extent that they can carry on a telephone conversation. Originally, only patients with profound hearing loss were deemed suitable for the procedure. One reason for this restrictive policy is that when a patient receives a cochlear implant, whatever hearing they have is destroyed. Eventually, it was discovered that patients with some residual hearing could benefit more from the procedure than those with profound hearing loss. For appropriate individuals, cochlear implants can be extremely beneficial. Each case must be examined individually to determine whether the cochlear implant is the best treatment available.

The use of cochlear implants can be controversial, especially among some deaf people. Just as spoken language helps define the culture of the hearing world, sign language helps define the culture of the deaf community. The issues surrounding the use of speech or American Sign Language by the deaf community illustrate the profound effects of language, hearing, and communication on one's sense of self.

5 Prevention of Noise-Induced Hearing Loss

Noise-induced hearing loss (NIHL) is a serious health problem. It occurs on the job as well as in nonoccupational settings. An estimated 10 million Americans have suffered irreversible hearing damage due to noise exposure. Another 30 million Americans are exposed to dangerous levels of noise every day.[10] This is especially tragic because NIHL is completely preventable. Although the consequences may vary for people who are exposed to identical levels of noise, some general conclusions can be stated. For example, studies have shown that sound levels of less than 75 dB are unlikely to cause permanent hearing loss, even after prolonged exposure. However, sound levels equal to or greater than 85 dB—about the same level as loud speech—for eight hours per day will produce permanent hearing loss after many years. At this time, it is not possible to predict a given individual's degree of sensitivity to dangerous noise. Some people may be more sensitive to noise exposures than others.

In the work environment, employers are obligated to protect their workers from hazardous noise.

Hearing-conservation programs, when implemented effectively, are associated with increased worker productivity and decreased absenteeism. They also lead to fewer workplace injuries and workman's compensation claims. Whenever hazardous levels of sound are encountered, either on the job or at home, you can protect yourself by using ear protection such as earplugs or special earmuffs. Do not simply put your fingers in your ears or stuff cotton in them. Additionally, anyone exposed to significant levels of noise for long durations should receive regular hearing tests to detect changes in hearing.

An estimated 10 million Americans have suffered irreversible hearing damage due to noise exposure.

Tinnitus is the medical term for the perception of sound when no external sound is present. The disorder is characterized by ringing, roaring, or repeated soft clicks in the ears. It is known that the ear continuously sends electrical impulses to the brain, even in the absence of sound. Some scientists speculate that when hair cells are damaged, the impulses are disrupted and the brain responds by generating its own sound signals. Normally, when an ear is stimulated by sound, auditory regions on both the left and right side of the brain become active. People experiencing tinnitus show brain activation in only one side of the brain, however. This difference in neural activity caused by external sounds (bilateral activation) versus tinnitus (unilateral activation) indicates that the disorder is likely to be a result of changes in the brain itself. Tinnitus may be produced by disturbances in auditory processing by the brain.

Over 50 million Americans experience tinnitus at some point in their lives. The disorder is perceived by some as an annoying background noise while others are incapacitated by loud noise that disturbs them day and night. Although the exact causes of tinnitus are not known, scientists agree that it is associated with damage to the ear. Possible triggers of tinnitus include NIHL, too much alcohol or caffeine, stress, inadequate circulation, allergies, medications, and disease. Of these factors, exposure to loud noise is by far the most probable cause of tinnitus. Perhaps not surprisingly, there is no single effective treatment. Depending on the suspected cause, individuals may be given drugs to increase blood flow, or provided guidance on ways to reduce their stress or to change their diets. The best advice for those concerned about NIHL is to limit exposure to hazardous noise (both proximity to and duration of), wear ear protection when exposed, and have hearing tests performed regularly.

Figure 17. *Ear protection, such as earplugs or special earmuffs, helps prevent noise-induced hearing loss.*

Glossary

amplitude: The displacement of a wave. In the case of a sound wave, the greater the amplitude of the wave, the greater the intensity, or pressure, of the sound. The extent to which air particles are displaced in response to the energy of a sound.

APD: See auditory processing disorder.

auditory cortex: The area of the brain (in the temporal cortex) that connects fibers of the auditory nerve and interprets nerve impulses in a form that is perceived as sound.

auditory nerve: The eighth cranial nerve, which connects the inner ear to the brainstem and is responsible for hearing and balance.

auditory processing disorder (APD): Reduced or impaired ability to discriminate, recognize, or comprehend complex sounds, such as those used in words, even though the hearing is normal (such as coat/boat or sh/ch).

basilar membrane: Found in the organ of Corti, it is the cellular membrane in which the hair cells are embedded. The basilar membrane moves in response to pressure waves in the cochlea, initiating a chain of events that results in a nerve impulse traveling to the brain.

brainstem: A region of the brain that connects the spinal cord to higher levels of the brain, such as the cortex.

cochlea: Snail-shaped structure in the inner ear that contains the organ of hearing. The cochlea is a coiled, fluid-filled cavity responsible for converting vibrational energy from the middle ear into nerve impulses that travel to the brain.

cochlear duct: See scala media.

cochlear implant: A medical, electronic device that bypasses the damaged structures in the inner ear and directly stimulates the auditory nerve. An implant does not restore or create normal hearing. Instead, under the appropriate conditions, it can give a deaf person a useful auditory understanding of the environment and help him or her understand speech. The implant is surgically placed under the skin behind the ear. An implant has four basic parts: a microphone, which picks up sound from the environment; a speech processor, which selects and arranges sounds picked up by the microphone; a transmitter and receiver/stimulator, which receives signals from the speech processor and converts them into electric impulses; and electrodes, which collect the impulses from the stimulator and send them to the brain.

conductive hearing loss: A type of hearing loss that results from dysfunction of the outer or middle ear (such as a punctured eardrum or buildup of ear wax) that interferes with the efficient transfer of sound to the inner ear; characterized by a loss in sound intensity.

critical period: A period of time during an organism's development in which the brain is optimally capable of acquiring a specific ability, provided that appropriate environmental stimuli are present. Humans as well as some animals are known to have a critical period during which language is acquired.

decibel (dB): A unit that measures the intensity of sound.

ear canal: A component of the outer ear that leads to the tympanic membrane (eardrum) of the middle ear. The ear canal is lined with wax and hairs that prevent small foreign material from traveling deeper into the ear.

endolymph: A fluid that is located in the labyrinth, the organ of balance in the inner ear.

eustachian tube: A small tube that connects the middle ear with the back of the throat. It allows the air in the middle ear to be refreshed periodically.

frequency: The number of times a sound vibrates per unit of time. Frequency is expressed in hertz (Hz), a unit of measurement equal to one cycle per second.

gene: The functional and physical unit of heredity. Genes are segments of DNA found along a chromosome. They typically encode information used to produce a specific protein. Human DNA is organized into 46 chromosomes—23 from the father and 23 from the mother. The study of mice with hereditary hearing loss has enabled researchers to begin understanding the role that DNA and genetics play in human hearing disorders.

hair cells: Found in the organ of Corti in the cochlea of the inner ear, these are the specialized receptors of hearing. The name refers to stereocilia, bundles of hairlike projections jutting upward from the cells. When the stereocilia are moved by sound vibrations, the hair cells translate this mechanical stimulation into an electrical nerve impulse that is carried to the brain by the auditory nerve.

hertz (Hz): A unit of frequency equal to one cycle per second.

impact noise: A short burst of sound.

imprinting: The process by which young individuals of a species acquire irreversible behavior patterns of that species. With respect to hearing, imprinting involves the ability of the brain to distinguish and process the sounds and rhythms of the first language or languages the young hear.

incus: The center bone of the series of three small bones, or ossicles, of the middle ear. Sometimes called the anvil.

infrasonic: Sounds with frequencies below 20 Hz and, therefore, beyond the range of human hearing.

intensity: The amplitude of a sound wave. Sound intensity, which is expressed in decibels, is measured in relation to an accepted reference, such as the threshold at which an average person can hear a sound.

inner ear: The most interior portion of the ear, made up of two interconnected parts: the vestibular system, a balance organ, and the cochlea, a hearing organ.

loudness: Our perceived impression of the intensity, frequency, and duration of a sound.

malleus: The first bone in the series of three small bones, or ossicles, of the middle ear. Sometimes called the hammer.

Ménière's disease: Inner ear disorder that can affect both hearing and balance. Ménière's disease can cause episodes of vertigo, hearing loss, tinnitus, and the sensation of fullness in the ear.

midbrain: A region of the brain that relays sound input to the auditory cortex.

middle ear: The part of the ear that includes the eardrum and ossicles and ends at the round window that leads to the inner ear. An air-filled space connected to the back of the throat by the eustachian tube.

NIHL: See noise-induced hearing loss.

noise-induced hearing loss (NIHL): Irreversible hearing loss caused by exposure to very loud impulse sounds, such as an explosion, or to less-intense sounds for an extended period of time. Loud noise levels damage hair cells of the inner ear.

organ of Corti: The sensitive organ of hearing within the cochlear duct. The organ of Corti contains specialized cells called hair cells that transduce sound vibrations into electrical impulses.

ossicles: The three smallest bones in the human body. The ossicles consist of the malleus, incus, and stapes (known also as the hammer, anvil, and stirrup, respectively), found in the middle ear. They are part of the system that amplifies sound vibrations that enter the middle ear.

ossicular chain: The three bones that make up the ossicles of the middle ear (the malleus, incus, and stapes).

otitis media: An inflammation of the middle ear, usually associated with a buildup of fluid related to a viral or bacterial infection. The obstruction can cause hearing problems, which may arise when the fluid interferes with the ability of the ossicles to conduct sound vibrations to the inner ear.

otosclerosis: An abnormal growth of bone in the middle ear, which prevents structures within the ear from working properly, causing hearing loss.

ototoxic: Any substance that damages auditory tissues, including a special class of antibiotics, called aminoglycoside antibiotics, that can damage hearing and balance organs for individuals who are sensitive.

outer ear: The part of the ear composed of the pinna and the ear canal.

oval window: An opening in the bony wall that separates the middle ear from the inner ear.

perilymph: A fluid, nearly identical to spinal fluid, that fills the cochlea.

perilymph fistula: The leakage of inner ear fluid into the middle ear. It is associated with head trauma, physical exertion, or exposure to severe pressure, but it can also occur without apparent cause.

phonemes: The basic sound elements of a spoken language.

pinna: The outer ear, which is composed of skin and cartilage. The pinna focuses sound waves into the middle and inner ears. Having two pinnae helps animals determine the location of a sound. In some animals, the pinna serves additional functions, such as heat dissipation.

pitch: The perception of a sound based on its frequency.

round window: An opening in the cochlea that allows pressure from sound waves to be released.

scala media: Also called the cochlear duct, this region between the upper and lower chambers of the cochlea contains the organ of Corti.

scala tympani: The lower chamber of the cochlea.

scala vestibuli: The upper chamber of the cochlea.

sensorineural hearing loss: Hearing loss caused by damage to the hair cells or nerve fibers of the inner ear.

sensory integration: The involuntary process by which the brain assembles a picture of our environment at each moment in time using information from all of our senses. Children with learning disabilities or autism have difficulties with sensory integration. (See the Web site of Sensory Integration International, The Ayres Clinic, *http://www.sensoryint.com/faq.html*.)

sound: Vibrational energy. A pressure disturbance propagated through a medium and displacing molecules from a state of equilibrium. The auditory perception of this disturbance. Something heard by the ears.

sound intensity: The magnitude of a sound, measured against a standard reference in units known as decibels (dB). Intensity refers to the amplitude of a sound.

sound waves: The longitudinal progressive vibrations in an elastic medium by which sounds are transmitted.

stapes: The final bone in the series of three small bones, or ossicles, of the middle ear. Sometimes called the stirrup.

stereocilia: Hairlike extensions jutting from one end of the inner ear's hair cells into the cochlear fluid.

subsonic: See infrasonic.

tectorial membrane: Found in the organ of Corti of the cochlea, this sheet of cells lies above the stereocilia of the hair cells. Movement of the basilar membrane (to which the hair cells are attached) causes the stereocilia to move against the tectorial membrane, initiating a nerve impulse that travels from the hair cell to the brain.

temporal lobe: A region of the brain that contains the auditory cortex, which is necessary for interpreting sounds.

tinnitus: The term for the perception of sound when no external sound is present. The sensation of ringing, roaring, buzzing, or clicking in the ears or head. An ailment that is associated with many forms of hearing impairment and noise exposure.

transduction: A process by which energy is converted from one form to another.

tympanic canal: See scala tympani.

tympanic membrane: The eardrum. A structure that separates the outer ear from the middle ear and vibrates in response to sound waves. These vibrations are transferred to the small bones in the middle ear.

ultrasonic: Sounds with frequencies above 20,000 Hz and, therefore, beyond the range of human hearing.

vertigo: The illusion of movement. A sensation that the external world is revolving around an individual (objective vertigo) or the individual is revolving in space (subjective vertigo). May be caused by an inner ear dysfunction.

vestibular canal: See scala vestibuli.

vestibular system: The system responsible for maintaining balance, posture, and the body's orientation in space. This system also regulates locomotion and other movements and keeps objects in visual focus as the body moves. Located next to the cochlea, the vestibular system consists of three semicircular canals oriented in different planes. Movement of fluid within the canals responds to movements of the head and visual information, allowing the brain to process an animal's current state of balance.

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Note from the NIDCD for the Teacher Who Has a Student Who Is Deaf or Hard-of-Hearing or Has Another Communication Disorder

Instruction about disorders of human communication can be sensitive, especially if you have a student in your classroom who is deaf or hard-of-hearing, who has specific language impairments, such as stuttering, or who has experienced other communication challenges. It may be helpful to point out to the class that one out of six people has some form of communication disorder and that a communication disorder or challenge may not be readily apparent. Many students may have relatives or friends with deafness, hearing loss, aphasia, balance disorders, or other disabilities. (Aphasia is the partial or total loss of the ability to use or understand language or produce speech; it's usually caused by stroke, brain disease, or injury.)

There are controversies within families about the best ways to deal with hearing loss. Some parents adopt an oral-auditory approach for their children, focusing on speech and acquisition of language. Other parents, especially those who are deaf themselves, opt to start with American Sign Language (ASL). For more information on communication considerations, go to *http://www.nidcd.nih.gov/health/hearing/commopt.asp*. The first lesson of this module features a person using ASL. For quick facts about ASL, go to *http://www.nidcd.nih.gov/health/hearing/asl.asp*. It is becoming increasingly likely that you will have a child in your class who has a cochlear implant. For more information about cochlear implants, visit *http://www.nidcd.nih.gov/health/hearing/coch.asp*.

Use the term *challenge* or *disability*—not *handicap*. The Council of Representatives, a group whose membership includes the full range of deafness or hard-of-hearing organizations and the educational and health professionals who relate to them, has indicated that the right descriptors to use are *people who are deaf or hard-of-hearing* or *people who are deaf or have a hearing loss*. Be attuned to the way the student or his or her family uses terms such as *deaf*, *hard-of-hearing*, or *hearing-impaired*. Grammatically, the word *deaf* should only be used as an adjective, as in *deaf person* or *deaf student*. It should not be used as a noun, as in *the deaf*. Some organizations, including schools for *the deaf*, still use the noun in their title for historical reasons.

For more information about hearing aids, early identification of hearing loss or deafness in the newborn nursery, or any other aspect of human communication, visit our Web site at *http://www.nidcd.nih.gov/health*. You can also call us toll-free at (800) 241-1044, or send an e-mail to *nidcdinfo@nidcd.nih.gov*.

Getting the Message

Figure 1.1. Regardless of the language, the meaning remains the same.

At a Glance

Overview

Students are introduced to language and communication. They listen to short readings in English and other languages, and investigate why they do or do not understand what they hear. The lesson concludes with students reading two short paragraphs relating to the critical period for language development.

Major Concepts

Hearing involves sound, while communication involves the brain. There is a critical period for language acquisition to occur.

Objectives

After completing this lesson, students will

- understand that languages are composed of different types of building blocks,
- recognize that understanding spoken language requires a process that moves from sound to hearing to understanding,
- recognize that there can be communication without sound and hearing, and
- recognize that the brain is central to communication in any form.

Teacher Background

Consult the following sections in Information about Hearing, Communication, and Understanding:

1 *Introduction* (page 25)
2 *Misconceptions Related to Sensory Perception and Hearing* (page 26)
3 *Major Concepts Related to Hearing and Communication* (page 27)
  3.1 *Communication is multisensory* (page 27)
  3.2 *Language acquisition: imprinting and critical periods* (pages 28–29)
  3.3 *Sound has a physical basis* (pages 29–32)
  3.4 *Perception of sound has a biological basis* (pages 32–38)

In Advance

Web-Based Activities

Activity	Web Version?
1	Yes
2	No

Photocopies

Activity 1	Master 1.1, *The Rhythm of Language* (Prepare an overhead transparency.)
Activity 2	Master 1.2, *Stories of Language Development* (Make 1 copy per student.)

Materials

Activity 1	computers with Internet connection and sound card
Activity 2	no materials, except photocopies

Preparation

Because this lesson involves a teacher-led discussion, the best approach is to use one computer for the entire class. This allows you to play the tracks in their recommended sequence and to control the discussion after each track is played. Before class, adjust the computer's sound system so that the entire class can hear the tracks as they are played.

The American Sign Language (ASL) video, used in Activity 1, is a large file. If you have a slow Internet connection, you may want to load the file before class begins. To do so, proceed to *http://science.education.nih.gov/supplements/hearing/student* and click on "Lesson 1—Getting the Message." When the page comes up, click on "Track 4" to allow the video to load in a separate window. By following this procedure, you can begin Lesson 1 without waiting for the large file to download.

This lesson requires access to the Web site. If you do not have Internet access at your school, you might consider using a computer at home or the library to record the sound tracks on a cassette and playing the tape in class as described below.

Procedure

Activity 1: *What Did You Say?*

Teacher note
In this activity, students listen to the first sentence of the Gettysburg Address spoken in different languages. After each track is played, students are asked what they can understand. Many students will not understand any words until a track spoken in English is played. If you have students who understand Chinese, Hebrew, Spanish, or American Sign Language, they will understand those tracks, although they may not identify the track as part of the Gettysburg Address.

1. **Introduce the activity by asking students how they learned language.**

   A common response is, "I learned from my parents." Students with younger siblings may have observed how young children acquire verbal skills by listening and imitating what they hear.

2. **Ask students what their first words were.**

   Answers will vary, although first words will be short words with simple sounds that young children have heard repeatedly, such as "mama" and "dada."

3. **Ask students why so many of them report having the same first words.**

   Students may respond that this has something to do with the nature of the sounds that infants hear. Perhaps babies sense patterns of sound. Some patterns may be easier to interpret than others. Begin focusing the discussion on the brain as the body organ that interprets the environment.

4. Go to the Web site *http://science.education.nih.gov/supplements/hearing/student* and click on "Lesson 1—Getting the Message."

5. Do NOT tell students that they will hear the Gettysburg Address. Also, do NOT tell students the language in which the material is being read. Begin by playing Track 1, then proceed to Track 2 and Track 3. As you play each of the sound clips, ask students to write down what information they get from listening. For instance, is the speaker male or female? Does the speaker sound angry? Happy? Calm? Do the students have any understanding of what is being said?

   This activity features links to six tracks. Each track plays the first part of Abraham Lincoln's Gettysburg Address. In addition to reading the original wording in English (Track 6), the sentence is also read in Chinese (Track 1), Hebrew (Track 2), Spanish (Track 3), American Sign Language (Track 4), and a more modern form of English (Track 5).

6. Play Track 4 (American Sign Language). As you play the video, ask students if they can tell what is being communicated.

7. Play Track 5 (modern English). Do the students have any greater recognition of what is being read, since this track is now in English?

8. Play Track 6 (traditional English). Can the students now identify the Gettysburg Address as the material being read?

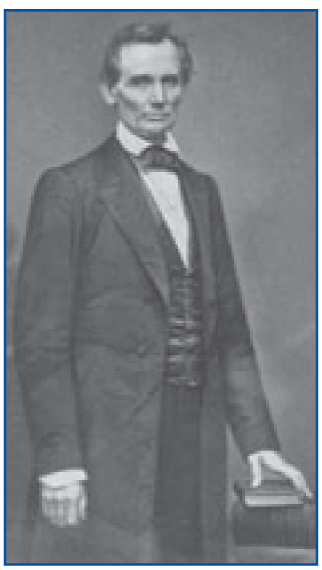


Figure 1.2. The power of Abraham Lincoln's Gettysburg Address can be felt in any language.

9. Ask the class why they could not understand what was being said in Chinese, Hebrew, Spanish, or American Sign Language. What makes languages different?

   Students probably will reply that what they heard was in a foreign language; it was not English. Languages differ in many ways. The basic sounds of speech, as well as how they are put together to form words, may be different. Also, the rhythm of sounds and pauses, the way the voice varies in pitch, and the patterns of loudness and softness vary.

10. Display the transparency made from Master 1.1, *The Rhythm of Language*, to demonstrate graphically the differences that exist in the rhythms of the four languages. Point out that the dark vertical lines represent speech. The height of the dark line is related to loudness: longer equals louder, shorter equals softer. There are brief periods in which no sound is made (no dark lines) between the periods of sound. The left-to-right distance represents the total time required to read the sentence from the Gettysburg Address.

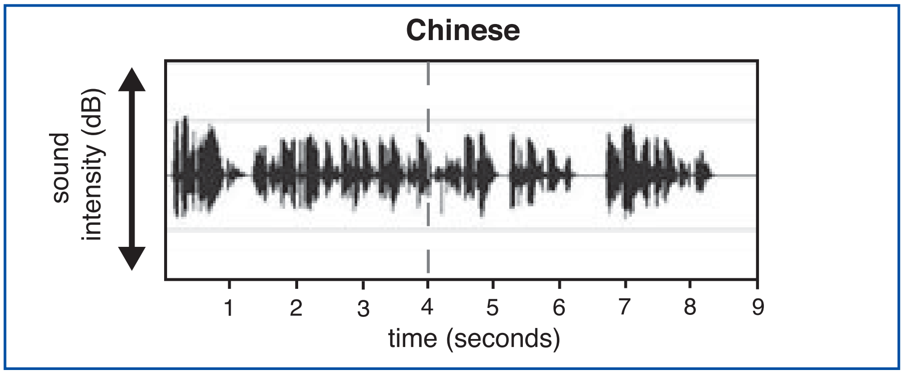


Figure 1.3. Speech can be represented graphically.

Students should recognize that in each language, some elements of speech are louder than others. Students also will note that there are differences in the rhythms (the alternation of sounds and silence) among languages.

11. **Even though students might not have understood the readings in Chinese, Spanish, or Hebrew, ask if they could tell whether the speaker was male or female, or whether the speaker was angry or calm. Ask if they could tell whether the male signer was angry or calm.**

    The brain interprets information with which it is presented. Interpretation relies on previous experiences. We learn that male voices are generally lower pitched and female voices, generally higher pitched. We learn what anger, happiness, and other emotional states look and sound like. If students could not identify the Gettysburg Address as the source in the modern reading, it may be because they lack the experience to interpret the material from one context and to place it in another.

NSES

Content Standard A: Recognize and analyze alternative explanations and predictions.

12. **Ask students what would happen if they did not hear a language when they were growing up.**

    Many students will assume that they could learn their first language at a later age, the way they do a foreign language in school. This discussion leads to Activity 2, where the focus continues to be on the central role of the brain in communication.

Activity 2: *When the Time Is Right*

1. **Give each student a copy of Master 1.2, *Stories of Language Development*. Instruct them to silently read the first story, "Birdsong."**

Figure 1.4. To acquire its song, a male white-crowned sparrow must hear it sung repeatedly during a critical period between one week and two months after hatching.

2. **After the class finishes reading, ask them what this story tells about the brain and its ability to use information.**

   The important point is that the young, male white-crowned sparrow has a specific time, or window of opportunity, in which to learn the song. Only during this time can the brain interpret the song, enabling the bird to sing it.

3. **Ask students to think about whether this story might be relevant to human development.**

   Students may respond that humans need to hear spoken language during a specific time to learn speech. Other students may answer that humans, with our larger brains, are not so dependent on a window of time for learning language.

4. **Instruct the class to read the second story, "Wild Child." Ask students how they interpret Victor's lack of verbal language and inability to develop verbal skills.**

   Students may make a connection between the idea of a critical period for language acquisition from "Birdsong" to the apparent lack of exposure to human language during a critical period in Victor's situation. If students do not offer this explanation, help them understand that Victor may have had difficulty learning spoken language because he did not hear it during a critical period when he was young.

5. **Ask students if they can think of another explanation for Victor's lack of verbal skills, besides his missed exposure to language during a critical period.**

It is also possible that Victor might have been born with a developmental disorder that left him unable to learn well at any age. Students should realize that there is no simple explanation. Scientists still debate the reasons for Victor's inability to demonstrate normal language and communication skills.

6. **Ask the class to help you develop "The Path to Understanding." Write this as a heading on the board. Then write "Sounds" on the left side of the board. Tell students that sounds are a starting point on the path to understanding. Finally, write "Understanding" on the right side of the board, as shown in Figure 1.5.**

   The class will work together to construct this diagram. Refer to Figure 1.8 to see the complete diagram.

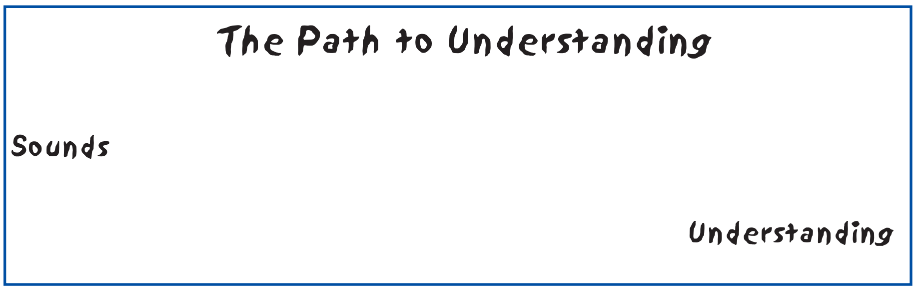


Figure 1.5

7. **Ask students to name different kinds of sounds.**

   Many will be named. Group them into three categories: voiced, musical, and environmental (environmental is everything that is not voiced or musical).

8. **Draw a forward arrow after "Sounds" on the developing "Path to Understanding" and ask students what is the next step in the pathway. Students should recognize that the ear is required to receive the sound (hearing). Write "Ear/Hearing" on the board.**

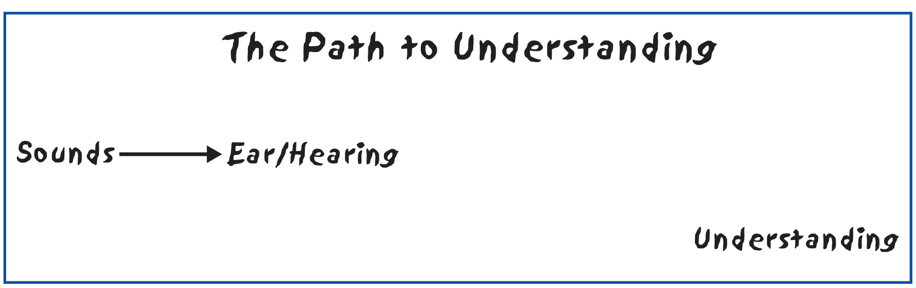


Figure 1.6

9. **Draw a forward arrow after "Ear/Hearing" and ask students what lies between "Hearing" and "Understanding."**

   Students should recognize that the brain is necessary to interpret sounds so that we understand the meaning behind the sound.

10. **Ask students what would happen if a person had a problem with hearing, ranging from a slight hearing loss to a complete hearing loss. Can a person still communicate?**

    Students should recognize that there are means of communication that do not require sound. An example is American Sign Language. If students do not suggest this, ask them to consider sign language.

11. **Ask students what is required to understand sign language.**

    Students should mention that the sense of vision and an agreed-upon series of hand signs are needed. If students gloss over the role of the brain, be sure to mention that the brain is required to interpret the visual input from signing so that we understand the meaning behind the sign.

12. **Ask the class where in the diagram the words "Sign Language" should appear. If a person communicates using sign language, how does he or she take in information? Write "Eye/Vision" on the board below "Ear/Hearing."**

    Sign language is similar to "Sounds" in the diagram. Therefore, write the words "Sign Language" beneath "Sounds." A person using sign language uses his or her eyes to take in the information in a manner similar to the ears taking in sounds. Draw an arrow leading from "Sign Language" to the words "Eyes/Vision."

Content Standard C: Behavior is one kind of response an organism can make to an internal or environmental stimulus. A behavioral response requires coordination and communication at many levels, including cells, organ systems, and whole organisms.

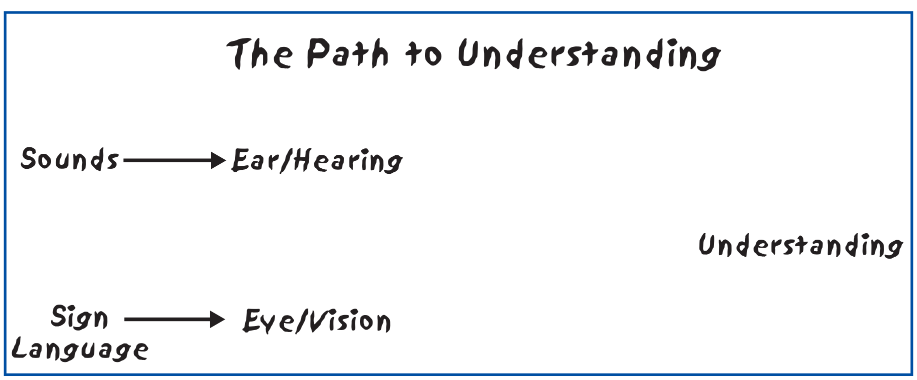


Figure 1.7

13. The final diagram on the board should look like the following figure:

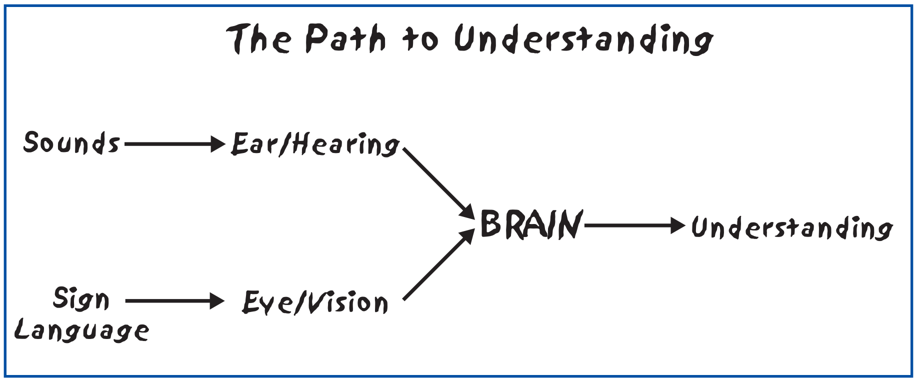


Figure 1.8

Teacher note
You may wish to save this diagram on the board to introduce Lesson 2.

14. **Ask the class whether a person who has neither sight nor hearing can communicate with others.**

    Yes, though it may seem impossible, people without both sight and hearing can learn to read, write, and communicate with others. Students may have heard of Helen Keller. Although she could not see or hear, she authored many books and reached a worldwide audience. She helped others understand that the abilities to communicate and function in society reside in our brains and are not tied to any one of our five senses.

15. **Ask the class to remember the "Birdsong" story. How do animals use their ability to communicate? How is animal communication similar to or different from human communication? Ask students if they think that studying animals can help us understand human communication. Why or why not?**

    Animals need to communicate for a variety of reasons, such as to find a mate, warn other members of their group of danger, or find their parents. Students should realize that animal communication is similar to human communication in that animals also take in sounds through their ears and process the information using their brains. Some students may feel that because no other animals use spoken language, they are of limited usefulness in exploring human communication. You can mention that mammals share many anatomical and physiological features with humans. Mammals also have similar versions of many human genes. These similarities are being used to investigate the relationship between hearing and communication. The comparison of the human and mouse genomes is very helpful in this regard.

Assessment:
Ask students to compare sounds that animals use for communication with words spoken by humans. Do students recognize that, similar to words, animal sounds are made up of a series of repetitive sounds or a combination of sounds to convey meaning? Do they understand that, as in humans, animals take in sound through their ears and interpret it in their brains?

Lesson 1 Organizer

Activity 1: *What Did You Say?*

What the Teacher Does	Procedure Reference
Review with class how they learned language as children.	Page 53 Steps 1–3
Log onto the student Web site and click on "Lesson 1—Getting the Message."	Page 54 Step 4
Play Tracks 1–3 in sequence, and ask students what information they can gain from the readings, such as • Is the speaker male or female? • Does the speaker sound angry, happy, or calm? • Can they understand any of what is being said?	Page 54 Step 5
Play Track 4 (American Sign Language) and ask students if they can tell what is being communicated.	Page 54 Step 6
Play Tracks 5 and 6 (modern and traditional English) and ask the class if they now can understand what is being said.	Page 54 Steps 7–9
Examine sound patterns of speech on Master 1.1, *The Rhythm of Language*.	Page 54 Step 10
Review the types of information that can be obtained without understanding the language.	Page 55 Step 11
Discuss the consequences of not hearing language when young.	Page 55 Step 12

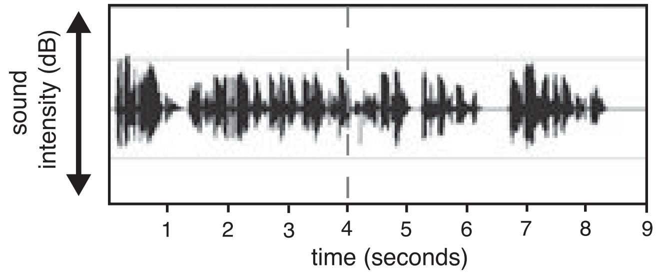
www = Involves using the Internet. T = Involves using a transparency.

Activity 2: *When the Time Is Right*

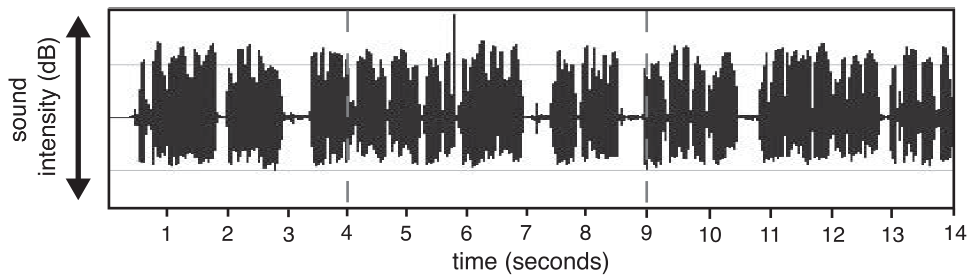
What the Teacher Does	Procedure Reference
Have students read "Birdsong" from Master 1.2, *Stories of Language Development,* and relate it to human development.	Pages 55–56 Steps 1–3
Have students read "Wild Child" from Master 1.2, *Stories of Language Development*. • Relate it to the concept of a critical period for language development. • Discuss possible explanations for Victor's lack of verbal development.	Pages 56–57 Steps 4 and 5 M
Work with students to construct "The Path to Understanding."	Pages 57–59 Steps 6–13
Discuss how a person who has neither sight nor hearing can communicate.	Page 59 Step 14
Have the class consider how animal communication and human communication are alike and different.	Page 59 Step 15

The Rhythm of Language

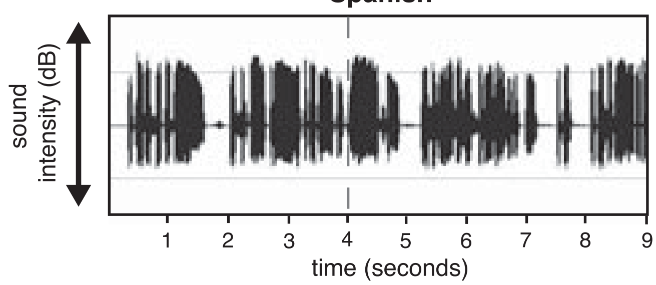
Chinese



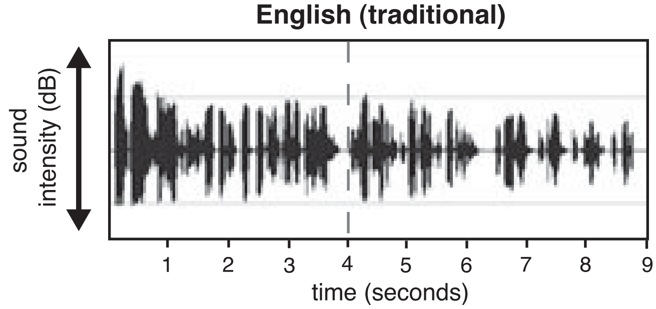
Hebrew



Spanish



English (traditional)



Stories of Language Development

BIRDSONG

A male white-crowned sparrow usually begins singing its full song between 100 and 200 days of age. Having the proper song is necessary for mating and marking its territory. However, to learn its song, the young bird must be exposed to an adult bird's song consistently and frequently between one week and two months after hatching. That is its critical period for learning its song. Both before and after this critical period, the male sparrow is unable to use any adult sounds to learn its characteristic song.

WILD CHILD

In 1799 in Aveyron, France, a boy thought to be about 11 or 12 years old was discovered in the woods foraging for food. He became known as the "wild child of Aveyron," because he behaved like an animal. He happily ate spoiled food, did not distinguish between hot and cold, thought nothing of romping unclothed through the snow, spent much of his time rocking back and forth like a caged animal, showed and accepted no affection, and possessed no verbal language. He was taken into the care of a French scientist, who spent a number of years trying to educate the boy. Victor, as he was named, eventually learned some basic skills and developed some language comprehension. However, he learned to say only two expressions: "milk" and "Oh, God."

Lesson 2
Explore/
Explain

Sound Communication

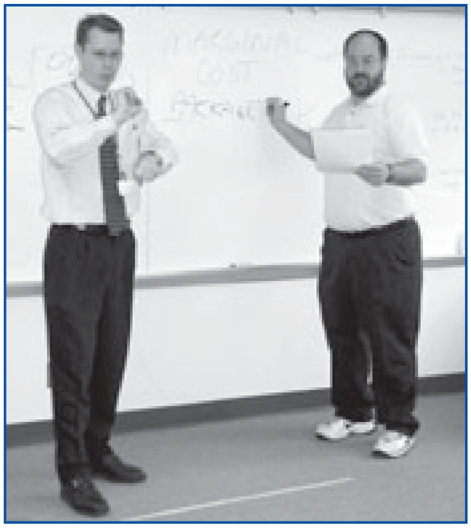


Figure 2.1. Human communication can involve both sight and sound.

At a Glance

Overview

Students watch and listen to human speech and explore visual and audio cues that aid their understanding. During a short walk, students listen to the sounds around them and classify them as environmental, voiced, or musical.

Major Concepts

The most effective communication is multisensory. Sound is a powerful and important means of communication. There are three categories of sounds: environmental, voiced, and musical.

Objectives

After completing this lesson, students will

- understand that sound is a powerful means of communication;
- appreciate that both audio and visual cues aid their understanding of speech;
- explain why the most effective communication is multisensory;
- realize that there are sounds around them that they take for granted; and
- be able to list the categories of sound (environmental, voiced, and musical).

Teacher Background

Consult the following sections in Information about Hearing, Communication, and Understanding:

3 Major Concepts Related to Hearing and Communication (page 27)
- *3.1 Communication is multisensory* (page 27)
- *3.2 Language acquisition: imprinting and critical periods* (pages 28–29)
- *3.3 Sound has a physical basis* (pages 29–32)
- *3.4 Perception of sound has a biological basis* (pages 32–38)

In Advance

Web-Based Activities

Activity	Web Version?
1	No
2	No

Photocopies

Activity 1	no photocopies needed
Activity 2	Master 2.1, *Sound Safari Data Sheet* (Make 1 copy per student and prepare an overhead transparency.)

Materials

Activity 1	no materials (except photocopies)
Activity 2	no materials (except photocopies)

Preparation

Activity 1
No preparations needed.

Activity 2
Make photocopies and overhead transparency of Master 2.1, *Sound Safari Data Sheet*.

Activity 1: *How Do We Understand?* — Procedure

Teacher note
The purpose of this activity is twofold. First, it helps students become aware of sounds they experience and normally take for granted. Second, it sets the stage for thinking about sound in terms of its loudness, pitch, and timing. As the module concludes, students will reflect on their own sound exposure and provide recommendations about how they can minimize their risk of noise-induced hearing loss.

PART 1—VISUAL CUES

1. **Remind the class that the previous lesson focused on human communication. If you have saved the Path to Understanding diagram from Lesson 1, review it with the class. Explain to students that they will now explore how humans understand what they hear.**

2. **Illustrate the multisensory nature of communication by silently mouthing a sentence such as, "I wonder if you can read my lips." Ask the class if they can repeat the sentence that you mouthed.**

   Students may be able to pick out some of the words, but the meaning of the sentence will remain obscure. If you have a hearing-impaired student in the class who is adept at reading lips, ask him or her to let the rest of the class respond first.

3. **Next, silently mouth a sentence such as, "You're the best class that I've ever had," while conveying a happy facial expression. As before, the exact meaning of the sentence will be obscure. Ask the class if they think the sentence was conveying a happy, sad, or angry thought. On what did the students base their impression?**

   You should stress that facial expressions help represent the emotion behind speech.

4. **Finally, silently mouth a sentence such as, "I've just won $1 million in the lottery." This time use a facial expression that conveys an angry or sad emotional state and ask the class to identify the emotion behind the sentence. Again, ask students to explain the basis for their answers.**

   The mixed messages sent by the mouthed words and the facial expression make the meaning of the sentence more difficult to establish.

5. **Ask the class to summarize how visual cues influence communication and understanding.**

   Students should realize that visual cues, such as facial expressions, affect how others interpret what is said.

Figure 2.2. Facial expressions can convey emotion.

PART 2—INTONATION CUES

1. **Ask the class whether they can think of any other aspects of speech (aside from the words spoken and visual cues) that help convey meaning.**

   Answers may vary. Be alert to answers that speak to characteristics about the speaker and not the meaning of what is being spoken (for example, accents and vocabulary).

2. **Write the following sentence on the board, "The blue fish is too big for that tank." Read the sentence aloud to the class, stressing the word "blue" as depicted in example *a* below, and have students discuss the meaning. Repeat the sentence stressing different words and discuss how the meaning of the sentence changes. Does this sentence always convey the same meaning?**

   For example:
   a. The *blue* fish is too big for that tank. (Meaning: The blue fish is too big, but fish of other colors are the appropriate size.)
   b. The blue *fish* is too big for that tank. (Meaning: The blue fish is too big, but other blue creatures are the appropriate size.)
   c. The blue fish is too big for *that* tank. (Meaning: The blue fish is too big for that tank but may be the appropriate size for some other tank.)

3. **Ask students to suggest another sentence that can take on different meanings depending on how it is said. Write the sentence on the board, and ask the class to see how many ways it can be read to give different meanings.**

   Another sentence that can take on different meanings depending on which words are stressed is, "We are going to the mall tomorrow."

4. **Ask the class to summarize how the manner in which words are spoken can affect our understanding.**

   Review the idea of how word stress changes the meaning of a sentence. Relate to students that actors often practice saying a line in different ways that change the meaning of the words being spoken.

Figure 2.3. *The meaning of spoken words can change depending on how the words are spoken.*

PART 3—EMOTIONAL CUES

1. **Ask the class, Can you detect the emotional state of the person speaking by his or her tone alone, or do you need to understand the words being spoken?**

   Answers will vary, though many students will believe that they can identify the speaker's emotional state just by hearing the tone and not the words.

2. **Test this idea by speaking a random string of numbers to the class, such as 7, 52, 12, 39, 75. Use a voice that suggests a specific emotion, such as anger, and ask the students to identify the emotion.**

   To avoid giving the class any visual cues from your facial expression, you might face away from the class while speaking.

3. **Ask for a volunteer to repeat the test by speaking a different string of numbers and using a different emotion. See if the class can identify the emotion. Repeat the test using different students, numbers, and emotions.**

Content Standard C:
Behavior is one kind of response an organism can make to an internal or environmental stimulus

Again, have the speaker face away from the class to eliminate cues from facial expressions.

4. **To reinforce the importance of multisensory communication, ask the class what other factors, besides hearing, help us communicate with others.**

   Answers should include the idea that visual cues, such as facial expressions and body language, help our brain interpret the speech that we hear.

5. **Wrap up the activity by asking students to list ways, other than speech, in which we can communicate.**

   Answers will vary but may include

reading and writing	body language
sign language	gestures
facial expressions	whistling

Activity 2: *Sound Safari*

Teacher note
The sound safari consists of a simple, five-minute walk down the school hallway. Decide ahead of time where the class will walk. Ideally, students will walk by areas that have a wide variety of sounds, such as the cafeteria, music class, and shop class. If weather permits, you might consider taking part of the walk outdoors.

1. **Remind the class that we categorize sounds as voiced, musical, or environmental. Ask students to give some examples of each category.**

2. **Explain to the class that they will take a short walk. Instruct students not to talk to each other during the walk and to keep noise to a minimum.**

   The goal is to concentrate on the number and types of sounds around them and list as many of them as possible. For the purposes of this activity, students should ignore any sounds made by students in the class (such as talking, coughing, feet shuffling, and writing) and only pay attention to those sounds that aren't produced by the class.

3. Give each student a copy of Master 2.1, *Sound Safari Data Sheet*. Explain that each of the sounds they list can be classified as voiced, musical, or environmental. Instruct students to list each of their sounds in the appropriate column on their data sheet.

   Environmental sounds are simply those that are not voiced or musical.

4. After returning to the classroom, place an overhead transparency of Master 2.1, *Sound Safari Data Sheet*, on the overhead projector. Ask students to call out the voiced sounds from their data sheets and write them down on the transparency. Repeat this process for the musical and environmental sounds.

5. Ask students whether their list of sounds was the same as that written on the transparency. Ask the class to account for differences.

   Students will have many of the same sounds on their lists. Differences arise when sounds are hard to hear or are ever present and therefore difficult to notice.

6. To conclude this activity, remind the class that visual and audio cues help us better understand speech. Ask the class if they can think of similar cues that help us understand musical and environmental sounds.

   Context is important. A piece of music played during a parade may convey a different emotion from the same music played at a funeral. A whistle blown by a policeman directing traffic has a different meaning from a whistle blown by an official at a sporting event.

Figure 2.4. The same sound can have different meanings that depend on context.

Content Standard A:
Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models.

Assessment:
Ask students to summarize, in writing, their thoughts about how audio and visual cues influence our ability to gain meaning from sound. Ask them to provide specific examples of sounds that can have different meanings depending upon their context. Ask students to share their ideas with the class.

Lesson 2 Organizer

Activity 1: *How Do We Understand?*

What the Teacher Does	Procedure Reference
Review the Path to Understanding diagram from Lesson 1.	Page 67 Part 1, Step 1
Silently mouth the sentence, "I wonder if you can read my lips," to the class. • Ask students if they can repeat the sentence.	Page 67 Part 1, Step 2
Use a happy expression to mouth the sentence, "You're the best class that I've ever had." • Ask students to identify the emotion.	Page 67 Part 1, Step 3
Use an angry or sad expression to mouth the sentence, "I've just won $1 million in the lottery." • Ask students to identify the emotion.	Page 67 Part 1, Step 4
Ask the class to summarize the roles of visual cues in human communication.	Page 68 Part 1, Step 5
Ask the students whether other aspects of speech convey meaning.	Page 68 Part 2, Step 1
Write the sentence, "The blue fish is too big for that tank," on the board. • Discuss how emphasizing different words can affect meaning.	Page 68 Part 2, Step 2
Have students suggest another sentence that can convey different meanings depending on how it is said.	Page 69 Part 2, Step 3

M = Involves copying a master. **T** = Involves using a transparency.

Summarize how word stress and intonation can affect meaning.	Page 69 Part 2, Step 4
Ask if a speaker's emotion affects understanding.	Page 69 Part 3, Step 1
Recite a random series of numbers using a voice that conveys a specific emotion. • Ask students to identify the emotion. • Repeat the activity having a student recite numbers using a different emotion.	Pages 69–70 Part 3, Steps 2 and 3
Reinforce the importance of multisensory communication. • What factors, besides hearing, help us communicate? • How can we communicate without using speech?	Page 70 Part 3, Steps 4 and 5

Activity 2: *Sound Safari*

What the Teacher Does	Procedure Reference
Have students give examples of voiced, musical, and environmental sounds.	Pages 70–71 Steps 1–3
Take class on a short walk through the school. • Have students record the sounds they hear on Master 2.1, *Sound Safari Data Sheet*.	Pages 70–71 Steps 2 and 3 M
After returning to classroom, • Construct a list of sounds heard on the transparency of Master 2.1, *Sound Safari Data Sheet*. • Have students compare their lists with the master list.	Page 71 Steps 4 and 5 T
Have students discuss how they use their senses to interpret musical and environmental sounds.	Page 71 Step 6

Sound Safari Data Sheet

Name____ Date___________________________

VOICED	MUSICAL	ENVIRONMENTAL

Master 2.1

Lesson 3
Explore/
Explain

Do You Hear What I Hear?

Figure 3.1. Children enjoy playing with sound.

At a Glance

Overview

Students learn how loudness is measured. Using a Web-based loudness-pitch square, students generate a hearing-response curve. They also listen to recordings that simulate hearing loss. Students investigate the relationships among loudness, pitch, and hearing.

Major Concepts

Loudness and pitch are distinct properties of sound. Loudness is related to the amplitude of the sound wave; pitch is related to its frequency. Humans do not hear all pitches equally well. Specifically, the loudness of very-low- and very-high-pitched sounds must be increased to detect them. A healthy sense of hearing is characterized by an ability to recognize a wide spectrum of pitches. Hearing loss may involve failure to detect specific pitches.

Objectives

After completing this lesson, students will

- be able to identify the decibel scale as the tool scientists use to describe a sound's relative loudness,
- be able to explain that loudness is related to the amplitude of the sound wave, while pitch is related to its frequency, and
- understand that humans do not hear all pitches equally well; loudness must be increased to detect certain pitches.

Teacher Background

Consult the following sections in Information about Hearing, Communication, and Understanding:
3.3 Sound has a physical basis (pages 29–32)
3.4 Perception of sound has a biological basis (pages 32–38)

In Advance

Web-based Activities

Activity	Web Version?
1	No
2	Yes

Photocopies

Activity 1	Master 3.1, *The Decibel Scale* (Make 1 copy per student.) Master 3.2, *Sound Intensity Table* (Make 1 copy per student and prepare an overhead transparency.)
Activity 2	Master 3.3, *Loudness and Pitch* (Make 1 copy per student.) Master 3.4, *Hearing Response* (Make 1 copy per student and prepare an overhead transparency.)

Materials

Activity 1	a small bell
Activity 2	a computer with an Internet connection and a sound card

Preparation

To achieve the best results, calibrate the computer sound levels with the Web activity. To do this, go to *http://science.education.nih.gov/supplements/hearing/web* click on "Web Portion of Student Activities." Then click on "Lesson 3—Do You Hear What I Hear?" After listening to the introduction, you will advance automatically to a page containing a large graph, the loudness-pitch square. Play the 2,000-Hz (2-kHz) tone at a value of about 20 on the loudness scale (y-axis). Adjust the volume control on the speakers so that the tone is barely audible. This will ensure that your computer plays the tones at appropriate volumes for the activity.

Activity 1: *Measuring Intensity*

Procedure

Teacher note
This activity is concerned with measuring levels of sound intensity. Sound **intensity** is a scientific measurement representing power per unit of area and is expressed as watts per meter squared (W/m^2). **Loudness**, on the other hand, is a subjective impression of sound intensity. Perception of loudness varies from person to person. It is influenced by factors such as sound frequency (we don't hear all frequencies equally well) and the performance of our hearing (a person with a partial hearing loss may perceive a given sound as being less loud than a person with normal hearing does). Although sounds of greater intensity are louder than sounds of lesser intensity, use of the term *loudness* does not permit us to make quantitative comparisons. Therefore, in this activity, we will focus on measuring and comparing sound intensity rather than loudness.

1. **Begin the activity by ringing a small bell until the class gives you their attention.**

   The bell serves as a vehicle to engage students' interest in the activity.

Figure 3.2. A bell may be rung loudly or softly.

2. **Challenge the class to name different ways to make the bell sound louder.**

   Students may suggest
   - ringing the bell more vigorously so the clapper hits the side with more force,
   - ringing the bell closer to their ears,
   - cupping their hands around their ears to better focus the bell's sound waves into them,
   - placing the ringing bell at the small end of a megaphone to better project the sound waves toward the class, and
   - placing the bell in front of a microphone that's wired to an amplification system.

3. **Explain that students will investigate the physical basis of loudness. However, before they can investigate loudness, they need to understand how scientists measure it. Distribute 1 copy of Master 3.1, *The Decibel Scale*, and Master 3.2, *Sound-Intensity Table*, to each student.**

4. **Explain that Master 3.2 contains a partially filled-out table that lists increasing sound levels (measured in decibels) with a description of a reference sound at some levels. Instruct students to complete the missing entries in the first two columns of the table.**

   If students have trouble understanding the relationship between sound intensity and decibels, use the first few entries on Master 3.2 as examples to clarify the relationship. Completing the worksheet will help students better understand the decibel scale and also reinforce the meaning of sound intensity and the large range of sound intensities that the human ear can detect. Only a few reference sounds are presented here. Students will have the opportunity to relate more sounds to the decibel scale during Lesson 5, *Too Loud, Too Close, Too Long.*

5. **Show the class the overhead transparency of Master 3.2 and ask them how they filled in the first two columns of the table.**

Sound Intensity	Decibels (dB)	Sounds
1	0	just detectable
10	10	
100	20	
1,000	30	
10,000	40	quiet room
100,000	50	
1,000,000	60	normal conversation
10,000,000	70	
100,000,000	80	alarm clock
1,000,000,000	90	
10,000,000,000	100	
100,000,000,000	110	rock concert (90–130 dB)
1,000,000,000,000	120	shout into ear at 20 cm
10,000,000,000,000	130	
100,000,000,000,000	140	air raid siren

Students should respond that the sound levels increase by powers of 10. Furthermore, the number of decibels (dB) corresponds to the number of zeros in the sound-intensity column, followed by a zero. That is, a sound intensity of 1,000 in the table has a decibel value of 3 (as in 3 zeros) followed by a zero, or 30 dB.

6. **To assess students' understanding of the decibel scale, instruct them to answer the questions on Master 3.1, *The Decibel Scale*.**

   Answers to questions on Master 3.1, *The Decibel Scale*, follow:

   Question 1. How many times more intense is a sound of 30 dB than a sound of 20 dB? A sound of 40 dB than a sound of 20 dB?

   A sound of 30 dB is 10 times more intense than a sound of 20 dB. A sound of 40 dB is 100 times more intense than a sound of 20 dB.

   Question 2. How many times more intense is the sound of an alarm clock than a quiet room?

   The sound of an alarm clock is 10,000 times more intense than a quiet room.

NSES

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

7. **Ask the class why a sound will seem "too loud" to one person but not to another person.**

   People have different preferences for sound intensities. For example, some people prefer to listen to music at higher intensities than others. Differences in loudness perception can also result from damage to the hearing pathway. A person with a partial hearing loss will hear a given sound as less intense compared to a person with normal hearing. People who prefer to listen to loud music put themselves at risk for noise-induced hearing loss.

8. **Ask the class how sound intensity is used in speech to communicate with others.**

   Sound intensity plays an important role in human speech. First, speaking loudly can convey an emotional state such as urgency or anger. Second, as seen in Lesson 2, putting greater stress (sound intensity) on a particular word can change the meaning of a sentence. Third, stressing a different syllable within a word can sometimes change its meaning.

Figure 3.3. Speech can be either loud or soft.

Activity 2: *Pitch Me a Curve*

Teacher note

In this activity, students generate a hearing-response curve, which depicts the threshold of hearing as a function of frequency. This technique is the basis for a test commonly used to detect hearing loss. However, this activity should not be used as a diagnostic tool in any way. Students will likely generate curves that differ from each other. These differences are much more likely to be caused by differences between computers than differences between students' hearing.

PART 1—LOUDNESS AND PITCH

1. **Ring the small bell again until the class gives you their attention. Challenge the students to name as many ways as possible of making the bell sound higher in pitch.**

   Although they may not be able to explain the physical basis for the bell's pitch, most students will probably know that its pitch is related to its size, and that the only way to increase the bell's pitch would be to change (decrease) its size or somehow to electronically change the sound waves that it produces.

2. **Explain to the class that they are now ready to study the relationship between loudness and pitch. Challenge students to explain the difference between these two properties of sound and to provide some practical illustrations of this difference.**

Students should understand already that loudness is described using words such as loud and soft, whereas pitch is described by words such as high and low. Students should be able to explain that both the low-pitched keys on the left of a piano keyboard and the high-pitched keys on the right can be played softly or loudly. Similarly, males (with lower-pitched voices) can sing as loudly or as softly as females (with higher-pitched voices).

3. **Ask the class to recall that sound travels as vibration. Explain that the physical basis of a sound's pitch is its frequency, or the number of vibrations per second.**

   Sounds of rapid vibrations are perceived as higher in pitch than sounds of slower vibrations. The unit hertz (abbreviated Hz) is used to measure the pitch (frequency) of sound. For example, a sound with a pitch of 262 Hz vibrates at a rate of 262 times per second, which corresponds to middle C on a piano.

4. **Explain to the class that they will use a Web-based activity to investigate the relationship between loudness and pitch and to understand the human hearing response to sound.**

5. **Have students proceed to *http://science.education.nih.gov/supplements/hearing/student* and click on "Lesson 3—Do You Hear What I Hear?" After listening to the introduction, you will advance automatically to a page containing a large graph, the loudness-pitch square.**

   Students should pay close attention to the introduction. It explains how changes in wave amplitude reflect soft versus loud sounds, and how changes in frequency reflect low- versus high-pitched sounds.

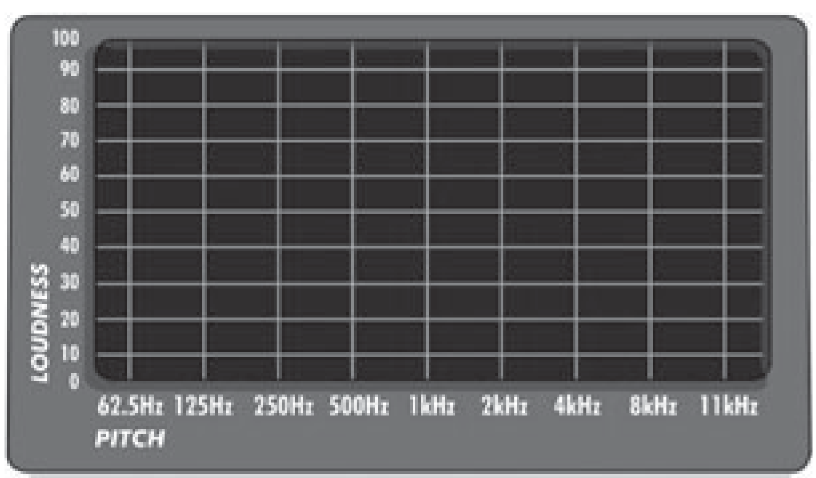


Figure 3.4. The loudness-pitch square.

NSES

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

6. **Explain to the class that they will perform two tasks using a loudness-pitch square. First, they will investigate the relative loudness of sounds at different pitches. Then, in Part 2, they will construct a hearing-response curve.**

   Students may work in teams, although each student should collect his or her own data.

7. **Distribute to each student a copy of Master 3.3, *Loudness and Pitch*.**

8. **In the first task, students select the lowest frequency (62.5 Hz) and click on a point halfway up the y-axis (50 on the loudness axis).**

   Depending on your computer, sound card, and speakers, you may not be able to hear the lowest or highest frequencies, even at the maximum intensity. Also, students might hear a very short "squeak" initially. Tell them to ignore this noise and listen for a constant, uniform tone.

9. **For the first constant, uniform tone that students hear at 50 on the loudness axis, tell them to assign that tone a value of 1 (on a scale of 1 to 10).**

   Other tones may be louder than this one, and they will be assigned an arbitrary number relative to 1.

10. **Students should then select the next higher frequency on the graph, clicking on the point at the same vertical height as before (50 on the loudness axis). Instruct students to assign the tone a numerical value based on its loudness relative to the first detectable tone (see Step 9). For example, if you think the second tone is twice as loud as the first, then you should assign the second tone a value of 2. This process is repeated for each of the remaining frequencies, always clicking on the same point on the loudness axis (at 50) for each frequency. Students should then enter their results on Master 3.3, *Loudness and Pitch.***

11. **Instruct the students to answer the discussion questions on Master 3.3, *Loudness and Pitch.***

Question 1. Did the sounds produced at each frequency seem equally loud? How did the loudness change with frequency?

Sounds vary in loudness as pitch (frequency) increases. At the low end of the spectrum, the sounds seem louder as frequency increases. As one moves up the spectrum, however, loudness seems to decrease at the higher frequencies.

Question 2. Why did you hear variation in loudness with changing pitch?

The hearing system's sensitivity to loudness varies with the frequency of the sound. Generally, the ear is most sensitive to sounds in the 3-to-4-kHz region. Sounds outside of this range must be more intense to be perceived as loud. Any student answer that relates this phenomenon to the functioning of the human hearing system is acceptable.

PART 2—HEARING-RESPONSE CURVE

Teacher note

In this second task, students generate a hearing-response curve. This curve has no clinical value and should not be viewed by students as an indication of whether or not they have a hearing impairment. However, if a student has responses that are well outside the norm and is concerned, encourage him or her to see the school nurse, a doctor, or an audiologist. The purpose of this task is to explore the different sensitivities of the human ear to different pitches. If you or the students have not already calibrated the sound level of their computer as described in the Preparation section at the beginning of this activity, instruct them to do so now.

1. **Give each student a copy of Master 3.4, *Hearing Response*.**

2. **Instruct students to start with the 62.5-Hz frequency and play the tone at the lowest setting for loudness. If they do not hear the tone, they should increase the loudness by clicking on a higher point on the vertical axis at that same frequency. They should continue this process until they find the loudness setting at which they can *first* hear the tone. Direct students to enter this loudness value in the appropriate space on Master 3.4, *Hearing Response*.**

   Note: the lowest frequency the students hear may be at 250 Hz, 125 Hz, or 62.5 Hz depending on the quality of the computer's sound card and speaker system.

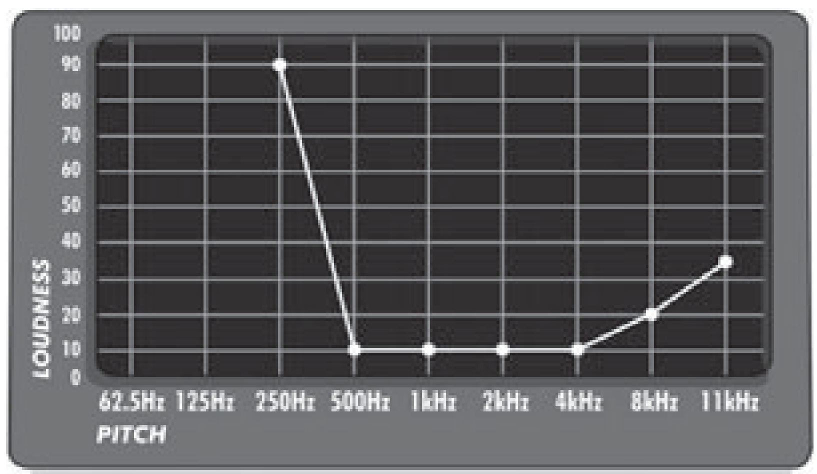
Content Standard A:
Use mathematics in all aspects of scientific inquiry.

3. **Students repeat this process for each of the higher frequencies by clicking on the lowest loudness setting and gradually increasing the volume. As before, they should record the loudness at which they first hear the tone. In the end, students will collect data representing the minimum relative loudness at which tones of various frequencies first can be heard.**

   Note: that at the two highest frequencies, students might hear a very short "squeak" initially. Instruct them to ignore this noise and listen for the loudness setting at which they hear a *constant*, high-pitched tone.

4. **Direct students to plot their results on the graph template provided on Master 3.4, *Hearing Response*. You can use an overhead transparency of Master 3.4 to explain how to create the graph.**

Student results will vary, although the shapes of their curves should be similar. The values on the y-axis are high at the lowest frequencies, drop for frequencies from 500 to 4,000 Hz, and slowly rise beginning around



8,000 Hz.

Figure 3.5. A sample hearing-response curve.

5. **Instruct the students to answer the discussion questions on Master 3.4, *Hearing Response.***

   Answers to questions on Master 3.4, *Hearing Response*, follow:

   Question 1. At what frequencies is your hearing most sensitive? Circle these frequencies on your graph.

Hearing is most sensitive at those frequencies for which sound can be detected at the lowest loudness levels. Human hearing is most sensitive at frequencies associated with human speech (between 250 and 4,000 Hz).

***Question 2**. As we get older or are repeatedly exposed to loud sounds, we tend to lose hearing at higher frequencies. How might the hearing-response curve change for an individual with high-pitched hearing loss?*

As hearing loss occurs, progressively louder sounds are required for higher-pitched sounds to be heard. The hearing-response curve for a person with high-pitched hearing loss would show a steeper curve on the part of the graph corresponding to high frequencies. Because louder sounds cause damage to hair cells, a mild hearing loss can lead to even greater hearing loss.

PART 3—HIGH-PITCHED HEARING LOSS

1. **Explain to the class that they are now ready to investigate the effect of high-pitched hearing loss on the understanding of sounds. Challenge students to predict how speech would sound if the high pitches are removed, or "filtered," from a sound file.**

2. **Explain that, as in the first lesson, students will again listen to someone reading the first sentence of President Lincoln's Gettysburg Address. Explain that the first reading will be an unfiltered version. (This is the same track used in Lesson 1 and labeled "traditional.") The second reading has removed pitches above 4,000 Hz. The third reading has removed pitches above 2,000 Hz. Instruct students not to change sound level settings while listening to the three recordings.**

3. **Have students proceed to *http://science.education.nih.gov/supplements/hearing/student* and click on "Lesson 3—Do You Hear What I Hear?" Near the top of the screen, click on the link labeled "Filtered Sound." Have students play each of the three sound tracks in the following order: normal; filtered 4,000 Hz; and filtered 2,000 Hz.**

4. **After the students have had an opportunity to listen to the unfiltered and filtered sound tracks, reconvene the class and ask the students the following questions:**

   a. **Which sound track might simulate how an older person with high-pitched hearing loss would hear the passage?**

Both the filtered 4,000-Hz and the filtered 2,000-Hz sound tracks simulate how a person with high-pitched hearing loss might hear the passage being read. The filtered 2,000-Hz sound track corresponds to a more severe hearing loss than does the filtered 4,000-Hz sound track.

b. Which sound track, filtered 4,000-Hz or filtered 2,000-Hz, is missing more pitches?

Pitches ranging from 2,000 Hz and above have been removed from the filtered 2,000-Hz sound track, while pitches ranging from 4,000 Hz and above have been removed from the filtered 4,000-Hz sound track. Therefore, the filtered 2,000-Hz sound track is missing pitches between 2,000 Hz and 4,000 Hz, which are present in the filtered 4,000-Hz sound track.

c. How does loudness change as the higher pitches are removed?

Loudness seems to decrease as pitches are removed.

d. How does your understanding of the words change as the higher pitches are removed?

Understanding becomes more difficult. Words seem to be less distinct. This is because some of the information provided by the sound has been lost.

e. How can a person compensate for such a hearing loss? What is the result of this compensation?

As hearing loss occurs, progressively louder sounds are required for hearing. An individual may turn up the volume on a television, stereo, or radio or ask a speaker to talk louder. Students may have noticed such behaviors exhibited by their grandparents or other older adults. A person with such a hearing loss may elect to use a hearing aid, which uses a microphone to collect and amplify sounds coming into the ear. The hearing aid does not restore normal hearing but can greatly aid hearing and communication.

Assessment: Have students investigate the hearing responses of another animal such as a dog, bat, or whale. Ask them to report on their animal's hearing range and compare it with that of humans. Ask them to predict how high-pitched hearing loss might affect the animal.

Lesson 3 Organizer

Activity 1: *Measuring Intensity*

What the Teacher Does	Procedure Reference
Ring a small bell and challenge the class to suggest ways of making the bell ring louder.	Page 77 Steps 1 and 2
Introduce the concept of the physical basis of loudness and the decibel scale using Masters 3.1, *The Decibel Scale,* and Master 3.2, *Sound-Intensity Table*.	Page 78 Step 3 M
Have the class complete Master 3.2, *Sound-Intensity Table,* and discuss their answers.	Pages 78–79 Steps 4 and 5 T
Instruct the class to answer the questions on Master 3.1, *The Decibel Scale*.	Page 79 Step 6
Discuss the relationship of loudness to human communication. • Ask why a sound may seem loud to one person but not to another. • Ask how sound intensity is used in human communication.	Page 79 Steps 7 and 8

Activity 2: *Pitch Me a Curve*

What the Teacher Does	Procedure Reference
Ring the small bell again and challenge the class to suggest ways of making the bell sound at a higher pitch.	Page 80 Part 1, Step 1
Ask the class to distinguish between loudness and pitch and relate their answers to the concept of sound waves.	Pages 80–81 Part 1, Steps 2 and 3
Have students log onto the Web site and click on the button labeled "Lesson 3—Do You Hear What I Hear?"	Page 81 Part 1, Steps 4 and 5 WWW

M = Involves copying a master.

T = Involves using a transparency.

WWW = Involves using the Internet.

Have students collect data on the relative loudness of sounds using the loudness-pitch square and Master 3.3, *Loudness and Pitch*.	Page 82 Part 1, Step 6–10
Have students answer questions on Master 3.3, *Loudness and Pitch*.	Pages 82–83 Part 1, Step 11
Have students collect data on a hearing-response curve using Master 3.4, *Hearing Response*.	Pages 83–84 Part 2, Steps 1–3
Have students plot their data and answer the questions on Master 3.4, *Hearing Response*.	Pages 84–85 Part 2, Steps 4 and 5
Challenge students to describe how speech would sound with high pitches removed.	Page 85 Part 3, Step 1
Have students return to the Web site and play unfiltered and filtered sound tracks.	Page 85 Part 3, Steps 2 and 3
Reconvene the class and discuss the following questions: • Which sound track might simulate how an older person with high-pitched hearing loss would hear the passage? • Which sound track, filtered 4,000-Hz or filtered 2,000-Hz, is missing more pitches? • How does loudness change as the higher pitches are removed? • How does your understanding of the words change as the higher pitches are removed? • How can a person compensate for high-pitched hearing loss? • What is the result of this compensation?	Pages 85–86 Part 3, Step 4

The Decibel Scale

Name____ **Date**____________________________

Imagine hearing the softest sound that you can possibly hear. Then imagine that this sound is made louder and louder until it is so loud, it is physically painful to hear it. How much louder do you think the loudest sound would be compared with the softest?

You may be surprised to learn that a painfully loud sound would be more than 16,384 times as intense as the softest sound. In other words, your ears can hear a range of sounds that increase from a sound intensity of 1 unit to an intensity of 100 trillion units. To think of it another way, you began life as a single cell. But by the time you reach adulthood, you'll be made of 100 trillion cells.

Because such an enormous range of numbers (from 1 to 100 trillion) can be difficult to work with, scientists have devised a special scale to use when measuring the intensity of sounds. This scale is called the decibel scale.

Study the patterns made by the numbers in the first two columns of the table on the next page. Then fill in the missing numbers in the columns labeled "Sound Intensity" and "Decibels (dB)."

Answer the questions below to learn more about the decibel scale.

1. How many times more intense is a sound of 30 dB than a sound of 20 dB? A sound of 40 dB than a sound of 20 dB?

2. How many times more intense is the sound of an alarm clock than a quiet room?

Sound-Intensity Table

Name____ Date______________________________

Sound Intensity	Decibels (dB)	Sounds
1	0	just detectable
10	10	
100	20	
1,000	30	
10,000	40	quiet room
		normal conversation
		alarm clock
		rock concert (90–130 dB)
		shout into ear at 20 cm
100,000,000,000,000	140	air raid siren

Loudness and Pitch

Name____ Date______________________________

Enter the results of your investigation of the relative loudness of sounds at different pitches (frequencies) as measured in hertz (Hz).

Frequency (Hz)	62.5	125	250	500	1,000	2,000	4,000	8,000	11,000
Relative loudness									

Discussion Questions

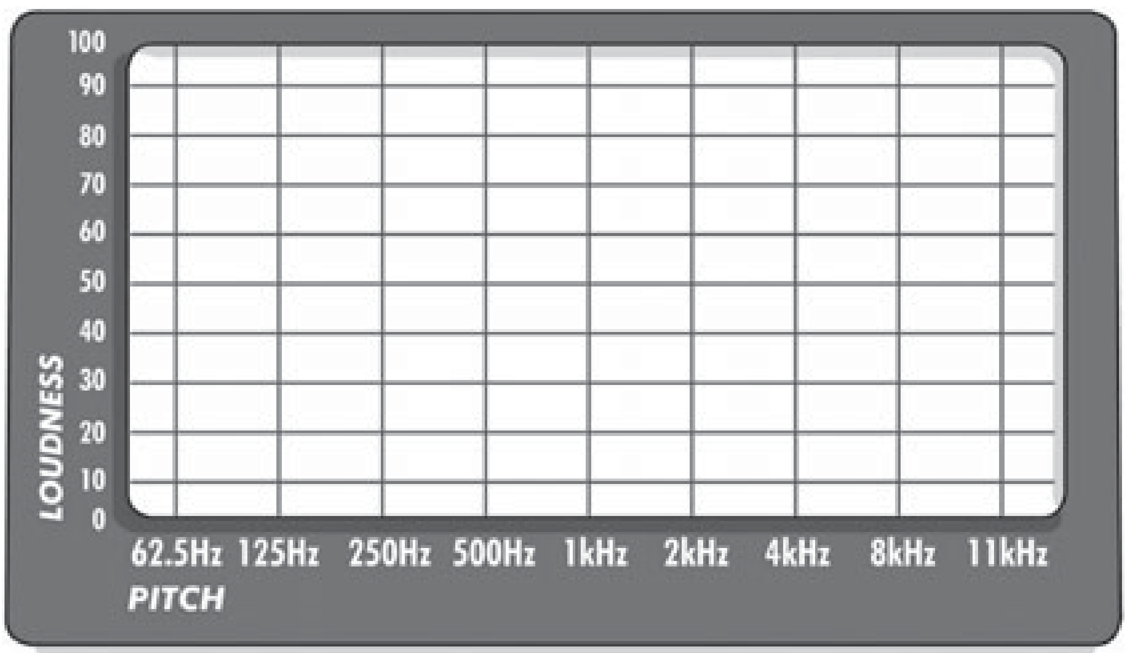
1. Did the sounds produced at each frequency seem equally loud? How did the loudness change with frequency?

2. Why did you hear variation in loudness with changing pitch?

Hearing Response

Name____ Date_____________________________

Frequency (Hz)	62.5	125	250	500	1,000	2,000	4,000	8,000	11,000
Loudness Value on y-axis									



Discussion Questions

1. At what frequencies is your hearing most sensitive? Circle these frequencies on your graph.

2. As we get older or are repeatedly exposed to loud sounds, we tend to lose hearing at higher frequencies. How might the hearing-response curve change for an individual with high-pitched hearing loss?

Lesson 4 Elaborate

A Black Box Problem: How Do I Hear?

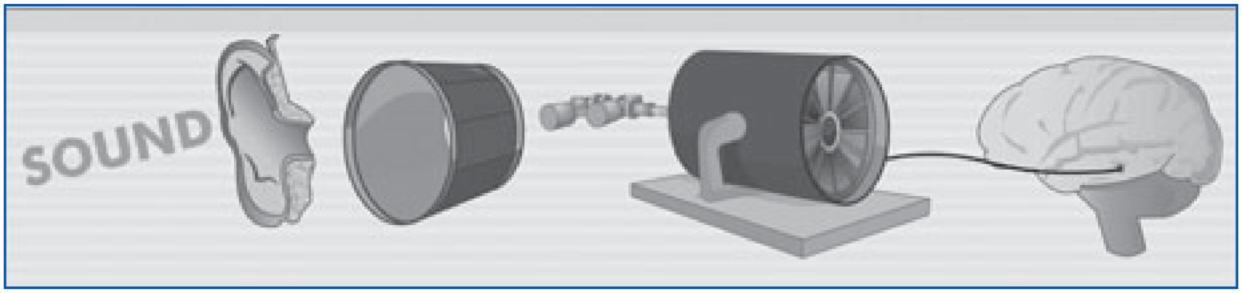


Figure 4.1. Sound energy must be converted into a form that can be processed by the brain.

At a Glance

Overview

Students assemble a diagram of the hearing pathway using information about its parts and their functions, describe how sound is represented at various points along the pathway, and predict the changes in hearing that might result from specific changes to the pathway.

Major Concepts

The hearing pathway processes sound in a series of steps that involve different structures within the ear. Hearing requires the passage of vibrational energy from one medium to another, as well as its conversion to electrical energy in the form of nerve impulses. Transduction, which occurs in the cochlea, is the conversion of vibrational energy to electrical energy. Damage to specific parts of the hearing pathway results in predictable changes in hearing. The interpretation of what one hears occurs in the brain.

Objectives

After completing this lesson, students will

- be able to describe the structure and function of the major parts of the hearing pathway,
- understand that hearing requires the conversion of vibrational energy to electrical energy,
- be able to describe changes in hearing associated with specific changes to the hearing pathway, and
- understand how technology can be used to compensate for hearing loss.

Teacher Background

Consult the following sections in Information about Hearing, Communication, and Understanding:

3.4 Perception of sound has a biological basis (pages 32–38)
4.6 Cochlear implants (pages 40–41)

In Advance

Web-Based Activities

Activity	Web Version?
1	Yes
2	No

Photocopies

Activity 1	Master 4.1, *The Mysterious Black Box* (Prepare an overhead transparency.) Master 4.2, *A Few Questions* (Prepare an overhead transparency.) Master 4.3, *Black Box Cards* (Make 1 set of 8 cards per team for print version.) Master 4.4, *The Bell Card* (Make 1 copy for print version.)
Activity 2	Masters 4.5, *Understanding Form and Function* (Make 1 copy per team.)

Materials

Activity 1	a small bell a lamp without a shade a computer with Internet connection and sound card
Activity 2	no materials needed (except photocopies)

Preparation

Activity 1 (print version)

To prepare the Black Box Cards, make copies from Master 4.3 and cut the cards along the dotted lines.

Activity 2 (print version)

No preparations are needed except photocopying.

Activity 1: *The Mysterious Black Box*

Procedure

Teacher note
The following procedure describes how to conduct the Web-based version of this activity, the preferred form of instruction. Instructions for conducting the alternative print-based version follow the Web-based instructions.

1. **Explain to the class that they will use a Web-based activity to explore the hearing pathway and the process by which it converts sound waves into signals that can be understood by the brain.**

   If you feel that your students would benefit from a more extensive introduction to the activity, consider having the class proceed through Steps 1–4 from the print-based procedure (pages 96–98).

2. **Explain to the class that they will view eight pictures, each representing a different part of the hearing pathway. As they position the cursor over each picture, they can read a brief description of that part's role in the hearing process. The students' task is to arrange the pictures in their proper sequence in the hearing pathway.**

   After students arrange the pictures in a sequence, they can test themselves by clicking on the "Try it" button. If a mistake has been made, only those pictures that are in the correct order remain where they are, while those that are incorrect move back to the starting position for the student to try again. When the correct sequence is assembled, the hearing pathway fades away and a cartoon animation appears. The animation shows how the sound is represented along the hearing pathway. A sound is heard only after the electrical impulse reaches the brain.

3. **Instruct students to proceed to *http://science.education.nih.gov/supplements/hearing/student* and click on "Lesson 4—A Black Box Problem: How Do I Hear?"**

   Students should pay particular attention to the introduction, which includes a cartoon that depicts how sound waves travel through the hearing pathway and introduces the term transduction. Transduction is the process by which sound is converted into a form that the brain can understand.

NSES

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

Content Standard B:
Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical.

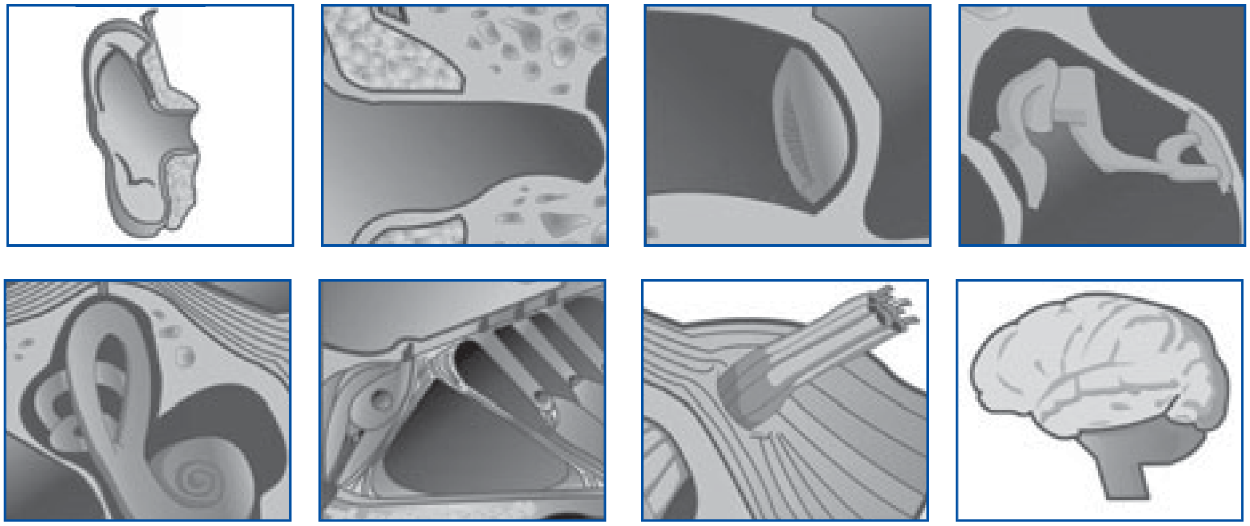


Figure 4.2. The parts of the human hearing pathway in their proper sequence.

As students perform this activity, circulate around the room and ask each team to explain why they put the pictures in the order they did.

Alternate version of Activity 1 for classes without access to computers:

1. **Turn on the lamp and ask the class how the light bulb produces its light.**

   Student responses will vary. Direct the discussion to how electrical energy flows through a wire to the light bulb filament where light, as well as heat, is generated.

2. **Write the word "transduction" on the board and explain that it refers to the process by which energy is converted from one form into another. Ask students if they can name other examples of transducers.**

   Students' examples may include flashlights, microphones, photocells, stereo speakers, engines, and other such devices. If no one mentions a biological system, ask the class if living things can transduce energy. Examples of biological transduction may include the process of photosynthesis, which converts light energy into chemical energy, or the process of respiration, which converts chemical energy into mechanical energy.

Figure 4.3. Examples of transducers.

3. **Display an overhead transparency made from Master 4.1, *The Mysterious Black Box.* Ask students to describe the picture and to identify the question it raises.**

NSES

Content Standard B:
Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical.

Content Standard A:
Identify questions that can be answered through scientific investigations.

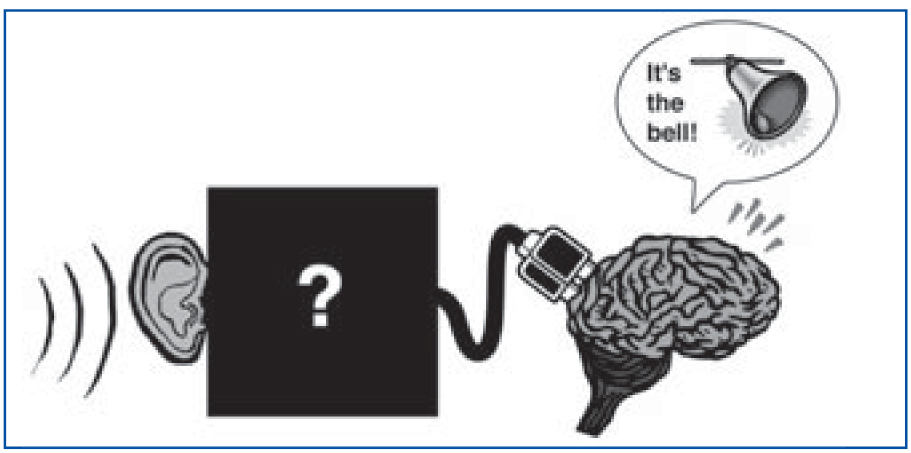


Figure 4.4. The Mysterious Black Box.

Guide the discussion so that students ask a focused question pertaining to hearing, such as, "What happens inside the hearing pathway to allow sound to be heard in the brain?"

Ask students to rephrase the question to include the concept of transduction: "How is sound converted to a signal that the brain can understand?"

Students should understand that the black box represents the parts of the hearing pathway that they cannot see. You may wish to explain that scientists are often able to observe only the beginning of a process and its outcome but not the events that lead from one to the other. The challenge of the black box is to identify and describe all of the intermediate steps.

4. **Display an overhead transparency made from Master 4.2, *A Few Questions.* Uncover the questions one at a time as the discussion proceeds. Invite students to speculate as to what happens inside the black box of hearing.**

   Sample answers to Master 4.2, *A Few Questions,* follow:

   Question 1. What do the lines between the bell and the ear indicate?

   The lines depict sound waves (vibrational energy) moving from the bell to the ear.

   Question 2. What is a sound wave?

   A sound wave is a wave of vibrational energy (or a pressure wave) that moves through a medium such as air or water.

   Question 3. Do vibrations reach all the way into the brain to let us hear sound?

   This question is analogous to the example of the lamp as a transducer. Just as light doesn't travel through wires to the light bulb, students should recognize that the actual vibrations do not travel to the brain. Instead, the ear converts the vibrational energy of sound into electrical energy, the energy of nervous impulses. To help students formulate this answer, you may wish to ask the analogous questions, "Does the light that enters our eyes go all the way to the brain?" and "When you touch someone's skin and they feel it, does the 'touch' go all the way to the brain?"

5. **Explain that in this activity, students will construct a flow chart that shows what happens inside the black box of hearing. Hold up a set of Black Box Cards and explain that each team will receive a set of eight cards that provides information about the structures and functions of the hearing pathway.**

   Each card includes a picture of a part of the hearing pathway and a brief explanation of the part's function. The team's first challenge is to assemble the cards in the correct order so that the sound of the bell will be heard in the brain.

6. Organize the class into teams of two or three students. Distribute a set of Black Box Cards to each team. Announce that teams have 10 minutes to put the cards in the correct sequence. During that time, while students are working, you will circulate through the room with a "testing device" (hold up the large Bell Card and the bell). Explain that when a team decides it has assembled the pictures in the proper order, you will use the device to test the sequence.

7. To test each team's pathway, give one team member the Bell Card and ask him or her to place it at the start of the flow chart. The Bell Card illustrates the vibrations produced as the bell rings. After the student puts the Bell Card in position, have the students explain what happens to the sound as it is transmitted through the hearing pathway. If the students' sequence of cards and explanation of events are correct, ring the bell to indicate that the impulse reached the brain, where it is interpreted. If the pathway is not correct, do not ring the bell and ask the team to try again.

8. Write the names of the hearing-pathway components on the board as follows:

   a. tympanic membrane (eardrum)
   b. ossicles (bones of the middle ear)
   c. pinna (outer ear)
   d. cochlea
   e. brain
   f. auditory nerve
   g. organ of Corti (containing hair cells)
   h. ear canal

   Instruct the teams to match the letter that corresponds to each component of the hearing system with its image.

   Figure 4.5 provides a visual guide for the correct order of Black Box Cards.

   As you review the functions of the components of the hearing pathway, draw attention to each part's name. After you have reviewed all eight components, introduce the terms "outer ear," "middle ear," and "inner ear," and ask students to place these labels at the appropriate points in the sequence of pictures that depicts the hearing pathway. Ask students to name the parts of the hearing pathway that are not part of the ear, such as the auditory nerve and the brain.

NSES

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

Assessment:
As students perform this activity, circulate around the room and ask each team to explain why they put the pictures in the order they did. If a team struggles to place the pictures in the correct order, ask the students various guiding questions to help them overcome their difficulties. If necessary, point out to the team that their sequence is correct up to a certain point.

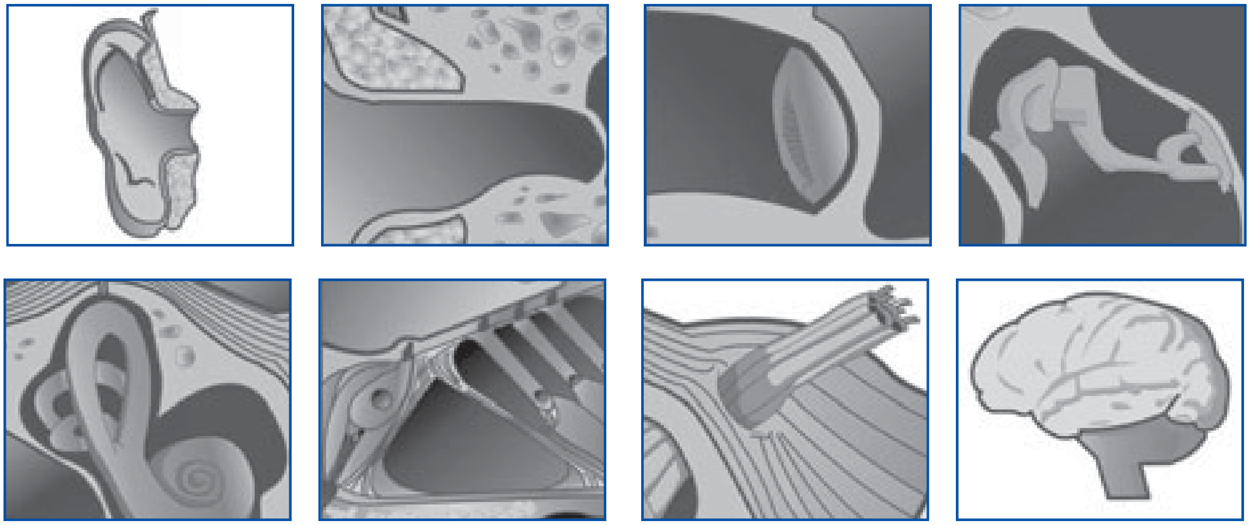


Figure 4.5. The Black Box Cards in their proper sequence.

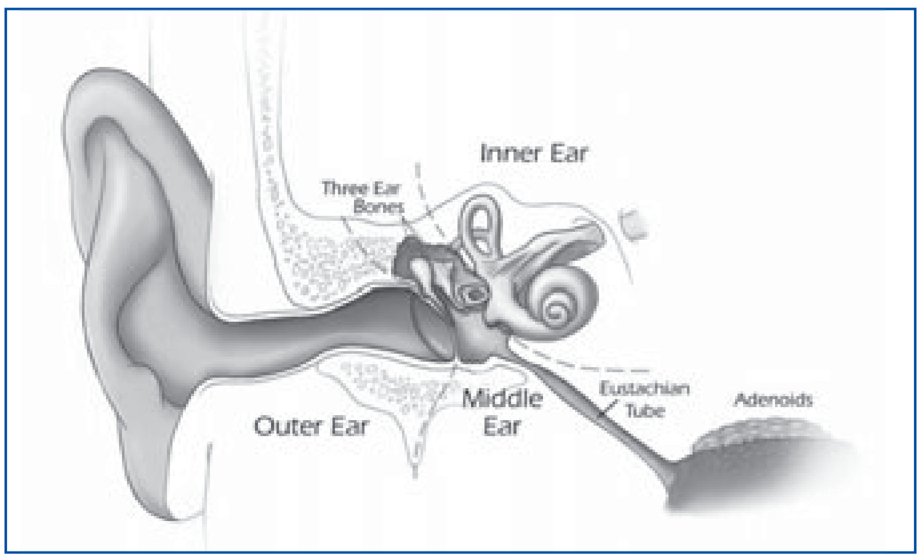


Figure 4.6. The hearing pathway showing the outer, middle, and inner ear.

9. Before proceeding, construct the hearing pathway on the board so that students may refer to it while engaged in Activity 2.

Activity 2: *Understanding Form and Function*

1. Review transduction with the class. Make sure students understand that transduction is the conversion of energy from one form into another. Ask the class where in the hearing pathway transduction occurs.

Students may respond that transduction occurs either in the cochlea or in the organ of Corti. If there is confusion, help students understand that the organ of Corti is found within the cochlea. Explain how the hair cells are organized in the cochlea, how they detect the pressure waves moving through the cochlea, and how they trigger the formation of electrical impulses.

NSES

Content Standard C: Living systems at all levels of organization demonstrate the complementary nature of structure and function.

The following points provide information that will help you guide the discussion.

- The cochlea is the hearing (as opposed to balance) part of the inner ear.
- When the bones of the middle ear (ossicles) vibrate in response to sound, they generate *pressure waves* in the fluid inside the cochlea.
- The organ of Corti, located within the cochlea, houses the hair cells that convert (transduce) sound from vibrational energy into electrical impulses.
- The base of the cochlea, near the ossicles, is stiff and narrow and responds to high-frequency sounds.
- The apex of the cochlea, away from the ossicles, is flexible and broad and responds to lower-frequency sounds.

2. **To ensure that students understand how sound is represented at various points along the hearing pathway, write the terms "vibration," "pressure wave," and "electrical impulse" on the board. Ask students to use the terms to identify the form in which sound energy is represented at each of the eight points pictured.**

• pinna	vibration
• ear canal	vibration
• eardrum	vibration
• ossicles	vibration
• cochlea	pressure wave
• organ of Corti	pressure wave
• auditory nerve	electrical impulse
• brain	electrical impulse

3. **Distribute to each team 1 copy of Master 4.5, *Understanding Form and Function*. Instruct team members to work together to complete the handouts.**

These masters contain tasks related to the hearing pathway and the treatment of hearing loss. Students may find it helpful to refer to the Black Box sequence of the hearing pathway as they answer the questions. In Part 2, if students have difficulty describing how hearing would be affected by the different situations, use probing questions to elicit answers.

Sample answers to tasks on Master 4.5, *Understanding Form and Function,* follow:

Part 1
Now that you have properly identified the ear's transducer, write "yes" beside each phrase that correctly describes one of its characteristics. Write "no" beside each phrase that does not.

yes	responds to pressure waves in a liquid
no	vibrates in response to sound waves
yes	converts vibrational energy to electrical energy
no	increases the force of vibrations inside the ear
yes	generates nervous impulses
yes	is located in the cochlea

Part 2
Use your understanding of the hearing pathway to predict the effect each of the following would have on hearing. Use the choices below for your answers.

For each of the following situations, hearing would
- be unaffected
- gain loudness
- lose loudness
- lose information about pitch
- be lost completely

lose loudness	fingers blocking the ear canal
lose loudness	ruptured eardrum
be lost completely	cut the auditory nerve
lose loudness	link between the incus and stapes broken
lose loudness	buildup of ear wax
gain loudness	hand cupped behind the pinna
lose loudness and lose information about pitch	damage to hair cells in the cochlea
lose information about pitch or be lost completely (depending on location)	damage to part of the brain that processes electrical impulses arriving from the cochlea

Part 3

Identify which statements refer to a hearing aid, which refer to a cochlear implant, or both.

a. It works as a transducer, converting vibrational energy to electrical (electrochemical and electromechanical) energy. Cochlear implant

b. It helps people whose hearing loss is caused by problems in the outer or middle ear. Hearing aid

c. It increases the vibrational energy entering the ear. Hearing aid

d. It helps sounds bypass injured or absent hair cells. Cochlear implant

e. It helps people whose hearing loss is caused by problems in the inner ear. Cochlear implant

f. It can help profoundly deaf people communicate using sound. Cochlear implant

4. **Conclude the activity by reviewing students' answers to the tasks posed on Master 4.5. During the discussion, supplement the information students have already been given about the hearing pathway as appropriate.**

For example, students may be interested to learn that hair cells are unparalleled in their ability to detect the minute levels of vibrational energy in sound waves, and that they respond 1,000 times faster to stimulation than do visual-receptor cells.

NSES

Content Standard C: Disease is a breakdown in structure or function of an organism.

Lesson 4 Organizer: Web Version

Activity 1: *The Mysterious Black Box*

What the Teacher Does	Procedure Reference
Introduce the concept of transduction as it relates to human hearing and explain that they will complete a Web-based activity about the hearing pathway.	Page 95 Steps 1 and 2
Have students log onto Web site and click on "Lesson 4—A Black Box problem: How Do I Hear?" • Instruct students to follow the directions and place the images of the hearing pathway in their proper sequence.	Pages 95–96 Step 3 (WWW)

Activity 2: *Understanding Form and Function*

What the Teacher Does	Procedure Reference
Review the concept of transduction.	Pages 100–101 Step 1
Write the terms "vibration," "pressure wave," and "electrical impulse" on the board and have the class apply them to each part of the hearing pathway.	Page 101 Step 2
Have students complete the tasks on Master 4.5, *Understanding Form and Function.*	Pages 101–103 Step 3 (M)
Review and discuss student responses to the tasks posed on Master 4.5.	Page 103 Step 4

WWW = Involves using the Internet.   M = Involves copying a master.

Lesson 4 Organizer: Print Version

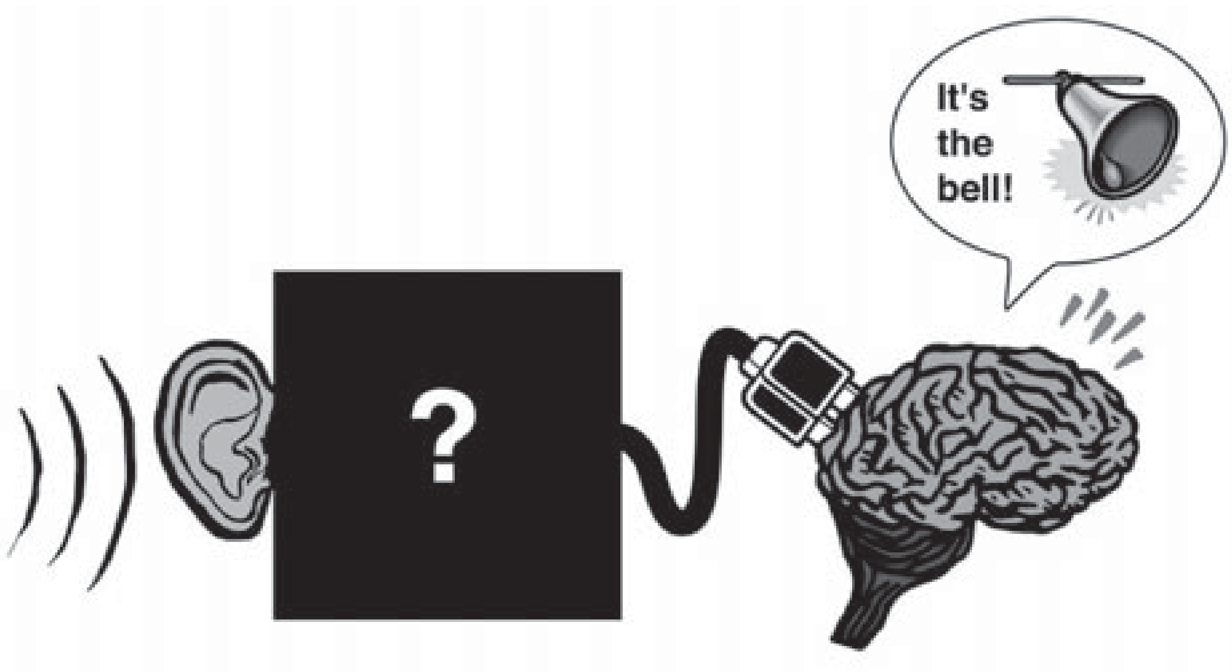
Activity 1: *The Mysterious Black Box*

What the Teacher Does	Procedure Reference
Turn on a lamp and ask how the light bulb produces light.	Page 96 Step 1
Write "transduction" on the board. • Explain that it refers to the process by which energy is converted from one form to another. • Ask students if they can name other examples of transducers.	Page 96 Step 2
Display a transparency of Master 4.1, *The Mysterious Black Box.* • Ask students to identify the question it raises.	Pages 97–98 Step 3 T
Display a transparency of Master 4.2, *A Few Questions.* • Ask students to answer the questions.	Page 98 Step 4 T
Explain that students will use Black Box Cards to construct a flow chart of the hearing pathway.	Page 98 Step 5
Distribute Black Box Cards (from Master 4.3) to each student team and instruct them to put the cards into the correct sequence.	Page 99 Step 6 M
Test each student team's card sequence. • Have each team explain their sequence. • If the sequence is correct ring the bell.	Page 99 Step 7

T = Involves using a transparency. M = Involves copying a master.

Write the names of the hearing-pathway components on the board. • Have students match the names with the images on their cards.	Pages 99–100 Step 8
Construct the hearing pathway on the board.	Page 100 Step 9
Activity 2: *Understanding Form and Function*	
What the Teacher Does	**Procedure Reference**
Review the concept of transduction.	Pages 100–101 Step 1
Write the terms "vibration," "pressure wave," and "electrical impulse" on the board and have the class apply them to each part of the hearing pathway.	Page 101 Step 2
Have students complete the tasks on Master 4.5, *Understanding Form and Function.*	Pages 101–103 Step 3 M
Review and discuss student responses to the tasks posed on Master 4.5.	Page 103 Step 4

The Mysterious Black Box



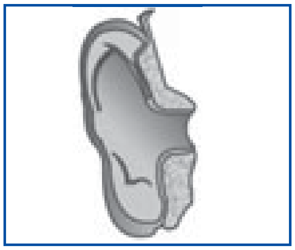
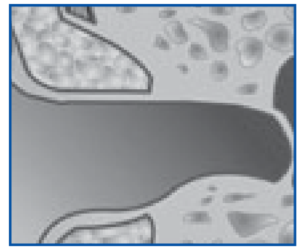
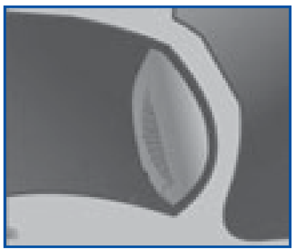
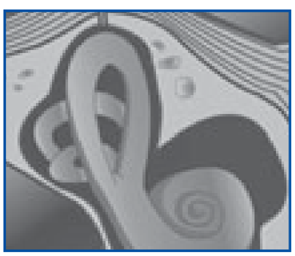
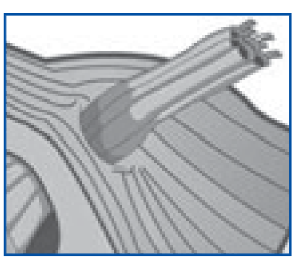
A Few Questions

1. What do the lines between the bell and the ear indicate?

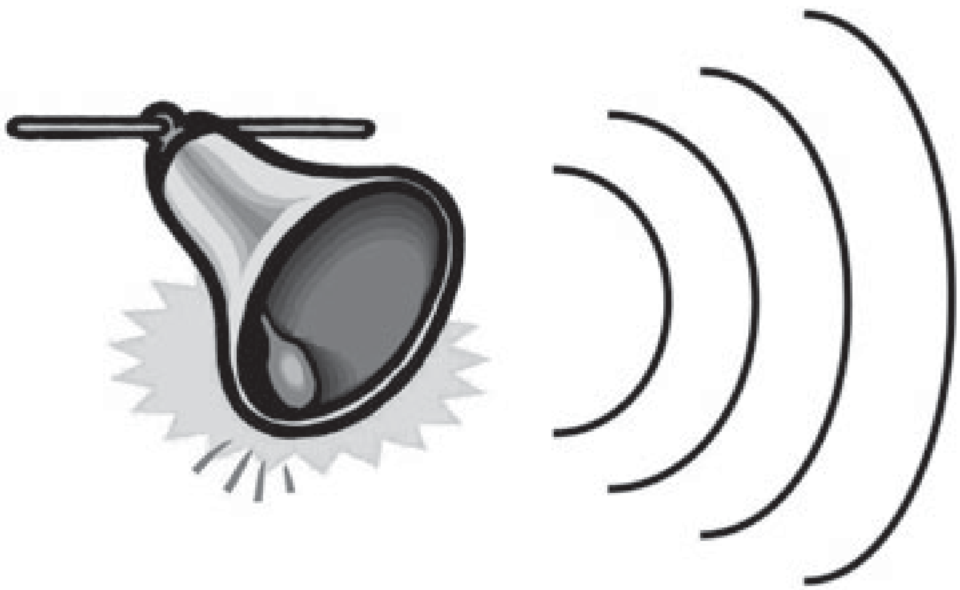
2. What is a sound wave?

3. Do vibrations reach all the way into the brain to let us hear sound?

Black Box Cards

 Focuses sound waves; helps in determining the direction from which sound waves arrive.	 Conducts sound waves to the eardrum.
 Vibrates in response to arriving sound waves.	 System of bones that works as a lever system to transmit vibrations deeper into the ear and to increase the vibrations' force.
 Liquid inside this structure transmits pressure waves in response to vibrations.	 Tiny hairlike extensions on the cells in this structure move in response to pressure waves in surrounding liquid, causing cells to make generate electrical impulses that vary according to the waves' amplitude and frequency.
 Carries electrical impulses to the brain.	 Interprets electrical impulses as sounds of varying pitch, loudness, and timing.

The Bell Card



Understanding Form and Function

Name(s)____ **Date**_____________________________

Part 1

Now that you have properly identified the ear's transducer, write "yes" beside each phrase that correctly describes one of its characteristics. Write "no" beside each phrase that does not.

_____ responds to pressure waves in a liquid

_____ vibrates in response to sound waves

_____ converts vibrational energy to electrical energy

_____ increases the force of vibrations inside the ear

_____ generates nervous impulses

_____ is located in the cochlea

Part 2

Use your understanding of the hearing pathway to predict the effect each of the following would have on hearing. Use the choices below for your answers.

For each of the following situations, hearing would

- be unaffected
- gain loudness
- lose loudness
- lose information about pitch
- be lost completely

________________ fingers blocking the ear canal

________________ ruptured eardrum

________________ cut the auditory nerve

________________ link between the incus and stapes broken

________________ buildup of ear wax

________________ hand cupped behind the pinna

________________ damage to hair cells in the cochlea

________________ damage to part of the brain that processes electrical impulses arriving from the cochlea

Understanding Form and Function

Part 3
People with hearing loss can sometimes be helped by technology. The two most common devices used by people with hearing loss are hearing aids and cochlear implants.

A hearing aid uses a small microphone to collect sound, which is then amplified as an electrical signal that is reconverted to sound using a small loudspeaker.

A cochlear implant uses a small microphone to collect sound, which is then electronically processed into a form that the brain can interpret. The information is then transmitted through a collection of electrodes.

Identify which statements refer to a hearing aid, which refer to a cochlear implant, or both.

a. It works as a transducer, converting vibrational energy to electrical (electrochemical and electromechanical) energy. __________

b. It helps people whose hearing loss is caused by problems in the outer or middle ear. __________

c. It increases the vibrational energy entering the ear. __________

d. It helps sounds bypass injured or absent hair cells. __________

e. It helps people whose hearing loss is caused by problems in the inner ear. __________

f. It can help profoundly deaf people communicate using sound. __________

Too Loud, Too Close, Too Long

Figure 5.1. Sounds can be too loud, too close, and too long.

At a Glance

Overview
Students begin with an analysis of loudness. They estimate the loudness of common environmental sounds, and then use their knowledge of hearing and loudness to evaluate the risk of noise-induced hearing loss for fictitious individuals. The module concludes with students evaluating their own sound exposure and providing "sound advice" to minimize their risk of noise-induced hearing loss.

Major Concepts
Noise-induced hearing loss leads to an inability to hear and understand speech and other sounds at normal loudness levels. Noise-induced hearing loss can be temporary or permanent. Noise-induced hearing loss can result from a one-time exposure to an extremely loud sound, repeated or long-term exposure to loud sound, or extended exposure to moderate sound. Noise-induced hearing loss can happen to people of all ages. The best way to protect one's hearing is to avoid loud noise whenever possible.

Objectives

After completing this lesson, students will

- be able to define noise-induced hearing loss as a diminished ability to hear and understand speech and other sounds at normal loudness levels resulting from exposure to loud noise;
- understand that noise-induced hearing loss can be temporary or permanent;
- recognize that people are vulnerable to noise-induced hearing loss if they are exposed to noise that is too loud, if they are too close to the source of noise, or if they are exposed to noise for an extended period of time;
- understand that noise-induced hearing loss can happen to people of all ages; and
- appreciate that noise-induced hearing loss is preventable and that the best way to protect one's hearing is to avoid loud noise whenever possible.

Teacher Background

Consult the following sections in Information about Hearing, Communication, and Understanding:

4 Hearing Loss (page 38)
4.1 Noise exposure (pages 38–39)
4.2 Aging (page 39)
4.3 Ototoxic drugs (page 39)
4.4 Disease and infections (pages 39–40)
4.5 Heredity (page 40)
4.6 Cochlear implants (pages 40–41)
5 Prevention of Noise-Induced Hearing Loss (pages 41–42)

In Advance

Web-Based Activities

Activity	Web Version?
1	No
2	No
3	No

Photocopies

Activity 1	Master 5.1, *Electron Micrographs of Hair Cells* (Make 1 copy per student.) Master 5.2, *Loud, Louder, and Loudest* (Make 1 copy per student.) Master 5.3, *Answer Key to Loud, Louder, and Loudest* (Make an overhead transparency.) Master 5.4, *Dangerous Sound Levels* (Make an overhead transparency.)
Activity 2	Master 5.5, *Some Everyday Sounds* (Make 1 copy per student.) Master 5.6, *Sound Diary Summary—Joe, the Guitarist* (Make 1 copy per team.) Master 5.7, *Sound Diary Summary—Maria, the Woodworker* (Make 1 copy per team.) Master 5.8, *Sound Diary Summary—Michael, the Land-scaper* (Make 1 copy per team.) Master 5.9, *Sound Diary Summary—George, the Firefighter* (Make 1 copy per team.) Master 5.10, *Hearing-Risk Evaluation Form* (Make 1 copy per student.) Master 5.11, *Ten Ways to Recognize Hearing Loss* (Optional: Make 1 copy per student.)
Activity 3	No photocopies needed.

Materials

Activity 1	no materials needed (except photocopies)
Activity 2	no materials needed (except photocopies)
Activity 3	no materials needed

Preparation

No preparations needed (except photocopying).

Procedure

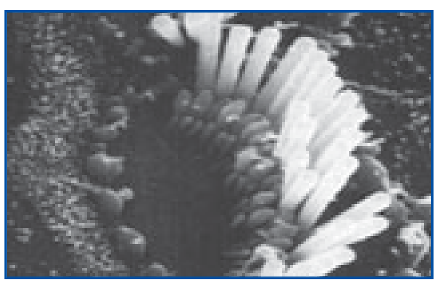
Teacher note
The sound levels at which hearing damage occurs (often reported by different sources as 80 dB or 85 dB) is not precise for every individual. We know that prolonged exposure (that is, over many years) to sounds over 85 dB, especially in work settings, does cause damage. Because some sources do cite exposures at 80 dB and lower, it is important for students to think about these numbers as a frame of reference for prevention awareness. They absolutely need to understand the permanent and irreversible damage caused by such things as exploding firecrackers, guns, and jackhammers.

Activity 1: *It's Too Loud!*

1. **Review with the class the components of the hearing pathway introduced in Lesson 4. Be sure that students recall the function of the hair cells in the organ of Corti.**

2. **Begin the activity by having students proceed to *http://science.education.nih.gov/supplements/hearing/student.* Students should then click on the button labeled "Lesson 5—Too Loud, Too Close, Too Long" and then on "watch video."**

3. **After students view the video of the hair cells, give each student a copy of Master 5.1, *Electron Micrographs of Hair Cells*. Ask students if they can tell which picture shows healthy hair cells and which shows damaged ones. Ask them to explain their reasoning.**



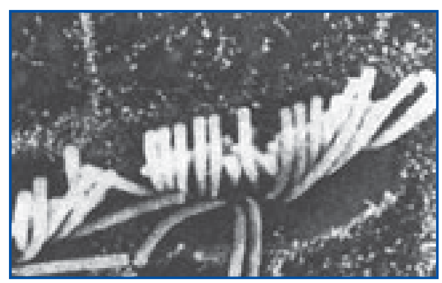


Figure 5.2. *Healthy hair cells (left) and damaged hair cells (right). Diameter of hair cells is approximately 10 µm (micrometers). (One micrometer is one-millionth of a meter.) Diameter of one stereocilium is approximately 250 nm (nanometers). (One nanometer is one-billionth of a meter.) For a video clip of the magnified version of healthy hair cells, go to this Web site:* http://science.education.nih.gov/supplements/hearing/student *and click on the button labeled "Lesson 5—Too Loud, Too Close, Too Long"*

Students should be able to recognize that the left-hand micrograph shows healthy hair cells. Healthy hair bundles (stereocilia) stand nearly straight up, while the micrograph featuring the unhealthy hair cells shows some damaged stereocilia lying down flat.

4. **Ask the class what might have caused the hair cells in the right-hand picture to become damaged.**

   Responses may include a disease (either genetic or infectious), an injury, or exposure to hazardous chemicals. If no one suggests loud noise as a possible cause, turn the discussion to that topic. Explain that the hair cells in the right-hand micrograph were damaged by exposure to loud noise.

5. **Ask the class to name some loud sounds**.

   Accept any reasonable answer. Possibilities include the sounds of airplane engines, power tools, rock concerts, car horns, and music played through stereo headphones.

6. **Ask students what is meant by a sound that is "too loud" and whether everyone's definition of "too loud" is the same.**

   Students likely will answer that a sound is too loud if it hurts or damages a person's ears or disturbs another person. Students should recognize that the phrase "too loud" is commonly used, and its definition varies greatly from person to person and situation to situation. To stimulate discussion, you may wish to invite several students to offer examples of situations in which their definition of "too loud" was very different from another person's definition.

7. **Ask students what might happen if a person is exposed to very loud sounds.**

   Sound that is too loud can permanently damage hearing, leading, for example, to difficulties in understanding speech and enjoying music. Scientists refer to such damage as noise-induced hearing loss.

8. **Explain that in this lesson, students will investigate the relationship between loudness and hearing loss.**

9. **Distribute 1 copy of Master 5.2, *Loud, Louder, and Loudest*, to each student. Direct students to follow the instructions on the worksheet to identify each sound as typically low- or high-pitched and also to rank the sounds in each list from softest to loudest.**

   Give students approximately five minutes to complete this task.

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Content Standard C: Living systems at all levels of organization demonstrate the complementary nature of structure and function.

10. **Display a transparency made from Master 5.3, *Answer Key to Loud, Louder, and Loudest*, and invite students to compare their rankings with those on the transparency. Invite students to share differences between their ranking and the ranking on the transparency. Discuss the possible reasons for these differences.**

    Answers will vary. For example, students may make different assumptions based on the distance from which the sound is heard. Students will also display variation in their interpretation of terms (for example, differences in what people call a "quiet" neighborhood).

11. **Make sure students notice the number that describes the difference in sound intensity between the loudest sound a healthy human ear can tolerate and the softest sound the human ear can hear. (The difference, 100 trillion times, appears in the footnote at the bottom of the answer key on Master 5.3.)**

    Students may be surprised to learn that the normal, undamaged human ear has such a wide range of hearing.

12. **Ask students to estimate where on the table some of the sounds to which they are commonly exposed might fall. For example, ask them where the following sounds might appear on the table: the school cafeteria during lunch, the sound in the halls between periods, the sound in the classroom during a test, and the sound going into their ears when they're listening to music using headphones.**

    As an option, you can task students with using an inexpensive sound meter to record actual sound levels in their environment. Sound meters can be purchased from some electronics stores for as little as $35. If you are going to use a decibel meter, remember to set it on the *A* setting. The A scale reduces the less harmful low-frequency sounds, emphasizing the higher-frequency sounds that are most harmful to hearing.

Figure 5.3. An inexpensive sound meter.

13. **Ask students to speculate whether low- or high-pitched sounds are more likely to produce noise-induced hearing loss.**

    The hearing pathway is more sensitive to higher-pitched frequencies. This means that high-pitched sounds can produce more damage at lower volumes than low-pitched sounds can. If necessary, remind students that in Lesson 3, *Do You Hear What I Hear?*, they demonstrated that higher-pitched sounds could be heard more easily at lower sound volumes.

14. **Ask students if there are factors other than loudness and pitch that contribute to noise-induced hearing loss. If necessary, prompt them to consider the length of time for which they are exposed to sound. On the board, write**
    - **Single exposure to a very loud sound**
    - **Repeated or long-term exposure to loud sound**
    - **Extended exposure to moderate sound levels**

15. **Ask students to offer examples of sounds and exposure lengths that might produce noise-induced hearing loss for each category listed on the board.**

    Students can refer to Master 5.3, *Answer Key to Loud, Louder, and Loudest*, to help them think of examples. Help students recognize that the noises that have the highest potential for noise-induced hearing loss are listed toward the top of Master 5.3. Ask students to distinguish situations in which even a single exposure would likely produce noise-induced hearing loss, situations in which repeated or long-term exposure might produce noise-induced hearing loss, and situations in which constant exposure may lead to noise-induced hearing loss.

16. **Display a transparency of Master 5.4, *Dangerous Sound Levels,* and point out the various decibel levels and exposure times that scientists consider to be hazardous. Ask students to describe the differences between their assessments and the assessments of the scientists.**

17. **Ask the class to think of ways to lower the risk for noise-induced hearing loss.**

    Students will suggest using some type of ear protection such as earplugs. They also may suggest reducing the noise level either by turning the volume down or moving farther away from the noise source.

NSES

Content Standard F: The potential for accidents and the existence of hazards imposes the need for injury prevention.

Activity 2: *Assessing Risk for Hearing Loss*

1. **Explain to the class that they will evaluate the risk for noise-induced hearing loss in fictitious individuals. Distribute 1 copy of Master 5.5, *Some Everyday Sounds*, to each student and explain that it lists loudness levels for some everyday sounds.**

2. **Organize students into teams of four. Provide each team with 1 copy of Masters 5.6, 5.7, 5.8, and 5.9, which contain sound diaries summarizing the sound exposure for different fictitious individuals. Instruct team members to individually pick a different person and analyze the sound diary for that individual.**

   Explain that:

   - Each team should use the information on Master 5.4, *Dangerous Sound Levels* (from the previous activity); Master 5.5, *Some Everyday Sounds*; and the information about their fictitious individuals to fill in the columns labeled "Estimated dB level" and "Suggestions for lowering risk of hearing loss."

   - Some of the activities that appear in the individual's sound diary are not specifically listed in Master 5.5, *Some Everyday Sounds*. Therefore, instruct students to make estimates about the loudness of unlisted sounds where necessary. They can use the column labeled "Comments" to indicate reasons for their choice of a particular dB level.

   - After students have finished their analysis, they can exchange their summaries, discuss their reasoning with each other, and modify the summaries as needed.

   - After the sound-diary summaries are completed, distribute copies of Master 5.10, *Hearing-Risk Evaluation Form*. Teams should place a checkmark next to the risk statement that they believe characterizes each of their fictitious individuals. Students should also justify their evaluations based on the information found in the sound diaries.

3. **After teams have completed their evaluations, convene the class and invite teams to discuss their work.**

   Although different teams may associate different dB levels with various activities, their evaluations should be similar. All four of the fictitious individuals are at risk for hearing loss for the following reasons:

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Content Standard F: Students should understand the risks associated with personal hazards.

Content Standard F: Important personal and social decisions are made based on the perception of benefits and risks.

Figure 5.4. Joe's guitar.

Joe, the guitarist: Joe is exposed to sound levels above 80 dB on a constant and prolonged basis. His exposure to loud sounds is primarily through his occupation as a musician. Using earplugs would eliminate his risk for noise-induced hearing loss. His long freeway commute and his frequent pit stops for food may also provide constant exposure to sounds in the higher-risk range. When listening to music or watching TV, Joe should set the sound volume to an appropriately low level.

Maria, the woodworker: Maria is exposed to sound levels above 80 dB on a constant and prolonged basis. Her exposure to loud noise is primarily through her occupational use of power tools. Using earplugs would eliminate her risk for noise-induced hearing loss. Also of concern is her use of a personal stereo for listening to music. She should ensure that the volume is kept at an appropriately low setting.

Figure 5.5. Maria's power saw.

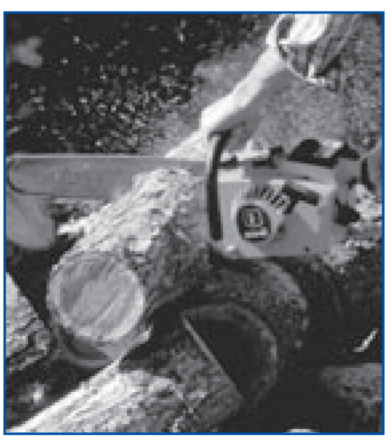


Figure 5.6. Michael's chain saw.

Michael, the landscaper: Michael also is exposed to sound levels above 80 dB on a constant and prolonged basis. His exposure to loud sounds is principally through his occupational use of lawn mowers and a chain saw. Using earplugs would eliminate his risk for noise-induced hearing loss. While at home, he should keep the TV sound volume at an appropriately low level. Students might remark about his exposure to loud noise from the occasional screaming of his two-year-old twins. Sometimes there are sounds that you just have to cope with.

George, the firefighter: George is exposed to sound levels above 80 dB on a constant and prolonged basis. His exposure to loud noise is primarily through his occupational use of a farm tractor and his contact with sirens and other loud noises in his role as a firefighter. Using earplugs would eliminate his risk for noise-induced hearing loss. His remodeling work involves the use of power tools. Earplugs should be used to eliminate exposure to hazardous sound from these sources as well. When listening to music or watching TV, the sound volume should be set at an appropriately low level.

Figure 5.7. George's tractor.

NSES

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

Activity 3: *Sound Advice*

1. **Close the lesson by asking students to consider the implications of what they have learned on their own lives. Ask them to identify sounds that they are exposed to that might be classified as "too loud."**

2. **Ask students to consider sounds they might be exposed to on weekends and during vacation periods. Are there any sounds that might be considered too loud or potentially hazardous?**

3. **To help students think about how to protect themselves, you may wish to draw their attention to the title of the lesson. Write the phrase *Too Loud, Too Close, Too Long* on the board. Ask the class to explain how it relates to noise-induced hearing loss.**

4. **As a means of wrapping up this module, ask each student to write a statement to include the following:**

   a. sounds they are exposed to that might put them at risk for noise-induced hearing loss and why they think those sounds put them at risk, and
   b. advice to themselves about what they can do to reduce their risk for hearing loss.

Possibilities include limiting the volume on radios, TVs, and personal music players; avoiding loud noises from tools, appliances, and traffic; increasing distance from the source of loud noises one can't avoid; wearing hearing protection when necessary; limiting exposure to loud sounds; and watching for and responding to warning signs that a sound is too loud.

5. **(Optional) Supply students with a copy of Master 5.11, *Ten Ways to Recognize Hearing Loss.***

Assessment:
Ask students to include information about parts of the hearing pathway that are susceptible to damage from noise-induced hearing loss. Also, ask students to describe how such hearing loss might impact their everyday lives.

Lesson 5 Organizer

Activity 1: *It's Too Loud*

What the Teacher Does	Procedure Reference
Review the parts of the hearing pathway.	Page 116 Step 1
Have students log onto Web site and click on "Lesson 5—Too Loud, Too Close, Too Long." • Students view video of hair cells.	Page 116 Step 2 WWW
Distribute Master 5.1, *Electron Micrographs of Hair Cells.* Ask students to identify which are healthy and which are damaged, and speculate about what caused the damage.	Pages 116–117 Steps 3 and 4 M
Discuss loud sounds. Ask the students, • Can they name some loud sounds? • What is "too loud"? • Is everyone's idea of "too loud" the same? • What happens when a person is exposed to sounds that are too loud?	Page 117 Steps 5–7
Investigate the relationship between loudness and hearing loss. • Have students identify sounds on Master 5.2, *Loud, Louder, and Loudest,* as low- or high-pitched. • Rank the sounds from softest to loudest.	Page 117 Steps 8 and 9 M
Have the class compare and contrast their sound rankings with those on Master 5.3, *Answer Key to Loud, Louder, and Loudest.*	Page 118 Step 10 T

WWW = Involves using the Internet.

M = Involves copying a master.

T = Involves using a transparency.

Make sure that students notice the difference in sound intensity between the softest and loudest sounds a human can hear without damage.	Page 118 Step 11
Ask the class to estimate the loudness of some common sounds.	Page 118 Step 12
Introduce the concept of noise-induced hearing loss. • Ask the class whether low- or high-pitched sounds are more likely to produce noise-induced hearing loss. • Have students consider how the duration of noise exposure is associated with noise-induced hearing loss. • Ask for examples of each type of noise exposure.	Pages 118–119 Steps 13–15
Have the class compare their responses with those from scientists using Master 5.4, *Dangerous Sound Levels.*	Page 119 Step 16 T
Ask the class to suggest ways to lower risk for noise-induced hearing loss.	Page 119 Step 17

Activity 2: *Assessing Risk for Hearing Loss*

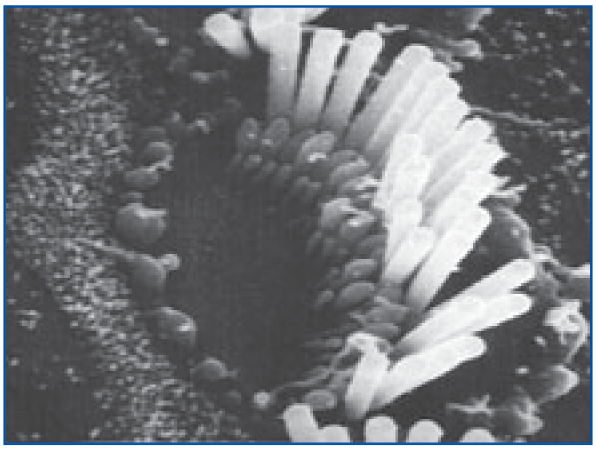
What the Teacher Does	Procedure Reference
Organize the class into teams of four students. • Distribute Master 5.5, *Some Everyday Sounds*, to each student. • Provide teams with sound diaries from different fictitious individuals (Masters 5.6, 5.7, 5.8, and 5.9). • Have teams analyze sound-level exposures for their individual and identify sounds that put them at risk for noise-induced hearing loss using Master 5.10, *Hearing-Risk Evaluation Form.*	Pages 119–120 Steps 1 and 2 M

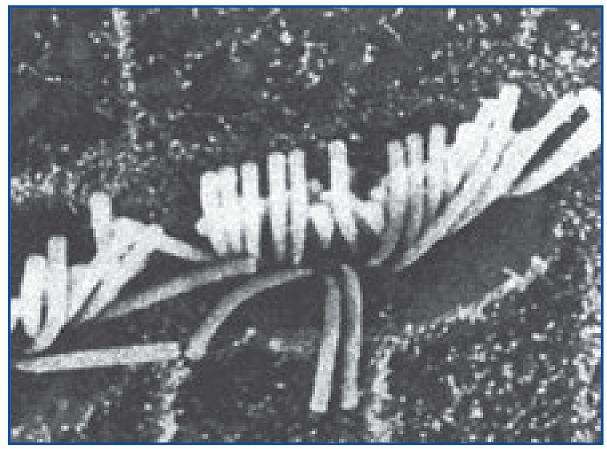
Reconvene class and have teams report their conclusions.	Page 120 Step 3

Activity 3: *Sound Advice*

What the Teacher Does	Procedure Reference
Ask the class to list some sounds that they are exposed to that might be considered potentially hazardous.	Page 122 Steps 1 and 2
Ask the class to relate noise-induced hearing loss to the phrase “too loud, too close, too long.”	Page 122 Step 3
Ask students to write statements • that identify sounds they are exposed to that might put them at risk for noise-induced hearing loss. • that list ways they can reduce their risk for noise-induced hearing loss.	Pages 122–123 Step 4
(Optional) Discuss ways to recognize hearing loss using Master 5.11, *Ten Ways to Recognize Hearing Loss.*	Page 123 Step 5

Electron Micrographs of Hair Cells





Healthy hair cells (left) and damaged hair cells (right). Diameter of hair cells is approximately 10 µm (micrometers). (One micrometer is one-millionth of a meter.) Diameter of one stereocilium is approximately 250 nm (nanometers). (One nanometer is one-billionth of a meter.) For a video clip of the magnified version of healthy hair cells, go to this Web site: *http://science.education.nih.gov/supplements/hearing/student* and click on the button labeled “Lesson 5—Too Loud, Too Close, Too Long.”

Loud, Louder, and Loudest

Name____ Date____________________________

Approximately how loud are the sounds listed below? Write each sound where you think it belongs on the page. Two sounds are provided as examples.

jet plane during takeoff, lawn mower, waterfall (at the base), large 18-wheel truck, quiet neighborhood, train, third row at an amplified rock concert, car horn, your living room at home, low whisper, electric vacuum cleaner, fire siren, traffic at a busy intersection

Sound Intensity (dB)	**Type of Sound**
140 (very painful)	
130	
120 (painful)	
110	chain saw
100	
90 (extremely loud)	
80	
70 (very loud)	
60	
50 (moderate)	
40	
30	
	low whisper
20	
10	
0 (softest sound humans can hear)	

Answer Key to Loud, Louder, and Loudest

Sound Intensity (dB)	Type of Sound
140 (very painful*)	jet plane during takeoff, fire siren
130	
	third row at an amplified rock concert
120 (painful)	
110	chain saw
100	
90 (extremely loud)	traffic at a busy intersection, waterfall (at its base)
	train, lawn mower
80	18-wheel truck
70 (very loud)	electric vacuum cleaner
60	living room at home
50 (moderate)	car horn
40	quiet neighborhood
30	
	low whisper
20	
10	
0 (softest sound humans can hear)	

*140 decibels (dB) is 100,000,000,000,000 (or 100 trillion) times more intense than 0 dB.

Dangerous Sound Levels

dB	Type of Sound
140	Threshold of pain
130	Threshold of pain
120	Threshold of pain
110	Regular exposure of more than 1 minute risks permanent hearing loss.
100	No more than 15 minutes of exposure is recommended.
90	Prolonged exposure to any noise above 90 dB can cause gradual hearing loss. Level at which hearing damage after 8 hours exposure begins: 85 dB.
80	Constant exposure may cause damage.
70	
60	Comfortable: under 60 dB
50	
40	
30	
20	
10	
0	

Some Everyday Sounds

Sound	dB level
hearing threshold	0
breathing	10
rustling leaves	20
whispering	25
library	30
refrigerator	45
average home	50
normal conversation	60
clothes dryer	60
washing machine	65
car	70
vacuum cleaner	70
busy traffic	75
noisy restaurant	80
outboard motor	80
inside car in city traffic	85
electric shaver	85
screaming child	90
passing motorcycle	90
convertible ride on highway	95

Sound	dB level
table saw	95
hand drill	100
tractor	100
diesel truck	100
circular saw	100
jackhammer	100
gas-powered mower	105
helicopter	105
chain saw	110
amplified rock concert	90–130
shout into ear	120
car horn	120
siren	120
threshold of pain	120–140
gunshot	140
jet engine	140
12-gauge shotgun	165
rocket launching	180

Sound Diary Summary—Joe, the Guitarist

Name(s)____ Date_____________________________

Joe is 20 years old, and he has been the lead guitarist in a rock band for four years. The group is doing well; they rehearse a lot and play at local clubs on weekends. Joe commutes on busy freeways quite a bit. He is single and likes his quiet life at home but still enjoys the fast pace of the big city when he's there.

Use *Some Everyday Sounds* and the table below to analyze Joe's exposure to sound. Enter an estimated dB level for each sound listed in the first column. Where appropriate, indicate how the risk of hearing loss might be lowered. In the right column, enter any information that explains your dB estimates. For example, your choice of a dB level for eating lunch assumes either a quiet or a noisy environment.

Source of sound (major activities)	Time per week (minutes)	Estimated dB level	Suggestions for lowering risk of hearing loss	Comments
morning activities	210			
breakfast at home	140			
freeway commute to/from work	300			
morning rehearsal	900			
lunch at restaurant	420			
lunch at home	120			
afternoon rehearsal	1020			
dinner at restaurant	600			
dinner at home	120			
gigs at local night spots	480			
listening to music	1300			
watching TV	480			
reading	120			

Sound Diary Summary—Maria, the Woodworker

Name(s)____ Date____________________________

Maria is 19 years old and single. Her father, a master craftsman, introduced her to tools and woodworking when she was in elementary school. She now works for a small business, designing and constructing cabinets and other fine wood products for the home. She lives in a small town and has a very short drive to work.

Use *Some Everyday Sounds* and the table below to analyze Maria's exposure to sound. Enter an estimated dB level for each sound listed in the first column. Where appropriate, indicate how the risk of hearing loss might be lowered. In the right column, enter any information that explains your dB estimates. For example, your choice of a dB level for eating lunch assumes either a quiet or a noisy environment.

Source of sound (major activities)	Time per week (minutes)	Estimated dB level	Suggestions for lowering risk of hearing loss	Comments
morning activities	315			
breakfast at home	150			
commute to/from work	50			
working in office designing projects	900			
using power tools to make cabinets	1500			
lunch in office	300			
lunch at home	120			
dinner at home	420			
college night classes	600			
listening to rock music on Walkman	900			
watching TV	600			
reading	850			

Sound Diary Summary–Michael, the Landscaper

Name(s)______________________________________ Date___________________________

Michael is 26 years old, a graduate of a local college, and the owner of his own landscaping and lawn-care service. He is married and the father of two-year-old twins. He drives a large pickup truck, which pulls a trailer containing his mowers, chain saw, shovels, and other equipment for work. Business is good, and he has many clients around town.

Use *Some Everyday Sounds* and the table below to analyze Michael's exposure to sound. Enter an estimated dB level for each sound listed in the first column. Where appropriate, indicate how the risk of hearing loss might be lowered. In the right column, enter any information that explains your dB estimates. For example, your choice of a dB level for eating lunch assumes either a quiet or a noisy environment.

Source of sound (major activities)	**Time per week (minutes)**	**Estimated dB level**	**Suggestions for lowering risk of hearing loss**	**Comments**
morning activities, caring for twins	320			
breakfast at home	120			
commute to/from jobs	700			
mowing lawns	1500			
tree trimming	300			
dinner at home	420			
watching TV	1320			
helping with twins at night	800			

Sound Diary Summary—George, the Firefighter

Name(s)__________________________________ Date__________________________

George is 23 years old and married. After graduating from college, he joined the local fire department. When he is not on duty, he works on his farm. He is also remodeling the basement of their home. George's wife is a violinist. Music is important to both of them.

Use *Some Everyday Sounds* and the table below to analyze George's exposure to sound. Enter an estimated dB level for each sound listed in the first column. Where appropriate, indicate how the risk of hearing loss might be lowered. In the right column, enter any information that explains your dB estimates. For example, your choice of a dB level for eating lunch assumes either a quiet or a noisy environment.

Source of sound (major activities)	Time per week (minutes)	Estimated dB level	Suggestions for lowering risk of hearing loss	Comments
morning activities	180			
breakfast at home	100			
breakfast at fire station	120			
tending animals	840			
plowing fields	1020			
lunch at home	150			
lunch at fire station	90			
time on firetruck	240			
dinner at home	600			
remodeling work	960			
listening to music	1000			
watching TV	500			
reading	500			

Hearing-Risk Evaluation Form

Name____ **Date**___________________________

Name of fictitious individual:_________________________________

My evaluation is that this individual is (check one)

_____ not at risk for noise-induced hearing loss.

_____ at risk for noise-induced hearing loss.

Justify your evaluation based on all of the information in the individual's sound diary. If you suggested a way to decrease the risk of hearing loss, indicate specifically how this action will help.

Ten Ways to Recognize Hearing Loss

Name____ **Date**____________________________

The following questions will help you determine whether you need to have your hearing evaluated by a medical professional.

1. Do you have a problem hearing over the telephone?
   Yes No
2. Do you have trouble following the conversation when two or more people are talking at the same time?
   Yes No
3. Do people complain that you turn the TV volume up too high?
   Yes No
4. Do you have to strain to understand conversation?
   Yes No
5. Do you have trouble hearing in a noisy background?
   Yes No
6. Do you find yourself asking people to repeat themselves?
   Yes No
7. Do many people you talk to seem to mumble (or not speak clearly)?
   Yes No
8. Do you often misunderstand what others are saying and respond inappropriately?
   Yes No
9. Do you have trouble understanding the speech of women and children?
   Yes No
10. Do people get annoyed because you misunderstand what they say?
    Yes No

If you answered “yes” to three or more of these questions, you may want to see an otolaryngologist (an ear, nose, and throat doctor) or an audiologist for a hearing evaluation.

The material on this page is for general information only and is not intended for diagnostic purposes. A doctor or other healthcare professional must be consulted for diagnostic information and advice regarding treatment.

Additional Web Resources for Teachers

National Institute on Deafness and Other Communication Disorders
http://www.nidcd.nih.gov
An information resource for researchers as well as the general public. It features:

American Sign Language: Quick Facts
http://www.nidcd.nih.gov/health/hearing/asl.asp

Cochlear Implants
http://www.nidcd.nih.gov/health/hearing/coch.asp

Gen "Y" Asks Why Not?
http://www.nidcd.nih.gov/health/education/news/patterson.asp

Has Your Baby's Hearing Been Screened?
http://www.nidcd.nih.gov/health/hearing/screened.asp

How Loud Is Too Loud? (bookmark)
English *http://www.nidcd.nih.gov/health/hearing/ruler.asp*
Spanish *http://www.nidcd.nih.gov/health/Spanish/ruler_sp.asp*

How Loud Is Too Loud? (interactive sound ruler)
http://www.nidcd.nih.gov/health/education/decibel/decibel.asp

How Loud Is Too Loud? (video clip)
http://www.nidcd.nih.gov/health/education/video/loud_vid.asp

Silence Isn't Always Golden
English *http://www.nidcd.nih.gov/health/hearing/silence.asp*
Spanish *http://www.nidcd.nih.gov/health/Spanish/silence_span.asp*
Vietnamese *http://www.nidcd.nih.gov/health/hearing/VietSilence.pdf*

Speech and Language Developmental Milestones
http://www.nidcd.nih.gov/health/voice/speechandlanguage.asp

Swat'z New? A Fly That's Setting the Hearing World Abuzz
http://www.nidcd.nih.gov/health/education/news/swatz.asp

Ten Ways to Recognize Hearing Loss (bookmark quiz)
English *http://www.nidcd.nih.gov/health/hearing/10ways.asp*
Spanish *http://www.nidcd.nih.gov/health/Spanish/10w_sp.asp*

Travel Inside the Ear (video clip)
http://www.nidcd.nih.gov/health/education/video/travel_vid.asp

What Are the Communication Considerations for Parents of Deaf and Hard-of-Hearing Children?
http://www.nidcd.nih.gov/health/hearing/commopt.asp

What Is Sound? (video clip)
http://www.nidcd.nih.gov/health/education/video/sound_vid.asp

Eisenhower National Clearinghouse
http://www.enc.org/

ENC's mission is to identify effective curriculum resources, create high-quality professional development materials, and disseminate useful information and products to improve K–12 mathematics and science teaching and learning.

- Science links:
http://www.enc.org/weblinks/science/
- Sound links:
http://www.enc.org/weblinks/science/0,1578,1%2DSound,00.shtm

League for the Hard of Hearing Noise Center
http://www.lhh.org/noise/index.htm

Contains fact sheets and other information resources on noise, from the League for the Hard of Hearing, a nonprofit organization whose mission is to improve the quality of life for infants, children, and adults with all degrees of hearing loss.

The Soundry
http://library.thinkquest.org/19537/

An interactive, educational site about sound. It was developed by students as part of a ThinkQuest science competition. (ThinkQuest Inc. is a nonprofit organization that offers programs designed to advance education through the use of technology.) You can click on the following sections:

- How We Perceive Sound: The Ear
- The Timeline
- The Physics of Sound
- The Interactive Sound Lab
- Applications of Sound

WISE EARS! National Campaign Web Site
http://www.nidcd.nih.gov/health/wise/index.asp

A national campaign sponsored by the National Institute on Deafness and Other Communication Disorders and the National Institute of Occupational Safety and Health. It includes links to about 90 member organizations and information about the prevention of noise-induced hearing loss.

Have WISE EARS! for Life
English *http://www.nidcd.nih.gov/health/hearing/wiseears.asp*
Spanish *http://www.nidcd.nih.gov/health/Spanish/wiseears_span.asp*

Appendix I

More About the National Institutes of Health

Begun as a one-room Laboratory of Hygiene in 1887, the National Institutes of Health today is one of the world's foremost medical research centers and the federal focal point for medical research in the United States.

What Is the NIH Mission and Organization?

The NIH mission is to uncover new knowledge that will lead to better health for everyone. NIH works toward that mission by

- conducting research in its own laboratories;
- supporting the research of nonfederal scientists in universities, medical schools, hospitals, and research institutions throughout the country and abroad;
- helping in the training of research investigators; and
- fostering communication of medical information.

NIH is one of eight health agencies of the Public Health Service, which, in turn, is part of the U.S. Department of Health and Human Services. NIH's institutes and centers encompass 75 buildings on more than 300 acres in Bethesda, Md. The NIH budget has frown from about $300 in 1887 to more than $23.5 billion in 2002.

What Is the Goal of NIH Research?

Simply described, the goal of NIH research is to acquire new knowledge to help prevent, detect, diagnose, and treat disease and disability, from the rarest genetic disorder to the common cold.

How Does NIH Help Scientists Reach This Goal?

Approximately 82 percent of the investment is made through grants and contracts supporting research and training in more than 2,000 research institutions throughout the United States and abroad. In fact, NIH grantees are located in every state in the country. These grants and contracts make up the **NIH Extramural Research Program**.

Approximately 10 percent of the budget goes to NIH's **Intramural Research Programs**, the more than 2,000 projects conducted mainly in its own laboratories.

The Intramural Research Programs are central to the NIH scientific effort. First-rate intramural scientists collaborate with one another regardless of institute affiliation or scientific discipline and have the intellectual freedom to pursue their research leads in NIH's own laboratories. These explorations range from basic biology, to behavioral research, to studies on treatment of major diseases. NIH scientists conduct their research in laboratories located on the NIH campus in Bethesda and in several field units across the country and abroad.

NIH Research Grants

Final decisions about funding extramural research are made at NIH headquarters. But long before this happens, the process begins with an idea that an individual scientist describes in a written application for a research grant.

The project might be small, or it might involve millions of dollars. The project might become useful immediately as a diagnostic test or new treatment, or it might involve studies of basic biological processes whose practical value may not be apparent for many years.

Peer Review

Each research grant application undergoes a peer-review process.

A panel of scientific experts, primarily from outside the government, who are active and productive researchers in the biomedical sciences, first evaluates the scientific merit of the application. Then, a national advisory council or board, composed of eminent scientists as well as public members who are interested in health issues or the biomedical sciences, determines the project's overall merit and priority in advancing the research agenda of the particular NIH funding institute.

Altogether, about 38,500 research and training applications are reviewed annually through the NIH peer-review system. At any given time, NIH supports 35,000 grants in universities, medical schools, and other research and research training institutions both nationally and internationally.

Who Are the Scientists NIH Supports?

Scientific progress depends mainly on the scientist. About 50,000 principal investigators—working in every state and in several foreign countries, from every specialty in medicine, every medical discipline, and at every major university and medical school—receive NIH extramural funding to explore unknown areas of medical science.

Supporting and conducting NIH's extramural and intramural programs are about 15,600 employees, more than 4,000 of whom hold professional or research doctorate degrees. The NIH staff includes intramural scientists, physicians, dentists, veterinarians, nurses, and laboratory, administrative, and support personnel, plus an ever-changing array of research scientists in training.

The NIH Nobelists

The roster of those who have conducted NIH research or who have received NIH support over the years includes the world's most illustrious scientists and physicians. Among them are 97 scientists who have won Nobel Prizes for achievements as diverse as deciphering the genetic code and identifying the causes of hepatitis.

Five Nobelists made their prize-winning discoveries in NIH laboratories. You can learn more about Nobelists who have received NIH support at *http://www.nih.gov/about/almanac/nobel/index.htm*.

What Impact Has NIH Had on the Health of the Nation?

NIH research has played a major role in making possible the following achievements of the last few decades:

- Mortality from **heart disease**, the number one killer in the United States, dropped by 36 percent between 1977 and 1999.
- Death rates from **stroke** decreased by 50 percent during the same period.
- Improved treatments and detection methods increased the relative five-year survival rate for people with **cancer** to 60 percent.
- Paralysis from **spinal cord injury** is significantly reduced by rapid treatment with high doses of a steroid. Treatment given within the first eight hours after injury increases the likelihood of recovery in severely injured patients who have lost sensation or mobility below the point of injury.
- Long-term treatment with anticlotting medicines cuts **stroke** risk by 80 percent from a common heart condition known as atrial fibrillation.
- In **schizophrenia**, where patients suffer frightening delusions and hallucinations, new medications can reduce or eliminate these symptoms in 80 percent of patients.
- Chances for survival increased for infants with **respiratory distress syndrome**, an immaturity of the lungs, due to development of a substance to prevent the lungs from collapsing. In general, life expectancy for a baby born today is almost three decades longer than one born at the beginning of the century.
- With effective medications and psychotherapy, the 19 million Americans who suffer from **depression** can now look forward to a better, more productive future.
- Vaccines protect against **infectious diseases** that once killed and disabled millions of children and adults.
- Dental sealants have proved 100 percent effective in protecting the chewing surfaces of chil-

dren's molars and premolars, where most **cavities** occur.

- In 1990, NIH researchers performed the first trial of **gene therapy** in humans. Scientists are increasingly able to locate, identify, and describe the functions of many of the genes in the human genome. The ultimate goal is to develop screening tools and gene therapies for cancer and many other diseases.

NIH Research in the 21st Century

NIH has enabled scientists to learn much since its humble beginnings. But many discoveries remain to be made:

- Better ways to prevent and treat cancer, heart disease, stroke, blindness, arthritis, diabetes, kidney diseases, Alzheimer's disease, communication disorders, mental illness, drug abuse and alcoholism, and AIDS, and other unconquered diseases.
- Ways to continue improving the health of infants and children, women, and minorities.
- Better ways to understand the aging process and behavior and lifestyle practices that affect health.

These are some of the areas where NIH's investment in health research promises to yield the greatest good for the greatest number of people.

For more about NIH, visit its Web site at *http://www.nih.gov.*

Appendix II

More about the NIDCD and Its Research

In 1988, Congress established the National Institute on Deafness and Other Communication Disorders as a separate Institute within the National Institutes of Health (NIH). Commonly referred to as the NIDCD, this Institute supports and conducts research and research training on normal mechanisms as well as diseases and disorders of hearing, balance, smell, taste, voice, speech, and language. These processes of sensing and interpreting are fundamental to the way individuals perceive the world around them and to their ability to communicate effectively with others.

In the past few years, NIDCD-supported scientists have made remarkable progress in research on human communication and its disorders. This progress has been further accelerated by research supported by other institutes at NIH and is now providing the foundation for current and future research to achieve an important goal: to help individuals with communication and sensory-system disorders.

The NIDCD has developed a strategic plan to draw attention to extraordinary research opportunities and compelling needs in the area of communication and sensory disorders. While this plan assists the NIDCD in focusing on specific areas of research, it is not intended to be an all-encompassing master plan for funding. The NIDCD's first priority continues to be the funding of high-quality research conceived and initiated by members of the research community that will help achieve the goals and objectives of the NIDCD.

What Are Some of the Problems the NIDCD Addresses?

In this information age, communication and technology skills will be central to a successful life for all Americans. The labor force of the 21st century will require intense use of these skills. However, for the one in six Americans who has communication disabilities, as well as their families who support them, each day can be a challenge. The simple acts of speaking, listening, and making wants and needs understood are often impossible. The days are often very challenging

- for the individual who has dizziness (vertigo);
- for people who find themselves suddenly unable to hear;
- for the person who cannot speak without stuttering, or who is unable to express ideas clearly after a stroke;
- for the adult who cannot use his or her voice to talk with a friend on the phone due to throat cancer;
- for the child with autism or the young deaf child who struggles with language and speech;
- for the individual whose ringing in the ear (tinnitus) is overwhelming;
- for an older person with a loss of balance that results in falls and fractured bones; and
- for an older person whose loss of hearing results in isolation and depression, or whose diminished sense of taste or smell affects nutrition and poses a danger.

Communication disorders have a major impact on education, employment, and the well being of Americans.

A Few Vital Statistics

Birth and Early Childhood

- More than 12,000 babies are born each year with a significant hearing loss, which can affect speech and language development.
- Two-thirds of children with acquired deafness also have some loss of balance.
- About 8 percent of American school-age children have problems developing and using language. These language difficulties underlie not only speaking problems but also the ability to read and write.
- Middle ear infection (otitis media) is the most frequently cited reason that a sick child visits a physician. In the United States, the estimated cost of otitis media each year is $5 billion in medical bills and lost wages. Children with otitis media suffer hearing loss during infection and often for an extended period of time after treatment is initiated.
- An estimated 2 million Americans stutter. Ten percent of children entering the first grade have moderate to severe speech disorders, including missing and substituted speech sounds and stuttering.

Adulthood

- Nearly 1 million American adults have a language disorder due to stroke or other brain injury.
- An estimated 2 million adults with progressive dementia (for example, Alzheimer's) experience significant language impairment.
- Tens of thousands of Americans each year develop cancer of the head and neck. Conventional cancer treatment usually damages organs critical for human speech and swallowing.
- Balance disorders may contribute to as many as half of all falls experienced by older people and cost the nation more than $8 billion per year in patient care. For individuals over age 75, balance disorders are the single most common symptom presented to primary-care physicians.
- More than 2 million adults have disorders of taste and smell. These problems are more prevalent in older people and affect a person's everyday life. For example, a substantial fraction of older adults loses the ability to detect the foul-smelling agent that is added to natural gas to warn of a potential leak.

What Progress Has Been Made?

What We Know

Past research has produced many significant discoveries and technologies that improve our ability to identify and treat people with communication problems. Because of research advances,

- Vaccines now prevent many illnesses from occurring, such as measles, mumps, meningitis, and rubella, which were once major causes of hearing loss.
- Much more is known about inherited (genetic) forms of hearing loss.
- Much more is known about how exposure to noise and toxins can damage hearing.

People with communication problems now have access to a wealth of new tools to improve communication, including cochlear (inner ear) implants, better hearing aids, electronic larynxes (voice boxes), and computerized speech devices.

- We can now identify newborn babies with hearing loss and toddlers with language problems at a much earlier age than in the past.

What We Don't Know

But research findings also teach us how much more there is to know. For example, we need to learn

- how to best help newborn children with hearing loss;
- which new devices or treatments are most beneficial for certain individuals and why a treatment works well for some people but not for others; and
- how new tools for diagnosis, such as brain-imaging methods, can also help doctors choose the best treatment for people with communication problems of varying causes.

To achieve the greatest benefit from finite research dollars, the NIDCD considers the effects that communication disorders have on the American people as well as areas that offer the greatest opportunity for significant progress at this time. After weighing these factors with scientists and representatives of the public, the NIDCD has identified a number of future research opportunities.

Future Research Opportunities

Why All This Interest in Research on Genes?

Doctors and scientists have long known that well-defined disorders of hearing and other aspects of human communication (language, speech, voice, etc.) often run in families. Changes called mutations in one or a few genes can have a dramatic effect on very complex functions, including hearing, speech, and language. Genes contain all the information that tells a cell how to make proteins. These proteins are the building blocks that determine the structure and function of all living cells, which in turn form the tissues, organs, and organ systems within the human body. Humans have 30,000 to 35,000 different genes. (This recent finding was somewhat surprising for researchers; previous predictions had ranged from 80,000 to 150,000 genes.) As scientists and physicians define the structure of the human genome, the identification of genes involved in human communication and communication disorders becomes more straightforward. Finally, learning about the nature of proteins made from these genes allows us to understand more about new and unsuspected cellular processes that are essential for effective communication. Once understood, these proteins may someday be targets for new treatment strategies. The willingness and generosity of families with hereditary communication disorders who agree to participate in studies with clinicians and scientists are what makes this research on gene discovery possible.

Understanding Leads to Education and Prevention

Changes in genes contribute to many communication disorders, either directly, by causing a critical group of cells to malfunction, or indirectly, by increasing sensitivity to damage caused by environmental factors such as noise, drugs and medications, or infections. Research aimed at understanding the identity and function of these genes may one day allow us to diagnose and classify patients with communication disorders based on specific genetic changes, in addition to recognizable symptoms. This knowledge could be directly applied to a clinical setting. For example, children diagnosed at birth with a mild hearing loss, who have a gene mutation that will cause progressive hearing loss and deafness by their teens, might be given additional educational help early in life so they may function better in the future. Such children and their parents might also be instructed to avoid noisy settings (rock concerts, loud radios, etc.), certain occupations, or certain medications that could cause the hearing loss to progress more rapidly.

Scientists and Physicians Can Find the Genes

To use genetics to prevent, diagnose, and treat communication disorders, we must first learn which genes are essential for the communication senses to function normally. Researchers can pinpoint which genes are critical to hearing by studying mice that are deaf due to mutations in certain genes since these same genes often affect hearing in humans. In mice, scientists can determine the function of a single gene by systematically altering the gene and observing any changes that occur. Much more can be learned about human hearing by applying the powerful tools of genetics to mice.

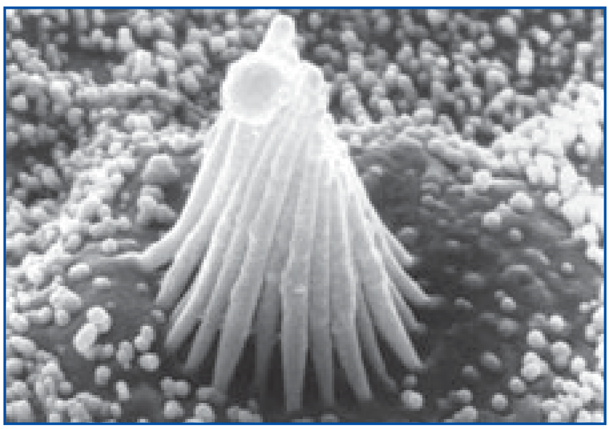
Many communication disorders are complex, with multiple components and causes. Some disorders are caused by complex genetic traits in which multiple genes are involved. Others are directly associated with a single underlying problem that has multiple effects. One gene can affect how other genes function, and small differences in several genes can cumulatively affect one's susceptibility to a disorder. Thus, it is necessary to understand the complex interactions of these genetic factors. Such knowledge could lead to the development of effective prevention and treatment strategies.

Nongenetic Factors

Not all communication disorders have a genetic basis. For example, hearing loss can be caused by infections, noise damage, or certain medications.

Infants who experience hearing loss can have difficulty learning to speak or understanding language later in life, if appropriate education and training are not provided. Impaired language skills affect all aspects of our ability to function in today's communication-driven society. Language impairment also can be caused by brain-injury or brain-developmental problems, in addition to childhood hearing impairment. Diseases of the larynx (voice box) can be caused by infections or by the presence of a tumor. More research is needed to identify additional nongenetic causes of communication disorders.

Increasing Potential for Recovery: How the Body Creates New Cells



Electron micrograph of a healthy hair cell.

Hair Cells in the Inner Ear

Most parts of the body that are damaged due to illness or injury have the ability to heal by regenerating healthy cells to replace those that have been damaged or lost. Until the recent past, the highly specialized hair cells of the inner ear, which are critical to hearing and balance, were considered irreplaceable if injured or destroyed. Recent discoveries in birds, however, confirm that specialized inner ear hair cells that have been destroyed by very loud noises can be replaced by regeneration of healthy hair cells. This research has inspired hope that damaged inner ear hair cells in humans, one of the major underlying causes of hearing loss, could be repaired or replaced. Future research is needed to explore whether the same processes that produce inner ear hair cells during development of the human embryo could be reactivated to achieve hair-cell regeneration in older individuals.

Sensory and Nerve Cells in the Nose

In contrast to the hair cells of the inner ear and many other sensory cells and neurons, the sensory nerve cells of the human olfactory system, our sense of smell, shows a remarkable ability to regenerate. The ability of these newly restored cells to make appropriate connections to brain regions that respond to specific odors needs to be intensively studied. Research identifying what factors make this possible could lead to the design of intervention strategies promoting the regeneration of nerve cells in other parts of the nervous system.

Recovering Speech and Language Ability

Adults who suffer brain damage as a result of a stroke often have problems expressing their thoughts. These speech and language disorders severely compromise their ability to communicate and decrease their quality of life. In contrast, infants and young children who have suffered comparable brain damage from birth injuries, childhood trauma, or extensive brain surgery sometimes develop or recover speech and language abilities. If researchers can determine why young children have the ability to recover from severe brain damage, then they may learn how adults can be helped to do the same.

Sensory cells in the hearing and balance organs in the inner ear develop connections with specific brain regions early in life. We know that the brain is particularly receptive to forming these connections at certain times in the young child's life. If these time-sensitive opportunities are missed because sensory information is not being transmitted to the brain, the ability to develop critical brain connections or pathways may be lost forever. This could occur, for example, in an infant with undetected severe hearing loss. Research is needed to identify these critical "windows of opportunity" for developing brain connections essential for communication. Important research findings in this area have already stimulated interest in major public health efforts, such as the screening of millions of newborn babies for hearing loss each year.

From Sensing to Interpreting

Understanding Human Communication

Human communication relies on complicated perceptual skills—taking information from the outside world through the senses (hearing, vision, touch, taste, and smell) and interpreting it in a meaningful way. Human communication also requires mental abilities, such as attention and memory. We still do not understand exactly how all of these processes work and interact, or how they malfunction in the case of communication disorders. But we do know that many communication disorders are caused by problems that occur even when the senses (such as hearing) are completely functional. Recently, new methods have been developed to study what happens after information is received by the sense organs. It is now possible to view parts of the brain directly while they're at work through computerized imaging technology, and to see changes as information flows from sensory organs to the brain. For example, a functional magnetic resonance imaging (fMRI) scan of the brain can be used to observe activity as language information is received, processed, and interpreted. Research studies that use powerful imaging techniques such as fMRI are especially valuable in the study of speech and language because these important forms of communication cannot be studied in animals.

Processing Information in the Brain

Aside from the advances being made in brain imaging, new ways are emerging for studying the basic organization and operation of human communication. Information processing in the brain involves the successive activation or stimulation of nerve cells. In other words, information moves continuously from one nerve cell to another like electricity moving along a wire. This activation process takes place when chemicals in one nerve cell are released, stimulating activity in the adjacent nerve cell. Research advances have provided new tools that allow scientists to determine the nature of chemicals that are found in the nerve-cell networks devoted to human communication. This knowledge could lead to new treatment strategies for individuals with communication disorders caused by abnormalities in critical nerve-cell networks.

Applying New Knowledge

As described in the previous sections, scientists have made great progress in recent years toward the goal of understanding human communication and its disorders. These advances have occurred as a result of unprecedented breakthroughs in genetics, other basic sciences, and technology. We can expect continued progress to be made as additional genes associated with specific communication disorders are identified and their functions revealed, and as more is learned about the function of the brain and other organs that are important for communication.

Although advances in basic research are of great theoretical and scientific importance, they represent only a first step toward improving the lives of individuals with communication disorders. The next step is to apply knowledge gained from basic research to clinical studies in which the ultimate goal is to develop the most appropriate and effective means of preventing, diagnosing, and treating communication disorders. For example, you may be familiar with hearing screening programs that have been established around the country to identify infants and young children who have significant hearing loss. The technology that enables us to screen newborns is a result of basic laboratory studies that measure the electrical signals from auditory centers in the brain (auditory brainstem response, or ABR) and tiny sounds generated by the inner ear (otoacoustic emissions). Because babies who are hearing-impaired can now be identified in their infancy, researchers can conduct clinical trials to establish and validate the most effective educational programs and treatments (including hearing aids or cochlear implants) and to determine the age at which treatment should begin for maximal success.

Clinical research is also needed to describe the range of differences that occur in human communication over a person's life span, such as production of speech sounds, hearing acuity, odor detection (sense of smell), and ability to maintain balance. These differences may then be related to an underlying gene or genes, which may help identify people who are at greater risk of developing problems. Clinical trials are also necessary to tell us which medical and behavioral interventions are safe and effective treatment methods for communication disorders. These may include evaluations of medications to treat Ménière's disease and autoimmune hearing loss, light therapy to treat warts on the vocal cords (laryngeal papillomas), electrical stimulation and medications to treat ringing in the ears (tinnitus), imaging techniques to assess brain damage and predict recovery from stroke, and physical therapy involving special positioning of the head for loss of balance (positional vertigo).

The NIDCD is committed to supporting research to develop devices that improve or restore communication abilities, or prevent communication disorders. Advances in basic science research and in bioengineering contributed to the development of the electrolarynx to restore speech after the removal of the voice box (larynx); digital, programmable hearing aids that fit inside the ear canal; cochlear and brainstem implants to improve the communication abilities of adults and children with severe-to-profound hearing loss; and video-game-like computer programs for treatment of disorders that may be associated with learning disabilities. Although these inventions emerged from basic knowledge regarding human communication, the ultimate success of current and future devices can only be determined by carefully designed clinical research studies. These clinical research studies are an important priority for the NIDCD.

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