The Brain: Understanding Neurobiology Through the Study of Addiction

under a contract from the
National Institutes of Health

U.S. Department of Health and Human Services
National Institutes of Health
National Institute on Drug Abuse

Center for Curriculum Development
5415 Mark Dabling Boulevard
Colorado Springs, CO 80918

BSCS Development Team
Nancy M. Landes, Principal Investigator
Anne L. Westbrook, Project Director
Debra A. Hannigan, Curriculum Developer
Ann C. Lanari, Research Assistant
Carol Vallee, Project Assistant
Karen Bertollini, Project Assistant
Mary Crist, Project Assistant
Carrie Hamm, Project Assistant
Raphaela Conner, Project Assistant
Barbara Perrin, Production Manager
Ric Bascobert, Editor
Diane Gionfriddo, Photo Research
Lisa Chilberg, Graphic Designer
Sandra Matthews, Evaluator

Videodiscovery, Inc., Development Team
Shaun Taylor, Vice President for Product Development
Michael Bade, Multimedia Producer/Project Director/Videographer
Greg Humes, Assistant Multimedia Producer
Cathy Saum, Graphic Designer
Lucy Flynn Zuccotti, Photo Research
Michele Moore, Assistant to Project Director
Jennifer Hunt, Costumes and Makeup
Mike Commins, Gaffer (Lighting)
Chet McKnight, Sound
Lee Strucker, Script Writer

Advisory Committee
Andrea Baruchin, Vanderbilt University, Nashville, Tennessee
Michael Dougherty, Hampden-Sydney College, Hampden-Sydney, Virginia
David Friedman, Wake Forest University, Winston-Salem, North Carolina
Reese Jones, University of California, San Francisco, California
Kathleen Ranwez, Pomona High School, Arvada, Colorado
Cathrine Sasek, National Institute on Drug Abuse, Bethesda, Maryland
Martin Shields, James Caldwell High School, West Caldwell, New Jersey
Susan Wooley, American School Health Association, Kent, Ohio

Writing Team
Mary Ann Cutter, University of Colorado, Colorado Springs, Colorado
JoAnne Dombrowski, Consultant, Somerton, Arizona
Michael Dougherty, Hampden-Sydney College, Hampden-Sydney, Virginia
David Friedman, Wake Forest University, Winston-Salem, North Carolina
Paula Henderson, Newark High School, Wilmington, Delaware
Laura McNicholas, Veterans Affairs Medical Center, Philadelphia, Pennsylvania
E. Leong Way, University of California San Francisco, San Francisco, California

Artist
Susan Bartel

Cover Design
Martha Blalock, Medical Arts and Photography Branch, National Institutes of Health

Cover Illustration
Anna Rose Childress, Ph.D., University of Pennsylvania School of Medicine

Design and Layout
Angela Greenwalt, Finer Points Productions

Photo Credits
Carlye Calvin

BSCS Administrative Staff
Carlo Parravano, Chairman, Board of Directors
Rodger W. Bybee, Executive Director
Janet Carlson Powell, Associate Director, Chief Science Education Officer
Larry Satkowiak, Associate Director, Chief Operating Officer

Videodiscovery, Inc., Administrative Staff
D. Joseph Clark, President
Shaun Taylor, Vice President for Product Development

National Institutes of Health
Bruce Fuchs, Office of Science Education
Lucinda Miner, National Institute on Drug Abuse
William Mowczko, Office of Science Education
Cathrine Sasek, National Institute on Drug Abuse
Gloria Seelman, Office of Science Education

Field-test Teachers
Domenica Altieri, Sonora High School, La Habra, California
William Barlow, Preston High School, Kingwood, West Virginia
Gwyn Bush, McNicholas High School, Cincinnati, Ohio
Jennifer Carpio, St. Joseph's Academy, St. Louis, Missouri
Kathy Cattrell, Crestview High School, Columbiana, Ohio
Aster Chin, Lowell High School, San Francisco, California
Katy Colvin, Fort LeBoeuf High School, Waterford, Pennsylvania
Linda Dizer, Girls Preparatory School, Chattanooga, Tennessee
Karen Emery, Shady Spring High School, Shady Spring, West Virginia
Fran Enright, Evergreen Senior High School, Evergreen, Colorado
Leon Fox, Perry High School, Perry, Iowa
Charlotte Freeman, Girls Preparatory School, Chattanooga, Tennessee
Marian Gonzalez, Lowell High School, San Francisco, California
Paula Henderson, Newark High School, Wilmington, Delaware
Wade Hill, Battle Mountain High School, Minturn, Colorado
John Johnson, Creekview High School, Carrollton, Texas
Karel Lilly, Foshay Learning Center, Los Angeles, California
Marilyn Link, North Carolina School of Science and Mathematics, Durham, North Carolina
Brian McCarry, Monsignor Bonner High School, Drexel Hill, Pennsylvania
Glenn Miller, Wheaton High School, Wheaton, Maryland
Tracy Peterson, Hamilton East High School, Hamilton, New Jersey
Kathleen Ranwez, Pomona High School, Arvada, Colorado
Ruth Regent-Smith, Pius XI High School, Milwaukee, Wisconsin
Martin Shields, James Caldwell High School, West Caldwell, New Jersey
Ann Sowd, Jackson High School, Massillon, Ohio
Sandra Sundlof, Wheaton High School, Wheaton, Maryland
Kay Thornton, Perry High School, Perry, Iowa
Linda Wright, Creekview High School, Carrollton, Texas
Lois Wysocki, Radnor High School, Radnor, Pennsylvania

Special Thanks
BSCS and Videodiscovery thank the following individuals for providing resources or reviewing specific activities in this unit:
Dr. William Armstrong, University of Tennessee;
Dr. Richard Cannon, National Heart, Lung and Blood Institute;
Dr. Monica Skarulis, National Institute of Diabetes and Digestive and Kidney Diseases;
Dr. Michael Phelps, UCLA School of Medicine;
Dr. Johannes Czernin, UCLA School of Medicine;
David Twomey, UCLA School of Medicine; and
Jim Strommer, UCLA School of Medicine.

Cover Image Description
The cover shows a positron emission tomography (PET) image of a human brain. Blood flow to a particular brain area, the amygdala, increases when a person addicted to cocaine experiences cravings for the drug. The image, when compared with those taken of people who aren't addicted to cocaine, reveals that just eliciting memories of drug abuse in the addicted person is sufficient to cause changes in brain activity.

This material is based on work supported by the National Institutes of Health under Contract No. 263-98-C-0056. 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.

Revised and reprinted March 2010
NIH Publication No. 09-4871 ISBN: 1-929614-05-5

Please contact the NIH Office of Science Education with questions about this supplement at *supplements@science.education.nih.gov*.

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. NIH's 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 the *National Science Education Standards*.[1] It was developed and tested by a team composed of teachers, scientists, medical experts, and other professionals with relevant subject-area expertise from institutes and medical schools across the country, representatives from the National Institute on Drug Abuse, and curriculum design experts from Biological Sciences Curriculum Study (BSCS) and Videodiscovery. The authors incorporated real scientific data and actual case studies into classroom activities. A three-year development process included geographically dispersed field tests by teachers and students. For the 2010 (fourth) printing, key sections of the supplement were updated, but the Student Lessons remain basically the same.

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 the BSCS 5E Instructional Model (page 3), multisubject 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 videos and interactive activities. The 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.

For a complete list of curriculum supplements, updates, availability, and ordering information, or to submit feedback, please visit our Web site or write to

Curriculum Supplement Series
Office of Science Education
National Institutes of Health
6100 Executive Boulevard
Suite 3E01 700 MSC 7520
Bethesda, MD 20892-7520

We appreciate the valuable contributions of the talented staff at Biological Sciences Curriculum Study (BSCS) and Videodiscovery, Inc. We are also grateful to the NIH scientists, advisors, and all other participating professionals for their work and dedication. Finally, we thank the teachers and students who participated in focus groups and field tests to ensure that these 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. We welcome your feedback.

Bruce A. Fuchs, Ph.D.
Director
Office of Science Education
National Institutes of Health
supplements@science.education.nih.gov

[1] The National Academy of Sciences released the *National Science Education Standards* in 1996, outlining 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

Begun as the one-room Laboratory of Hygiene in 1887, the National Institutes of Health (NIH) today is one of the world's foremost biomedical and behavioral research centers and the federal focal point for health research in the United States.

Mission and Goals

The NIH mission is science in pursuit of fundamental knowledge about the nature and behavior of living systems and the application of that knowledge to extend healthy life and reduce the burdens of illness and disability. The goals of the agency are to

- foster fundamental creative discoveries and innovative research strategies and their applications as a basis for advancing significantly the nation's capacity to protect and improve health;
- develop, maintain, and renew scientific resources—both human and physical—that will ensure the nation's ability to prevent disease;
- expand the knowledge base in medical and associated sciences in order to enhance the nation's economic well-being and ensure a continued high return on the public investment in research; and
- exemplify and promote the highest level of scientific integrity, public accountability, and social responsibility in the conduct of science.

NIH works toward meeting those goals by providing leadership, direction, and grant support to programs designed to improve the health of the nation through research into the

- causes, diagnosis, prevention, and cure of human diseases;
- processes of human growth and development;
- biological effects of environmental contaminants;
- understanding of mental, addictive, and physical disorders; and
- collection, dissemination, and exchange of information in medicine and health, including the development and support of medical libraries and the training of medical librarians and other health information specialists.

Organization

Composed of 27 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. NIH encompasses 75 buildings on more than 300 acres in Bethesda, Md., as well as facilities at several other sites in the United States. The NIH budget has grown from about $300 in 1887 to more than $30 billion in 2009.

Research Programs

One of NIH's principal concerns is to invest wisely the tax dollars entrusted to it for the support and conduct of this research. 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. These projects 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 of treatments for major diseases.

Grant-Making Process

The grant-making 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 or behavioral processes whose clinical value may not be apparent for many years.

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

About 38,500 research and training applications are reviewed annually throughout 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.

The Nobelists

The roster of people who conducted NIH research or who have received NIH support over the years includes some of the world's most illustrious scientists and physicians. Among them are 115 winners of Nobel Prizes for achievements as diverse as deciphering the genetic code and identifying the causes hepatitis. You can learn more about Nobelists who have received NIH support.

Impact on the Nation's Health

Through its research, NIH has played a major role in making possible many achievements over the past few decades, including these:

- Mortality from heart disease, the number one killer in the United States, dropped by 36 percent between 1977 and 1999.
- Improved treatments and detection methods increased the relative five-year survival rate for people with cancer to 60 percent.
- 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.
- 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 the general population for cancer and many other diseases.

Science Education

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

This curriculum supplement is one such science education effort, a collaboration among four partners: the NIH National Institute on Drug Abuse, the NIH Office of Science Education (OSE), Biological Sciences Curriculum Study, and Videodiscovery, Inc.

OSE learning tools support teachers in training the next generation of scientists and scientifically literate citizens. These materials cover information not available in standard textbooks and allow students to explore biological concepts by using real world examples. In addition to the curriculum supplements, OSE provides a host of valuable resources accessible through the OSE Web site.

We welcome your comments about existing resources and suggestions about how we may best meet your needs. Feel free to write us.

For more about NIH, visit its Web site.

About the National Institute on Drug Abuse

The National Institute on Drug Abuse (NIDA), one of the research institutes that comprise the National Institutes of Health, was established in 1974 as the Federal focal point for research, treatment, prevention and training services, and data collection on the nature and extent of drug abuse. NIDA's mission is to lead the nation in bringing the power of science to bear on drug abuse and addiction. This charge has two critical components. First, NIDA supports and conducts research across a broad range of disciplines to explore the biomedical and behavioral foundations of drug abuse. Second, NIDA ensures that the results of research are rapidly and effectively disseminated so that the scientific findings can be used to improve drug abuse and addiction prevention, treatment, and policy.

NIDA is the world's leading supporter of research on the health aspects of drug abuse and addiction. NIDA-supported science addresses the most fundamental and essential questions about drug abuse, ranging from the molecule to managed care, and from DNA to community outreach research. When NIDA was founded, many people incorrectly viewed drug abuse as a problem of people with character flaws and weak wills. Today, thanks to the research accomplishments of hundreds of scientists, those simplistic ideologies are being replaced by a better understanding of the complex biological, behavioral, social, and public health aspects of drug abuse. Scientists have shown that while initial experimentation with drugs may be voluntary, continuing drug abuse changes the brain in fundamental and long-lasting ways. These brain changes trigger the compulsive drug-seeking and drug-taking behaviors that are the hallmarks of drug addiction. NIDA's scientists have clearly shown that drug abuse is a preventable behavior and drug addiction is a treatable brain disease. Among the many and diverse accomplishments over the past three decades, NIDA-supported research has

- identified the molecular sites in the brain where every major drug of abuse—opioids, cocaine, PCP, and THC (the active ingredient in marijuana)—has its initial effect. These discoveries, together with computer-aided drug design, are paving the way to development of novel medications to break the cycle of addiction.
- produced a neurobehavioral model to explain drug-taking behavior to improve treatment and rehabilitation methods.
- supported the development of three medications, LAAM, buprenorphine, and naltrexone, through the approval process by the FDA for the treatment of opiate addiction.
- supported the development and evaluation of pharmacologic treatment for newborns withdrawing from exposure to narcotics.
- defined nicotine addiction and the scientific basis for therapy using nicotine gum and skin patches.
- pioneered innovative community-based research on AIDS prevention efforts that showed that drug users will change AIDS risk behaviors, which can reduce their susceptibility to HIV infection and AIDS.
- demonstrated that participation in methadone treatment significantly reduces HIV seroconversion rates and decreases high-risk behaviors.
- demonstrated that successful drug abuse treatment reduces criminality as well as relapse to addiction.
- demonstrated the value of treating the depression and other mental disorders of people who abuse drugs to improve the results of addiction therapy.
- measured the positive impact of comprehensive research-based community drug prevention strategies that involve the media, schools, families, neighborhoods, and the workplace.
- demonstrated that science education about drug abuse and the brain improves student achievement in science.

- used advanced imaging techniques to identify in awake humans the specific brain circuits that are involved in craving, euphoria, and other sequelae of drug addiction. These exciting studies are providing the foundation for the development of new, targeted medications to block individual aspects of drugs.
- used molecular genetic technologies to clone the genes for the major receptors for virtually every abusable drug, thus providing scientists with the tools necessary to study in fine detail how drugs of abuse exert their many behavioral effects.
- produced genetically engineered animals in which a particular drug receptor had been eliminated, or "knocked out." These animals are providing unprecedented insight into how drugs exert their many effects in the brain and produce addiction.
- demonstrated that prenatal exposure to cigarettes has long-term effects on cognitive performance.
- successfully immunized rats against the psychostimulant effects of cocaine, thus opening up the possibility of developing a vaccination against cocaine addiction.

The results of these and other achievements through NIDA-funded research offer this country's best hope for solving the medical, social, and public health problems of drug abuse and addiction.

The need for greater knowledge of drug abuse continues to grow. Ever-changing drug use patterns, the continuing transmission of HIV infection among people who abuse drugs, and the need to develop new and effective treatment and prevention methods underscore the importance of research in finding new and better ways to alleviate the pain and devastation of addiction. NIDA's goals for the future include

- to design and develop new medications for marijuana and stimulant (such as cocaine and methamphetamine) addiction by building on the recent molecular discoveries that have uncovered the basis for addiction in the brain.
- to develop techniques to detect subtle effects of drug exposure in children of drug-using parents so that early preventive or clinical interventions can be instituted.
- to broaden research on women and addiction to determine the biological and behavioral differences that need to be addressed in effective drug abuse prevention and treatment.
- to reduce the spread of HIV infection through improved drug abuse interventions and better understanding of the interactions of drugs of abuse and the body's immune system.
- to apply state-of-the-art neuroimaging techniques to the problems of drug abuse prevention and treatment.
- to design, develop, and test new behavioral therapies and promote their use for appropriate patient populations.
- to study the treatment of special clinical problems presented by people who abuse drugs and have HIV, tuberculosis, hepatitis, and other infections.
- to understand the organization and financing of drug abuse treatment and its benefits to the larger healthcare system.
- to identify the protective and resiliency factors that prevent drug use in those individuals with multiple risk factors so more effective prevention techniques can be developed.
- to strengthen the research infrastructure, by providing additional opportunities for research training and career development for clinical researchers and improved mechanisms for training and mentoring minority researchers.
- to expand the use of scientific information to educate the public about the real nature of drug abuse and addiction and the hope and promise for more effective prevention and treatment.
- to broaden the dissemination of research findings and improve drug abuse prevention and treatment practice and policy.
- to counter the growing abuse of prescription medications, including opioid analgesics (such as painkillers), stimulants (such as ADHD medications), and CNS depressants (such as sleep and anxiety medications).

The Essence of Drug Addiction

By Nora Volkow, M.D., Director, National Institute on Drug Abuse

What Is Addiction?

More than three decades of research supported by the National Institute on Drug Abuse (NIDA) has proven that addiction is a complex brain disease characterized by compulsive, at times uncontrollable, drug craving, seeking, and use that persist despite potentially devastating consequences. Addiction is also a developmental disease; that is, it usually starts in adolescence or even childhood and can last a lifetime if untreated. Disagreements about the nature of addiction remain: namely, whether it reflects voluntary or involuntary behavior and whether it should be punished or treated as a health issue. Even though the first time a person takes a drug, it is often by choice—to achieve a pleasurable sensation or desired emotional state—we now know from a large body of research that this ability to choose can be affected by drugs. And when addiction takes hold in the brain, it disrupts a person's ability to exert control over behavior—reflecting the compulsive nature of this disease.

The human brain is an extraordinarily complex and fine-tuned communications network made up of billions of cells that govern our thoughts, emotions, perceptions, and drives. Our brains reward certain behaviors such as eating or procreating—registering these as pleasurable activities that we want to repeat. Drug addiction taps into these vital mechanisms geared for our survival. And although not a life necessity, to an addicted person, drugs become life itself, driving the compulsive use of drugs—even in the face of dire life consequences—*that is the essence of addiction*.

How Does Addiction Take Hold in the Brain?

The rewarding effects of drugs of abuse come from large and rapid upsurges in dopamine, a neurochemical critical to stimulating feelings of pleasure and to motivating behavior. The rapid dopamine "rush" from drugs of abuse mimics but greatly exceeds in intensity and duration the feelings that occur in response to such pleasurable stimuli as the sight or smell of food, for example. Repeated exposure to large, drug-induced dopamine surges has the insidious consequence of ultimately blunting the response of the dopamine system to everyday stimuli. Thus the drug disturbs a person's normal hierarchy of needs and desires and substitutes new priorities concerned with procuring and using the drug.

Drug abuse also disrupts the brain circuits involved in memory and control over behavior. Memories of the drug experience can trigger craving as can exposure to people, places, or things associated with former drug use. Stress is also a powerful trigger for craving. Control over behavior is compromised because the affected frontal brain regions are what a person needs to exert inhibitory control over desires and emotions.

That is why addiction is a brain disease. As a person's reward circuitry becomes increasingly dulled and desensitized by drugs, nothing else can compete with them—food, family, and friends lose their relative value, while the ability to curb the need to seek and use drugs evaporates. Ironically and cruelly, eventually even the drug loses its ability to reward, but the compromised brain leads addicted people to pursue it, anyway; the memory of the drug has become more powerful than the drug itself.

Why Are Some People More Vulnerable Than Others?

Like many other diseases, vulnerability to addiction is influenced by multiple factors, with genetic, environmental, and developmental factors all contributing. Genetics accounts for approximately half of an individual's vulnerability to addiction, including the effects of the environment on gene function and expression. Elements of our social environments—culture, neighborhoods, schools, families, peer groups—can also greatly influence individual choices and decisions about behaviors related to substance abuse, which can in turn affect vulnerability. Indeed, addiction is a quintessential gene-by-environment-interaction disease: a person must be exposed to drugs (environment) to become addicted, yet exposure alone does not determine whether that will happen—predisposing genes interact with this and other environmental factors to create vulnerability. In fact, environmental variables such as stress or drug exposure can cause lasting changes to genes and their function, known as epigenetic changes, which can result in long-term changes to brain circuits. Genes may also mitigate the effects of environment—which is why, for example, two substance-abusing individuals growing up in the same high-risk environment may have very different outcomes.

Adding to the complexity, the contributions of environmental and genetic risk factors may also vary during the different life stages of childhood, adolescence, and young adulthood. Adolescence is the period when addiction typically takes hold. Additionally, because their brains are still undergoing rapid development in areas that contribute to decision-making, judgment, and risk-taking, adolescents tend toward immediate gratification over long-term goals. This can lead to risk-taking, including experimenting with drugs. When coupled with their increased sensitivity to social or peer influences and decreased sensitivity to negative consequences of behavior, it is easy to see why adolescents are particularly vulnerable to drug abuse.

How Can People Recover Once They're Addicted?

As with any other medical disorder that impairs the function of vital organs, repair and recovery of the addicted brain depends on targeted and effective treatments that must address the complexity of the disease. We continue to gain new insights into ways to optimize treatments to counteract addiction's powerful disruptive effects on brain and behavior because we now know that with prolonged abstinence, our brains can recover at least some of their former functioning, enabling people to regain control of their lives.

That said, the chronic nature of the disease means that relapsing to drug abuse is not only possible but likely, with relapse rates similar to those for other well-characterized chronic medical illnesses such as diabetes, hypertension, and asthma. For all these diseases, including drug abuse, treatment involves changing deeply embedded behaviors, so lapses should not be considered failure but rather indicate that treatment needs to be reinstated or adjusted, or that alternate treatment is needed. But addicted individuals also need to do their part. Even though they are dealing with a compromised brain that affects decision-making and judgment, people with drug abuse or addiction must also take responsibility to get treatment and actively participate in it.

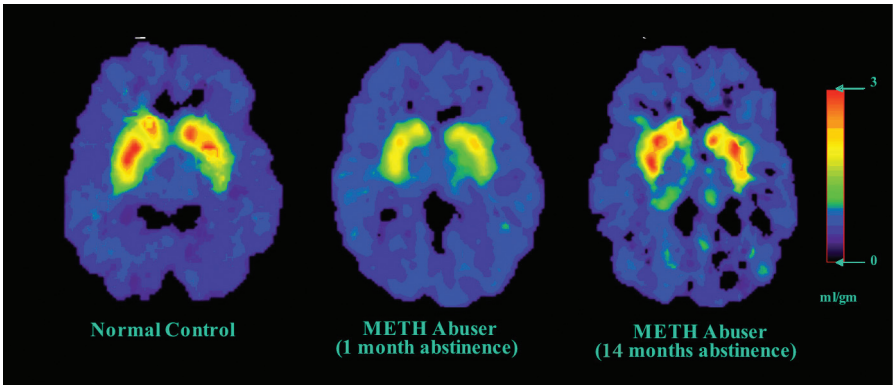
What Is Our Best Approach to Stopping Drug Abuse in This Country?

Although we have a range of effective addiction treatment options in our clinical toolbox, we still don't have enough to address the many facets of this problem. Research continues to search for improved prevention and treatment options and to reveal promising new strategies to help people deal with their compulsive drug use.

Science-based approaches to tackling drug abuse and addiction will yield smart solutions that bring positive change. As a society, the success of our efforts to deal with the drug problem depends on having an accurate understanding of it. Education

is key. Education can impart knowledge to equip parents to be effective interveners with their children. Knowledge will also help our youth make more informed choices and perhaps think twice before they make a decision.

More information on drug abuse and addiction can be found on the NIDA homepage. Free publications can be ordered online from NIDA DRUG*PUBS*, Research Dissemination Center or by calling 1-877-NIDA-NIH or 1-877-643-2644.



Recovery of brain dopamine transporters in methamphetamine (METH) abuser after protracted abstinence. With treatment that keeps abusers off METH, drug-altered brains can recover at least some of their former functioning, as these images illustrate. Using positron emission tomography, we can measure the level of dopamine transporters (DAT) in the striatal region of the brain as an indicator of dopamine system function. The METH abuser (center) shows greatly reduced levels of DAT (yellow and green), which return to nearly normal following prolonged abstinence (red and yellow). Source: Volkow, N.D., et al. 2001. Journal of Neuroscience *21:9414–18.*

Introduction to the Module

What Are the Objectives of the Module?

The Brain: Understanding Neurobiology Through the Study of Addiction has several objectives. The first is to help students understand major concepts in neurobiology. The brain controls everything a person does, including regulating breathing and heart rate, movement, thought, and emotions. The module seeks to provide students with a fundamental knowledge of how the neurons in the brain convey information to regulate these diverse functions.

The second objective is to provide students with factual information on how drugs of abuse alter the function of the brain. Drugs of abuse exert their effects by altering the communication between neurons. Some of the changes resulting from drug abuse are short-term while others are long-term, and potentially permanent. At some point in drug abuse, the brain changes and the person abusing drugs becomes addicted. The addicted person has a compulsive need to continue to take drugs despite adverse physical, social, and emotional consequences. Scientists continue to investigate what changes occur in the brain when a person becomes addicted to drugs.

Science plays an important role in assisting individuals as they make choices about enhancing personal and public welfare. In this module, students see that science provides evidence that can be used to support ways of understanding and treating human disease. In addition to being the world's largest supporter of research into drug abuse and addiction, the National Institute on Drug Abuse is committed to ensuring the rapid and effective dissemination of research findings to improve drug abuse and addiction prevention, treatment, and policy. This module is one way to provide this information to the public.

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

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

Why Teach the Module?

One challenge for science teachers is to make science meaningful to high school students. Students at this age want to see the relevance of the material to their lives. This module presents fundamental principles of neurobiology in relation to drugs of abuse. This link to drugs grabs students' attention because, in today's world, drugs affect virtually all students either directly or indirectly. This real-life context engages students and makes neurobiology something more than just another topic to memorize for biology class. They can apply the information to make decisions about their lives.

"Excellent information on drug actions and neurobiology presented in an inquiry format. Students handled difficult concepts because of the way they were presented."
—Field-test Teacher

"It appears that students really did learn the material on neurotransmission and drug addiction. I actually heard one student kidding another about their dopamine levels! Another student was in my room after school explaining to an underclassman how information gets from one part of the body to the other—complete with diagrams on the board."
—Field-test Teacher

"The topic is of interest to students. The information is current and goes beyond what is available in textbooks."

—Field-test Teacher

What's in It for the Teacher?

The Brain: Understanding Neurobiology Through the Study of Addiction meets many of the criteria used to assess teachers and their programs.

- The module is **standards based** and meets science content, teaching, and assessment standards as expressed in the *National Science Education Standards*. It pays particular attention to the standards that describe what students should know and be able to do with respect to **scientific inquiry**.
- The module includes an Internet-based **multimedia component** that features minidocumentaries, animations, and interactive activities.
- It is an **integrated** module, drawing most heavily from the subjects of science, mathematics, health, and language arts.
- Finally, the module includes built-in **assessment** tools, indicated by an assessment icon in the lessons.

In addition, the module provides a means for **professional development**. Teachers can engage in new and different teaching practices without completely overhauling their entire program. In *Designing Professional Development for Teachers of Science and Mathematics*[1], Susan Loucks-Horsley et al. write that replacement modules, such as *The Brain: Understanding Neurobiology Through the Study of Addiction*, can "offer a window through which teachers can get a glimpse of what new teaching strategies look like in action." By experiencing a short-term module like this one, teachers can "change how they think about teaching and embrace new approaches that stimulate students to problem solve, reason, investigate, and construct their own meaning for the content." The use of a replacement module like this 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 the high school curriculum with the lessons presented in this module. This information is presented to help teachers make decisions about incorporating this material into their curriculum.

Major Topics Presented in *The Brain: Understanding Neurobiology Through the Study of Addiction*

Topics	Lesson 1	Lesson 2	Lesson 3	Lesson 4	Lesson 5
Localization of brain function	•				
General functions of specific brain areas	•				
Anatomy of the neuron		•			
Neurotransmission		•	•		
Mechanism of drug action on neurons			•	•	
Environmental, behavioral, and genetic influences on addiction				•	•
Addiction as a chronic disease				•	•

Implementing the Module

The five lessons in this module are designed to be taught in sequence for approximately two weeks as a replacement for part of the standard curriculum in high school biology. 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?

The Brain: Understanding Neurobiology Through the Study of Addiction is designed to help students develop the following major goals associated with scientific literacy:

- to understand a set of fundamentals about neurobiology and how drugs of abuse change the brain;
- to recognize that drug addiction is a treatable, chronic brain disease;
- to experience the process of scientific inquiry and develop an enhanced understanding of the nature and methods of science; and
- to appreciate 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 form a conceptual whole that will provide students with a fundamental knowledge of neurobiology, drug abuse, and drug addiction. Students begin by learning how different areas of the brain regulate specific functions, including feeling pleasure (Lesson 1—*The Brain: What's*

Conceptual Flow of the Lessons

Lesson	Learning Focus*	Major Concepts
Lesson 1 *The Brain: What's Going On in There?*	Engage/Explore	Specific brain regions control specific brain functions.
Lesson 2 *Neurons, Brain Chemistry, and Neurotransmission*	Explore/Explain	Neurons convey information using electrical and chemical signals.
Lesson 3 *Drugs Change the Way Neurons Communicate*	Explain/Elaborate	Drugs affect the biology and chemistry of the brain.
Lesson 4 *Drug Abuse and Addiction*	Explain/Elaborate	Addiction is a brain disease.
Lesson 5 *Drug Addiction Is a Disease — So What Do We Do about It?*	Elaborate/Evaluate	Drug addiction is a recurring chronic disease that can be treated effectively, similar to other chronic diseases.

*See *How Does the BSCS 5E Instructional Model Promote Active, Collaborative, Inquiry-Based Learning?* on page 4.

Going On in There?). Students extend their understanding of the brain by learning how neurons in the brain relay information through electrical and chemical signals (Lesson 2—*Neurons, Brain Chemistry, and Neurotransmission*). Once students understand how neurons communicate, they explore how drugs of abuse alter the function of the brain by disrupting the signaling process between neurons (Lesson 3—*Drugs Change the Way Neurons Communicate*). Students can then apply their knowledge of how drugs act at the cellular level to understand that drug addiction is a brain disease that is signified by changes in the brain, some of which may persist a long time or may be permanent (Lesson 4—*Drug Abuse and Addiction*). Finally, students consider how treatment for the disease of drug addiction compares with that for other chronic diseases (Lesson 5—*Drug Addiction Is a Disease, So What Do We Do about It?*). The chart *Conceptual Flow of the Lessons*, on page 3, illustrates the sequence of major concepts addressed by the five lessons.

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

The Brain: Understanding Neurobiology Through the Study of Addiction supports teachers in their efforts to reform science education in the spirit of the National Research Council's 1996 National Science Education Standards (NSES). The content of the module is explicitly standards based: each time a standard is addressed in a lesson, an NSES icon appears in the margin and the applicable standard is identified. The chart *Content Standards: Grades 9–12*, on page 5, lists the specific content standards that this module addresses.

Teaching Standards

The suggested teaching strategies in all the lessons support you as you work to meet the teaching standards outlined in the *National Science Education Standards*. The module helps teachers of science plan an inquiry-based science program by providing short-term objectives for students. It also includes planning tools such as the *Conceptual Flow of the Lessons* chart (page 3) and the *Suggested Timeline* and the *Abbreviated Timeline* (pages 17–18) for teaching the module. You can use this module to update your curriculum in response to your students' interest in this topic. The focus on active, collaborative, and inquiry-based learning helps teachers support the development of student understanding and nurture a community of science learners.

The structure of the lessons in this module enables teachers to guide and facilitate learning. All the activities encourage and support student inquiry, promote discourse among students, and challenge students to accept and share responsibility for their learning. Using the BSCS 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 you can encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.

Assessment Standards

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

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

Because learning does not occur through a process of passive absorption, the lessons in this module promote active learning. Students are involved in more than listening and

Content Standards: Grades 9–12

NSES Content Standard	Correlation to *The Brain: Understanding Neurobiology Through the Study of Addiction*
Standard A: As a result of activities in grades 9–12, all students should develop	
Abilities necessary to do scientific inquiry	
• Identify questions and concepts that guide scientific investigations.	Lessons 1, 2, 3, 4, 5
• Design and conduct scientific investigations.	Lesson 3
• Use technology and mathematics to improve investigations and communications.	Lessons 1, 2, 3, 4, 5
• Formulate and revise scientific explanations and models using logic and evidence.	Lessons 2, 3, 4, 5
• Recognize and analyze alternative explanations and models.	Lessons 1, 2, 3, 4
• Communicate and defend a scientific argument.	Lessons 1, 2, 3
• Use mathematics in all aspects of scientific inquiry.	Lesson 4
Understandings about scientific inquiry	
• Scientists rely on technology to enhance the gathering and manipulation of data.	Lessons 1, 4
• Mathematics is essential in scientific inquiry.	Lessons 3, 4
Standard C: As a result of their activities in grades 9–12, all students should develop understanding of	
The cell	
• Cells have particular structures that underlie their functions.	Lesson 2
• Most cell functions involve chemical reactions.	Lesson 2
• Cell functions are regulated.	Lessons 2, 3
• Cells can differentiate, and complex multicellular organisms are formed as a highly organized arrangement of differentiated cells.	Lessons 1, 2
Behavior of organisms	
• Multicellular animals have nervous systems that generate behavior.	Lessons 1, 2, 3
• Organisms have behavioral responses to internal changes and to external stimuli.	Lessons 1, 2, 3
• Behavioral biology has implications for humans, as it provides links to psychology, sociology, and anthropology.	Lessons 4, 5
Standard E: As a result of their activities in grades 9–12, all students should develop	
Understandings about science and technology	
• Science often advances with the introduction of new technologies.	Lessons 1, 4
Standard F: As a result of their activities in grades 9–12, all students should develop understanding of	
Personal and community health	
• The severity of disease symptoms depends on many factors, such as human resistance and the virulence of the disease-producing organism.	Lessons 4, 5
• Personal choice concerning fitness and health involves multiple factors.	Lessons 4, 5
• An individual's mood and behavior may be modified by substances.	Lessons 1, 4, 5
• Families serve basic health needs, especially for young children.	Lesson 5
Standard G: As a result of their activities in grades 9–12, all students should develop understanding of	
Nature of scientific knowledge	
• Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available.	Lessons 1, 2, 3, 4, 5
Historical perspectives	
• Usually, changes in science occur as small modifications in extant knowledge.	Lesson 1

reading. They are developing skills, analyzing and evaluating evidence, experiencing and discussing, and talking to their peers about their own understandings. Students work collaboratively with others to solve problems and plan investigations. Many students find that they learn better when they work with others in a collaborative environment than they can when they work alone in a competitive environment. When all this active, collaborative learning is directed toward inquiry science, students succeed in making their own discoveries. They ask questions, observe, analyze, explain, draw conclusions, and ask new questions. These inquiry experiences include both those that involve students in direct experimentation and those in which students develop explanations through critical and logical thinking.

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

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

This module provides a built-in structure for creating a constructivist classroom: the BSCS 5E Instructional Model. This 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 five words that begin with the letter "E": Engage, Explore, Explain, Elaborate, and Evaluate. The following paragraphs illustrate how the 5Es are implemented across the lessons in this module.

Engage

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

The Engage lesson in this module, Lesson 1—*The Brain: What's Going On in There?*, is designed to

- pique students' curiosity and generate interest,
- initiate students' thinking about the function of the brain,
- encourage students to compare their ideas with the ideas of others, and
- allow teachers to assess what students do or do not understand about the stated outcomes of the lesson.

Explore

In the Explore phase of the module, Lesson 1—*The Brain: What's Going On in There?* and Lesson 2—*Neurons, Brain Chemistry, and Neurotransmission*, students explore the function of the brain both as a body organ and as a collection of interacting cells. The lessons provide a common set of experiences within which students can compare their thoughts about what they are observing and experiencing.

During the Explore phase of the lessons, students

- use their skills of observation, logic, and deduction to gain an understanding of the process by which neurons relay information;
- acquire a common set of experiences with their classmates so they can compare results and ideas; and
- observe, describe, record, compare, and share their ideas and experiences.

Explain

The Explain components of Lesson 2—*Neurons, Brain Chemistry, and Neurotransmission* and Lesson 3—*Drugs Change the Way Neurons Communicate* provide opportunities for students to connect their previous experiences and to

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

In the Explain lessons in this module, students
- explain concepts and ideas about neurotransmission;
- incorporate the correct scientific terminology into their explanations;
- add new information about the actions of drugs to their understanding of neurotransmission;
- revise their ideas;
- compare their current thinking with what they previously thought;
- listen to and compare others' explanations of their results with their own; and
- become involved in student-to-student discourse in which they explain their thinking to others and debate their ideas.

Elaborate

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

In the Elaborate lessons in this module, parts of Lessons 3 and 4, *Drug Abuse and Addiction*, students
- add information about the effects of drugs to increase their understanding of neurotransmission;
- consider the factors, including physical, environmental, and social, that influence the outcome of an individual's drug abuse;
- connect ideas, solve problems, and apply their understanding in these new situations;
- 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 provides only a "snapshot" of what the students understand and how far they have come from where they began. In reality, the evaluation of students' conceptual understanding and ability to use skills begins with the Engage lesson and continues throughout each stage of the model, as described in the following section. Combined with the students' written work and performance of tasks throughout the module, however, the Evaluate lesson can serve as a summative assessment of what students know and can do.

The Evaluate lesson in this module, Lesson 5, *Drug Addiction Is a Disease—So What Do We Do about It?*, provides opportunities for students to
- demonstrate what they understand about the function of the brain and the effects of drugs on that function;
- integrate information from the previous lessons to form a deeper understanding of both neurobiology and drug abuse;
- assess their own progress by comparing their current understanding with their prior knowledge;
- apply their knowledge to situations in the real world; and
- ask new questions that take them deeper into a concept or topic area.

To review the relationship of the BSCS 5E Instructional Model to the concepts presented in the module, see the chart *Conceptual Flow of the Lessons*, on page 3.

When a teacher uses the BSCS 5E Instructional Model, he or she engages in practices that are very different from those of a traditional teacher. In response, students also participate in their learning in ways that are different from those seen in a traditional classroom. The charts *What the Teacher Does* and *What the Students Do*, on pages 8 and 9, outline those differences.

What the Teacher Does

Stage	That is *consistent* with the BSCS 5E Instructional Model	That is *inconsistent* with the BSCS 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 redirect the students' investigations when necessary • Asks questions to help students make sense of their experiences • Provides time for students to puzzle through problems	• Provides answers • Proceeds too rapidly for students to make sense of their experiences • Provides closure • Tells the students that they are wrong • Gives information and facts that solve the problem • Leads the students step-by-step to a solution
Explain	• Encourages students to use their common experiences and data from the Engage and Explore lessons to develop explanations • Asks questions that help students express understanding and explanations • Requests justification (evidence) for students' explanations • Provides time for students to compare their ideas with those of others and perhaps to revise their thinking • Introduces terminology and alternative explanations after students express their ideas	• Neglects to solicit students' explanations • Ignores data and information students gathered from previous lessons • Dismisses students' ideas • Accepts explanations that are not supported by evidence • Introduces unrelated concepts or skills
Elaborate	• Focuses students' attention on conceptual connections between new and former experiences • Encourages students to use what they have learned to explain a new event or idea • Reinforces students' use of scientific terms and descriptions previously introduced • Asks questions that help students draw reasonable conclusions from evidence and data	• Neglects to help students connect new and former experiences • Provides definitive answers • Tells 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 BSCS 5E Instructional Model	That is *inconsistent* with the BSCS 5E Instructional Model
Engage	• Become interested in and curious about the concept or topic • Express current understanding of a concept or idea • Raise questions such as, What do I already know about this? What do I want to know about this? How could I find out?	• Ask for the "right" answer • Offer the "right" answer • Insist on answers or explanations • Seek closure
Explore	• "Mess around" with materials and ideas • Conduct investigations in which they observe, describe, and record data • Try different ways to solve a problem or answer a question • Acquire a common set of experiences so they can compare results and ideas • Compare their ideas with those of others	• Let others do the thinking and exploring (passive involvement) • Work quietly with little or no interaction with others (only appropriate when exploring ideas or feelings) • Stop with one solution • Demand or seek closure
Explain	• Explain concepts and ideas in their own words • Base their explanations on evidence acquired during previous investigations • Become involved in student-to-student conversations in which they debate their ideas • Record their ideas and current understanding • Reflect on and perhaps revise their ideas • Express their ideas using appropriate scientific language • Compare their ideas with what scientists know and understand	• Propose explanations from "thin air" with no relationship to previous experiences • Bring up irrelevant experiences and examples • Accept explanations without justification • Ignore or dismiss other plausible explanations • Propose explanations without evidence to support their ideas
Elaborate	• Make conceptual connections between new and former experiences • Use what they have learned to explain a new object, event, organism, or idea • Use scientific terms and descriptions • Draw reasonable conclusions from evidence and data • Communicate their understanding to others	• Ignore previous information or evidence • Draw conclusions from "thin air" • Use terminology inappropriately and without understanding
Evaluate	• Demonstrate what they understand about the concept(s) and how well they can implement a skill • Compare their current thinking with that of others and perhaps revise their ideas • Assess their own progress by comparing their current understanding with their prior knowledge • Ask new questions that take them deeper into a concept or topic area	• Disregard evidence or previously accepted explanations in drawing conclusions • Offer only yes-or-no answers or memorized definitions or explanations as answers • Fail to express satisfactory explanations in their own words • Introduce new, irrelevant topics

How Does the Module Support Ongoing Assessment?

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

- performance-based activities, such as participating in discussions of how drugs affect brain function or constructing graphs;
- oral presentation to the class, such as explaining analysis of data; and
- 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 being assessed appear in the margin beside each step that includes an embedded assessment.

How Can Controversial Topics Be Handled in the Classroom?

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

In this module, students have a variety of opportunities to discuss, interpret, and evaluate basic science and health issues, some in the light of values and ethics. As students encounter issues about which they feel strongly, some discussions might become controversial. How much controversy develops will depend on many factors, such as how similar the students are with respect to socioeconomic status, perspectives, value systems, and religious preferences. 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 into 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 are often 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 Web Site

The Web component of *The Brain: Understanding Neurobiology Through the Study of Addiction* is a wonderful tool that can help you organize your use of the module, engage student interest in learning, and orchestrate and individualize instruction. The site features simulations and illustrations that articulate with the lessons.

Hardware and Software Requirements

The site can be accessed from Apple Macintosh and IBM-compatible personal computers. Links for downloading the Adobe Flash plug-in are provided on the Web site's Getting Started page. *This plug-in is required for the activities to function properly.* The recommended hardware and software requirements for using the site are listed below.

Recommended Setup

- Pentium class IBM compatible running Windows XP (Service Pack 2) or higher, with at least 256 MB RAM
- G4 Macintosh running Mac OS 10.4 or higher, with at least 512 MB RAM
- Screen resolution of 1024 by 768 pixels or higher
- High-speed Internet connection
- Web browser: Mozilla Firefox 2.0 or higher, Microsoft Internet Explorer 6.0 or higher, or Safari 3.0 or higher
- Browser settings: JavaScript enabled
- Adobe Reader version 7.0 or higher (downloadable for free)
- Adobe Flash browser plug-in, version 9 or higher (downloadable for free)
- QuickTime Player version 7.1.6 or higher (downloadable for free)

Note: The above setup (or better) is recommended. Although your computer configuration may differ from this, the site may still be functional on your computer. The most important items in this list are current browsers and plug-ins.

Getting the Most Out of the Web Site

Before you use this or any other piece of instructional software in your classroom, it may be valuable to identify some of the benefits you expect software to provide. Well-designed instructional multimedia software can

- motivate students by helping them enjoy learning—students want to learn more when content that otherwise might be uninteresting is enlivened;
- offer unique instructional capabilities that allow students to explore topics in greater depth—technology offers experiences that are closer to actual life than print-based media offer;
- support you in experimenting with new instructional approaches that allow students to work independently or in small groups—technology gives teachers increased credibility among today's technology-literate students; and
- increase your productivity—technology helps teachers with assessment, record keeping, and classroom planning and management.

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

Collaborative Groups

We designed many of the activities in this module to be completed by groups of students working together. Although individual students working alone can complete many of the specific steps, this strategy will not stimulate the types of student-student interactions that are part of active, collaborative, inquiry-based learning. Therefore, we recommend that you organize collaborative groups of two to four students each, depending on the number of computers available. If necessary, up to six students may work as a group, although the students may not be as involved in the activity. Students in groups larger than this will have difficulty organizing the student-computer interactions equitably. This can lead to one or two students' assuming the primary responsibility for the computer-based work. Although large groups can be efficient, they do not allow all students to experience the in-depth discovery and analysis that the Web site was designed to stimulate. Group members not involved directly may become bored or uninterested.

We recommend that you keep students in the same collaborative groups for all the activities in the lessons. This will allow each group to develop a shared experience with the Web site and with the ideas and issues that the activities present. A shared experience will also enhance your students' perceptions of the lessons as a conceptual whole.

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

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

Web Activities for People with Disabilities

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

Contact us at

Curriculum Supplement Series
Office of Science Education
National Institutes of Health
6100 Executive Boulevard
Suite 3E01 MSC7520
Bethesda, MD 20892-7520
supplements@science.education.nih.gov

Using the Student Lessons

The heart of this module is the set of five lessons that follow. These lessons are the vehicles that we hope will carry important concepts related to neurobiology and drug addiction to your students. To review the concepts in detail, refer to the chart *Conceptual Flow of the Lessons,* on page 3.

Format of the Lessons

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

At a Glance offers a convenient summary of the lesson.

- The **Overview** provides a short summary of student activities.
- The **Major Concept** section lists the central idea the lesson is designed to convey.
- **Objectives** lists two to four specific understandings or abilities students should have after completing the lesson.
- The **Basic Science–Health Connection** describes how the material in the lesson illustrates the relationship between basic science and personal and public health. The mission of the NIH is to "uncover new knowledge that will lead to better health for everyone." This mission statement recognizes that basic science and personal and public health are inextricably linked and form a powerful whole. Research into the basic processes of life leads inevitably to strategies for improving health, and questions about health trigger research into basic processes.

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

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

- **Web-Based Activities** tells you which of the lesson's activities make use of the module's Web site as the basis for instruction.
- **Photocopies** lists the paper copies or transparencies that need to be made from masters, which follow the student lessons.
- **Materials** lists all the materials other than photocopies needed for each of the activities in the lesson.
- **Preparation** outlines the things you need to do to be ready to teach each of the activities in the lesson.

Procedure outlines the steps for each activity in the lesson. It provides implementation suggestions and answers to questions. Within the procedure, annotations provide additional commentary.

- **Tip from the Field Test** includes field-test teachers' suggestions for teaching strategies, classroom management, and module implementation.
- **Note** gives information about special points to remember as you are teaching the activity.
- **Assessment** provides you with strategies for assessing student progress throughout the module and is identified by an assessment icon (see next page).
- The **Icons** shown on the next page identify specific annotations:

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

identifies when to use the Web site as part of the teaching strategy. Instructions in the Procedures section tell you how to access the Web site and the relevant activity. Specific information about using the Web site can be found in Using the Web site (see pages 13–14). A print-based alternative to each Web activity is provided for classrooms in which Internet access is not available.

identifies a print-based alternative to a Web-based activity to use if the Internet is 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 the activity masters, transparencies, and the Web 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. It can be a handy resource during lesson preparation as well as during classroom instruction.

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

Timelines for Teaching the Module

There are several ways to complete the five lessons in this module. Each timeline assumes 45 minutes of instruction per day.

The Suggested Timeline (on page 17) outlines the optimal plan for completing the five lessons in this module. The plan assumes you will teach the activities on consecutive days. If your class requires more time to complete the activities, discuss issues raised in this module, or complete the activities on the Web, adjust your timeline accordingly.

The Abbreviated Timeline (page 18) outlines a schedule for completing the lessons in the curriculum supplement in one week. By this timeline, students skip some activities and focus on ones that convey the most important concepts. Students will miss a great deal of the richness of the unit and the details that add interest to the material, but they can still benefit from learning many new concepts.

Suggested Timeline

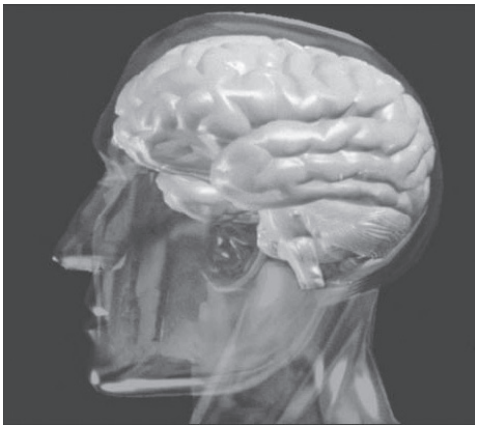
Timeline	Activity
3 weeks ahead	Reserve computers Check performance of Web site. Bookmark URL if possible. Be sure appropriate versions of the required plug-ins are installed on the computers.
1 week ahead	Make photocopies and transparencies Gather materials
Day 1	**Lesson 1** Activity 1: *What Does the Brain Do?* Activity 2: *Positron Emission Tomography and Brain Function*
Day 2	**Lesson 1 (continued)** Activity 3: *Parts of the Brain* Activity 4: *Who Was Phineas Gage?* Activity 5: *Where Do Drugs Act?*
Day 3	**Lesson 2** Activity 1: *Anatomy of a Neuron* Activity 2: *How Do Neurons Communicate?*
Day 4	**Lesson 2 (continued)** Activity 3: *Do All Neurotransmitters Have the Same Effect?* Activity 4: *One Neuron Signals Another*
Day 5	**Lesson 3** Activity 1: *Drugs Alter Neurotransmission*
Day 6	**Lesson 3 (continued)** Activity 2: *How Does Caffeine Affect You?* Activity 3: *Routes of Administration*
Day 7	**Lesson 4** Activity 1: *How Does Drug Abuse Begin?* Activity 2: *Drug Abuse Is Voluntary; Addiction Is Compulsive*
Day 8	**Lesson 4 (continued)** Activity 3: *When Does Abuse Become Addiction?* Activity 4: *Environmental, Behavioral, and Social Influences on Drug Abuse and Addiction* Activity 5: *Long-term Effects of Drug Abuse and Addiction*
Day 9	**Lesson 5** Activity 1: *Is Addiction Treatable?* Activity 2: *Evaluating the Case Studies* Activity 3: *Is Treatment for Drug Addiction Effective?* Activity 4: *Addiction Is a Brain Disease*

Abbreviated Timeline

Timeline	Activity
3 weeks ahead	Reserve computers Check performance of Web site. Bookmark URL if possible. Be sure appropriate versions of the required plug-ins are installed on the computers.
1 week ahead	Make photocopies and transparencies Gather materials
Day 1	**Lesson 1** Activity 1: *What Does the Brain Do?* Activity 2: *Positron Emission Tomography and Brain Function* Activity 3: Omit Activity 4: (assign as homework) *Who Was Phineas Gage?* Activity 5: *Where Do Drugs Act?*
Day 2	**Lesson 2** Activity 1: *Anatomy of a Neuron* Activity 2: *How Do Neurons Communicate?* Activity 3: Omit Activity 4: Omit
Day 3	**Lesson 3** Activity 1: *Drugs Alter Neurotransmission* Activity 2: Omit Activity 3: Omit
Day 4	**Lesson 4** Activity 1: *How Does Drug Abuse Begin?* Activity 2: *Drug Abuse Is Voluntary; Addiction Is Compulsive* Activity 3: Omit Activity 4: (assign as homework) *Environmental, Behavioral, and Social Influences on Drug Abuse and Addiction* Activity 5: (have students watch the minidocumentary independently during free time or assign Master 4.6 as homework) *Long-term Effects of Drug Abuse and Addiction*
Day 5	**Lesson 5** Activity 1: *Is Addiction Treatable?* Activity 2: *Evaluating the Case Studies* Activity 3: *Is Treatment for Drug Addiction Effective?* Activity 4: (assign as homework) *Addiction Is a Brain Disease*

LESSON 1
Engage/Explore

The Brain: What's Going On in There?



Source: NIDA. 1996. The Brain & the Actions of Cocaine, Opiates, and Marijuana. Slide Teaching Packet for Scientists.

At a Glance

Overview
Students examine images of human brains that illustrate that specific regions of the brain regulate specific functions. They extend that knowledge to learn that drugs of abuse activate a brain circuit known as the reward system. This same circuit is stimulated in response to basic survival needs, which produces feelings of pleasure.

Major Concept
Specific brain regions control specific brain functions.

Objectives
By the end of these activities, students will
- understand that particular functions are localized to specific areas of the brain,
- appreciate that imaging techniques allow scientists to study activity in the brain, and
- recognize that normal behaviors can activate the reward system in the brain and that drugs of abuse affect those same reward circuits.

Basic Science–Health Connection
The brain controls virtually everything humans experience, including movement, sensing our environment, and regulating our involuntary body processes such as breathing, as well as controlling our emotions. Ongoing scientific research into the organization and function of the brain has led, and will continue to lead, to new treatments of diseases such as Parkinson's disease, epilepsy, stroke, and mental illnesses (including depression and schizophrenia).

The brain is the organ of behavior. It is also the organ of our minds. Both overt behavior and consciousness are manifestations of the work of our brains. Other people can see an individual's overt behaviors, whereas consciousness is apparent only in our individual minds. The field of neuroscience studies how people control their behaviors, thoughts, and feelings, and how these actions sometimes get out of control.

Background Information

The brain processes a huge amount of information in a remarkably efficient manner. Think about driving a car. It is something most of us do without much difficulty. But to do it properly, we must perform a remarkable number of tasks. First we have to make sure that our body is in working order: heart rate and breathing have to be properly regulated and body temperature held steady, and we certainly have to be sure we don't fall asleep. Despite the complexity of these tasks, we carry them out with no conscious involvement on our part. Then, there are the things we are aware of. We have to see the road and hear the traffic (or the radio), use information from our feet, legs, hands, and arms to know where the gas pedal and steering wheel are, and then generate the body movements to control the direction and speed of the car. All of this often takes place while we are talking to someone else in the car, or even while talking on the phone (although this is not a good idea). The magnitude and speed of data processing needed to do this are stunning, but most of us consider driving to be an easy task.

Different Brain Regions Contribute to the Regulation of Different Functions

How does the brain carry out multiple tasks at one time? The answer is that the brain splits the larger task—driving, in our example—into smaller ones: seeing, hearing, moving, and so forth. Even those tasks are split into their component parts. One part of the human brain analyzes the movement of objects that we see, while another part is responsible for actually recognizing them. In short, specific parts of the brain carry out specific tasks. Not only that, but each part of the brain specializes in a specific kind of task. This means that whenever that task needs to be done, the appropriate information is processed by that part of the brain.

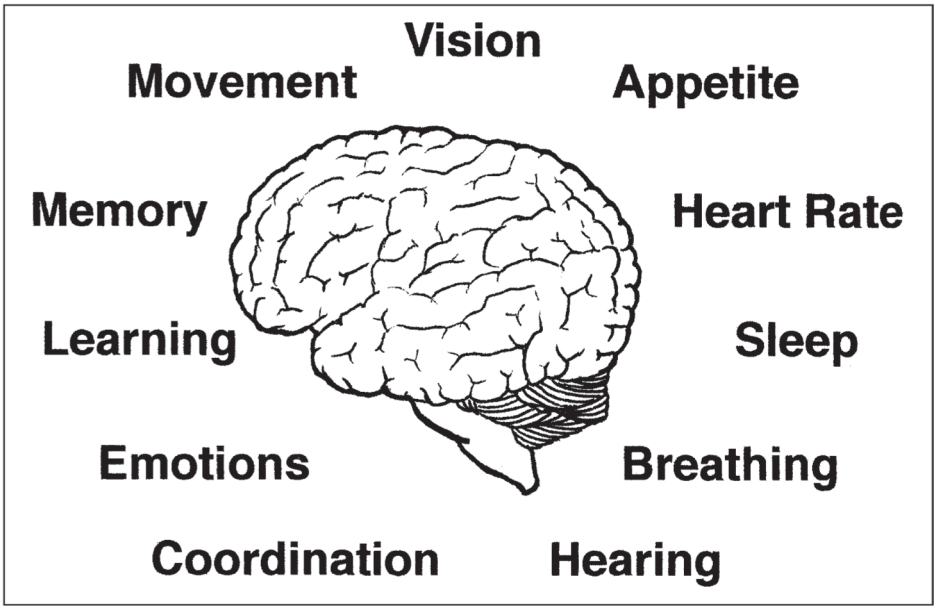


Figure 1.1: *The human brain regulates everything a person does.*

The flip side of this organizational scheme is that if a part of the brain is damaged, then the job it used to undertake cannot be done. For example, damage to the occipital lobe at the back of the brain can cause blindness, but it has no effect on a person's ability to hear or move. Because the job of seeing is highly compartmentalized, individuals who have lost one aspect of sight, such as the ability to see colors or to recognize faces, may still be able to do other visual tasks. Imagine being able to recognize someone by hearing his or her voice, but not being able to recognize his or her face when you see it.

The advantage of this localization of function is when larger jobs are parceled out throughout the brain, they all can be done at once. This "division of labor" adds great speed to our ability to perceive what is happening in the world around us, to analyze it, and then to generate appropriate responses. Dealing with information in this way is called **parallel processing**.[1] (Superscript numbers refer to references listed by section on pages 153–156.) Computer scientists have used this concept in the development of computers.

The human brain consists of several large regions, each of which is responsible for some of the activities necessary for life. These include the brainstem, cerebellum, limbic system, diencephalon, and cerebral cortex.[2,3]

The **brainstem** is the part of the brain that connects the brain and spinal cord (Figure 1.2). This part of the brain is involved in coordinating many basic functions such as heart rate, breathing, eating, and sleeping.

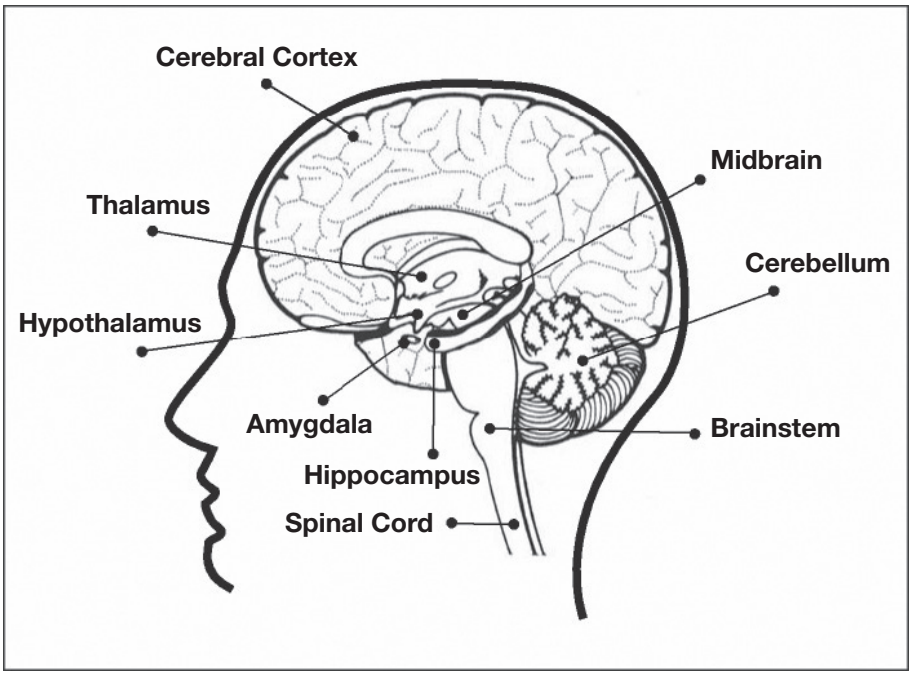


Figure 1.2: *This drawing of a brain cut in half illustrates some of the major regions of the brain. Source: National Institute on Drug Abuse (1997). Mind Over Matter: The Brain's Response to Drugs, Teacher's Guide.*

The **cerebellum** coordinates the brain's instructions for skilled repetitive movements and for maintaining balance and posture.

The **limbic system**, as discussed in the next section, is involved in regulating emotions, motivations, and movement. It includes the amygdala and hippocampus, which is important for memory formation.

The **diencephalon** contains the thalamus and hypothalamus. The thalamus is involved in sensory perception and regulating movement. The hypothalamus is an important regulator of the pituitary gland, which directs the release of hormones throughout the body.

The **cerebral cortex** makes up the largest part of the brain mass and lies over and around most of the other brain structures. It is the part of the brain responsible for thinking, perceiving, and producing and understanding language. The cortex can be divided into areas that are involved in vision, hearing, touch, movement, smell, and thinking and reasoning (Figure 1.3).

Drugs Act on the Reward System in the Brain

Just as specific areas of the brain control seeing and hearing, specific brain areas also regulate emotions, motivations, and movement. These functions are carried out by a part of the brain called the **limbic system**. The limbic system influences how we respond to the world around us. Imagine a cool sunny day. You finish your work early and head to your favorite park for a leisurely walk with your dog. You are feeling so mellow that when the dog slobbers on your clean shirt, you merely scratch him behind the ears.

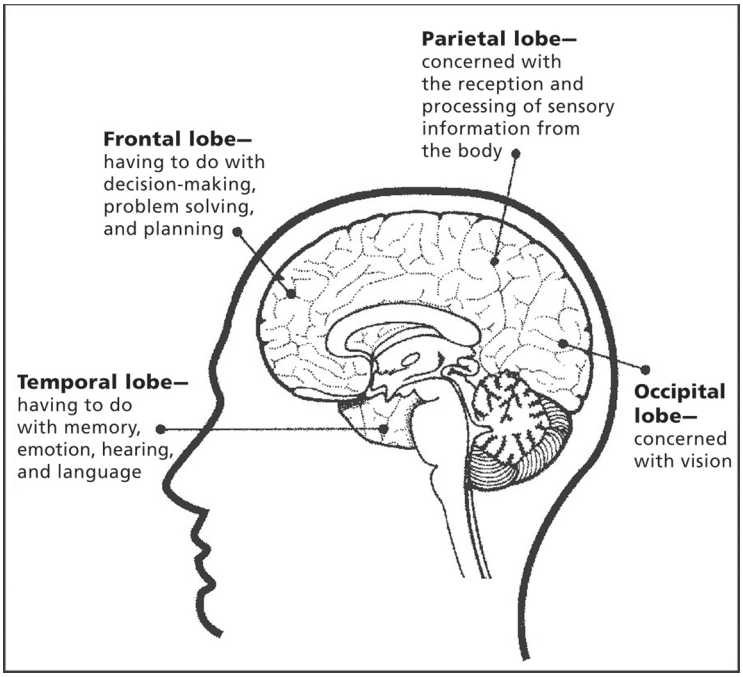


Figure 1.3: *This drawing of a brain cut in half illustrates the lobes of the cerebral cortex and describes their main functions. Source: National Institute on Drug Abuse (1997). Mind Over Matter: The Brain's Response to Drugs, Teacher's Guide.*

You might have a very different reaction on another day when you have to work late, traffic is backed up, and the dog runs away instead of coming to welcome you home. This time when the dog slobbers on you (after he finds his way home again), you shove him away and scold him.

The feelings you have in those two different situations are a result of your limbic system at work. The limbic system uses memories, information about how your body is working, and current sensory input to generate your emotional responses to current situations.

The limbic system is involved in many of our emotions and motivations, particularly those related to survival, such as fear and anger. The system is also involved in pleasurable activities necessary for survival, such as eating and sex. If something is pleasurable, or rewarding, you want to do it again. Pleasurable activities engage the **reward circuit (or system)**, so the brain notes that something important is happening that needs to be remembered and repeated.[1,2] The reward system includes several interconnected structures—the **ventral tegmental area (VTA)**, located at the top of the brain stem; the **nucleus accumbens**; and the **prefrontal cortex** (Figure 1.4). Neurons from the VTA relay messages to the nucleus accumbens and the prefrontal cortex. Information is also relayed back from the cortex to the nucleus accumbens and the VTA.

Most drugs of abuse activate these same VTA and nucleus accumbens neurons; that is why drugs produce pleasurable feelings to the drug user. And, because the feelings are pleasurable, the user wants to continue to experience the pleasure that he or she felt during previous drug use.

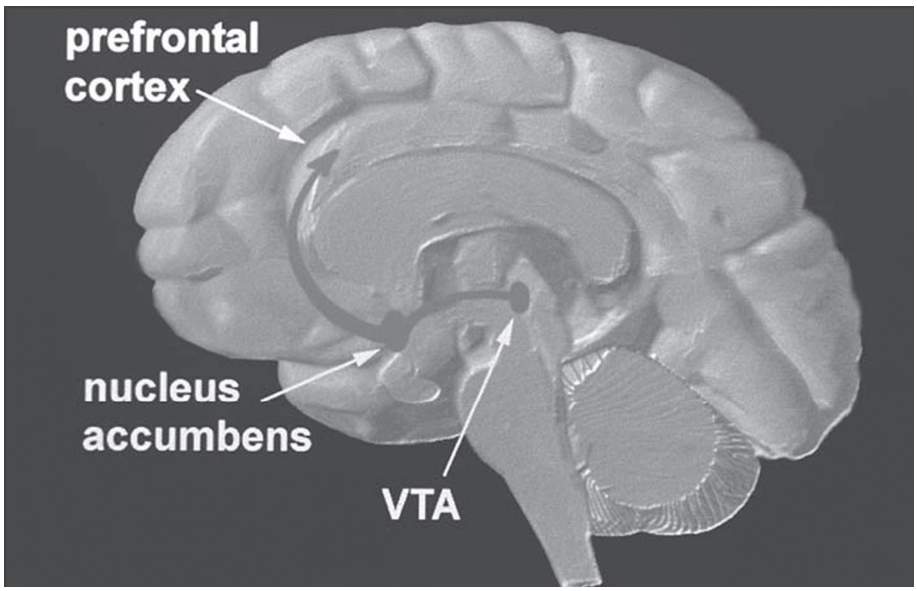


Figure 1.4: *This drawing of a brain cut in half illustrates the brain areas and systems involved in the reward system, or pleasure circuit. Neurons in the ventral tegmental area (VTA) extend axons to the nucleus accumbens and part of the prefrontal cortex. Source: National Institute on Drug Abuse (1996). The Brain & the Actions of Cocaine, Opiates, and Marijuana. Slide Teaching Packet for Scientists.*

One of the reasons that drugs of abuse can exert such powerful control over our behavior is that they act directly on the more evolutionarily primitive brainstem and limbic structures, which can override the cortex in controlling our behavior.

Different drugs of abuse affect the neurons of the reward system in different ways. The activities in Lesson 3 in this module will elucidate the mechanisms by which drugs of abuse exert their effects.

Imaging the Brain

Scientists increasingly use newer technologies to learn more about how the brain works and how drugs of abuse change how the brain works. Historically, scientists could examine brains only after death, but new imaging procedures enable scientists to study the brain in living animals, including humans.

One of the most extensively used techniques to study brain activity and the effects of drugs on the brain is **positron emission tomography (PET)**. PET measures the spatial distribution and movement of radioisotopes in tissues of living subjects. Because the patient is awake, the technique can be used to investigate the relationship between behavioral and physiological effects and changes in brain activity. PET scans can detect nanomolar concentrations of tracer molecules and achieve spatial resolution of about 4 millimeters. In addition, computers can reconstruct images obtained from a PET scan in two or three dimensions.

PET requires the use of compounds labeled with positron-emitting isotopes.[4,5] A cyclotron accelerates protons into the nucleus of nitrogen, carbon, oxygen, or fluorine to generate these isotopes. The additional proton makes the isotope unstable. To become stable again, the proton must break down into a neutron and a positron. The unstable positron travels away from the site of generation and dissipates energy along the way. Eventually, the positron collides with an electron, leading to the emission of two gamma rays at 180° from one another. The gamma rays reach a pair of detectors that record the event. Because the detectors respond only to simultaneous emissions, scientists can precisely map the location where the gamma rays were generated. The labeled radioisotopes are very short-lived. The half-life (the time for half of the radioactive label to disintegrate) of the commonly used radioisotopes ranges from approximately two minutes to less than two hours, depending on the specific compound. Because a PET scan requires only small amounts (a few micrograms) of short-lived radioisotopes, pharmacological and radiological effects are negligible or even nonexistent.

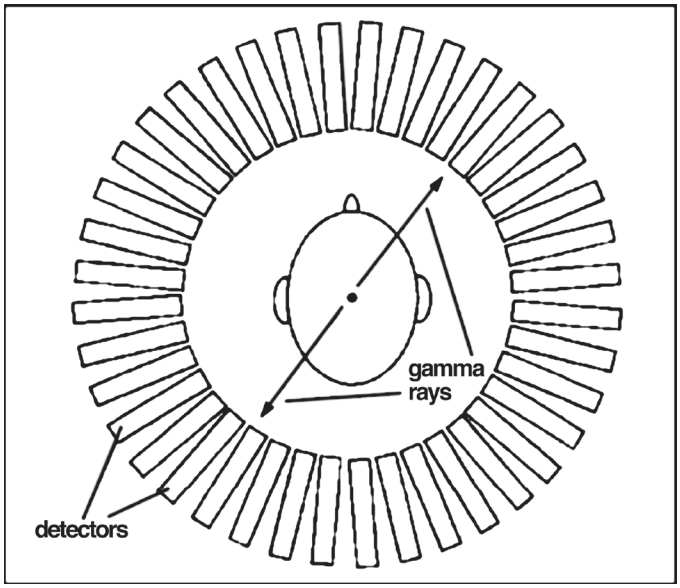


Figure 1.5: *When an unstable positron collides with an electron, the particles are annihilated and two gamma rays are emitted at 180° from each other. Detectors record gamma-ray emission to localize the site of positron annihilation.*

PET scans can answer a variety of questions about brain function, including questions about the activity of neurons. Scientists use different radiolabeled compounds to investigate different biological questions. For example, radiolabeled glucose can identify parts of the brain that become more active in response to a specific stimulus. Active neurons metabolize more glucose than inactive neurons. Active neurons will emit more positrons. This will show as red or yellow on PET scans compared with blue or purple in areas where the neurons are not highly active. PET also helps scientists investigate how drugs affect the brain by enabling them to

- determine the distribution of a drug in the body,
- measure the local concentration of a drug at binding sites,
- estimate receptor occupancy or density,
- evaluate the effects of drugs on other neurotransmitter systems, and
- investigate the activity of enzymes that metabolize the drug.[5]

Although in the context of drug abuse, PET is currently used only as a research tool, it is a powerful diagnostic and monitoring tool for other diseases. For example, PET scans may be used to locate tumors in cancer patients, monitor the spread of cancer, and evaluate the effectiveness of cancer treatment. PET scans are able to reveal the presence of tumors because of the rapid metabolism characteristic of cancerous cells. PET images reveal this increased glucose utilization by cells that have high metabolic rates. PET is an accurate test for coronary heart disease because it can detect areas of diminished blood flow to the heart. Doctors also employ PET to reveal changes in the brain that occur with Alzheimer's disease, Parkinson's disease, or seizure disorders. PET is a valuable tool because it

- is safe,
- replaces multiple testing procedures with a single exam,
- can detect diseases before they show up on other tests,
- can show the progress of disease, and
- reduces or eliminates the need for invasive procedures such as surgery.

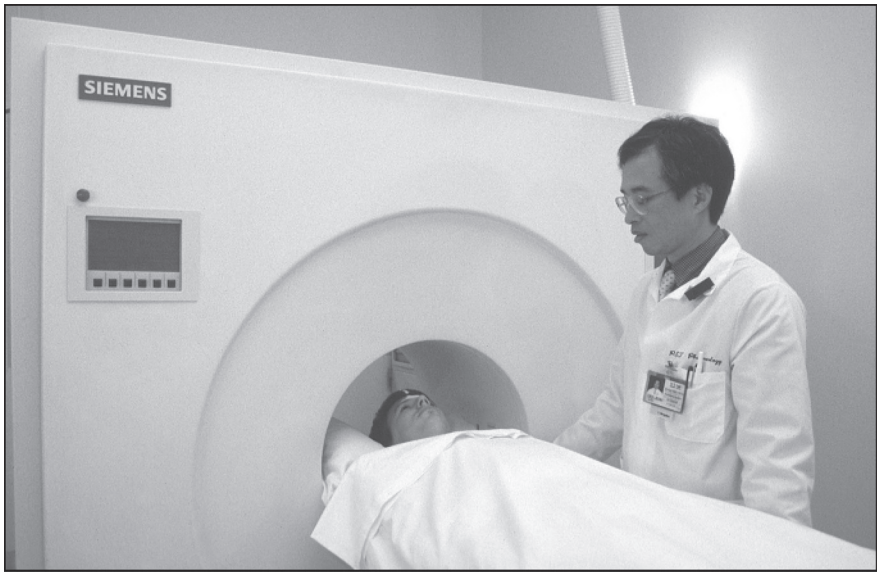


Figure 1.6: *Photograph of PET imaging equipment. Photo courtesy of UCLA School of Medicine.*

Different Neuroimaging Techniques Provide Different Information about the Brain

PET scanning is a major neuroimaging technique used in drug abuse research. However, researchers also use other techniques when they are better for answering a specific question. Similar to PET, single photon emission computed tomography (SPECT), magnetic resonance imaging (MRI), and electroencephalography (EEG) are noninvasive procedures that can measure biological activity through the skull and reveal the living brain at work.[4,6] Each technique has its own advantages, and each provides different information about brain structure and function. Scientists often use more than one technique when conducting their research studies.

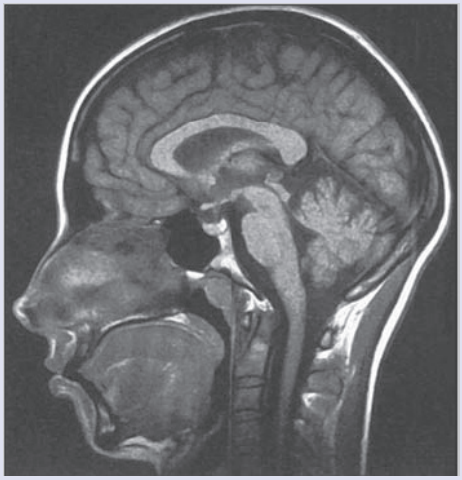


Figure 1.7: *MRI image of human brain. Photo courtesy of Penrad Imaging, Colorado Springs, CO.*

Similar to PET, SPECT imaging uses radioactive tracers and a scanner to record data that a computer constructs into two- or three-dimensional images of active brain regions. Because the tracers used in SPECT take longer to decay than those for PET, longer periods of time between tests are required for SPECT so a patient does not receive or accumulate too high a "load" of radioactivity. While PET is more versatile than SPECT and produces more detailed images with a higher degree of resolution, SPECT is much less expensive than PET and can address many of the same drug abuse research questions.

MRI uses magnetic fields and radio waves to produce high-quality two- or three-dimensional images of brain structures without injecting radioactive tracers. In this procedure, a large cylindrical magnet creates a magnetic field around the research volunteer's head, and radio waves are sent through the magnetic field. Sensors read the signals, and a computer uses the information to construct an image. Using MRI, scientists can image both surface and deep brain structures with a high degree of anatomical detail, and they can detect minute changes in these structures over time. A modification of this technique, called functional MRI (fMRI), enables scientists to see images of blood flow in the brain as it occurs. fMRI provides superior image clarity along with the ability to assess blood flow and brain functions in just a few seconds. However, PET retains the advantage of being able to identify which brain receptors are being bound by neurotransmitters, abused drugs, and potential treatment compounds.

EEG uses electrodes placed on the scalp to detect and measure patterns of electrical activity in the brain. The greatest advantage of EEG is speed: it can record complex patterns of neural activity occurring within fractions of a second after a stimulus has been administered. The drawback to EEG is that it does not provide the spatial resolution of fMRI or PET. Researchers often combine EEG images of brain electrical activity with MRI scans to localize brain activity more precisely.

In Advance

Web-Based Activities

Activity	Web Component?
1	No
2	Yes
3	Yes
4	No
5	No

Photocopies

For the class	For each group of 3 students	For each student
1 transparency of Master 1.3, *PET Image Tasks* 1 transparency of Master 1.4, *Major Regions of the Brain* 1 transparency of Master 1.5, *Areas of the Cerebral Cortex and Their Functions* 1 transparency of Master 1.7, *The Reward System*	1 copy of Master 1.1, *Positron Emission Tomography (PET) Images** 1 copy of Master 1.2, *Interpreting PET Images*	1 copy of Master 1.6, *What Happened to Phineas Gage?*

* The online version of Activity 2 is the preferred approach. Copies of Master 1.1 are needed only if the Internet is unavailable for classroom use. If needed, make one set of color photocopies for each team of three students. Field-test teachers recommend laminating the color copies to help preserve them.

Materials

Activity	Materials
Activity 1	6 to 8 index cards (3" x 5" or 4" x 6")
Activity 2	overhead projector, computers (optional)
Activity 3	computers or overhead projector
Activity 4	none
Activity 5	overhead projector

Preparation

Prepare task cards for Activity 1, Step 1 (see page 28). Decide which tasks you wish students to do. Write the instructions for each task on an index card.

Arrange for the class to have access to the Internet for Activities 2 and 3, if possible.

Procedure

Activity 1: What Does the Brain Do?

This activity is designed to engage students in learning about the brain and to help the teacher assess the students' prior knowledge of the scope of functions regulated by the human brain.

1. **Ask for six to eight volunteers (one for each task) to participate in an activity. Ask them to come to the front of the room, and give each volunteer one of the prepared task cards. Then ask each volunteer, one at a time, to perform the task listed on his or her task card.**

   The specific tasks can and should be very diverse. The following list suggests some appropriate tasks:

   - wave hands in the air
   - eat
   - hop up and down on the right foot
   - walk around the classroom
   - look out the window
   - recite the Pledge of Allegiance
   - sing "Mary Had a Little Lamb"
   - do an algebra problem (e.g., Solve the following problem: 5x + 14 = 34. What is the value of x?)
   - recall and describe the way to get from the classroom to the cafeteria (e.g., Give directions to walk from this classroom to the cafeteria.)
   - read a sentence aloud (e.g., Read the following sentence aloud: "Four score and seven years ago our fathers brought forth on this continent, a new nation, conceived in Liberty, and dedicated to the proposition that all men are created equal."[8])

2. **After the volunteers perform the tasks, ask the students to identify the part of the body that is involved in all of the tasks.**

   The goal for this question is for students to acknowledge that the brain is involved in regulating all human physiological, behavioral, and emotional functions. For example, point out that all students are breathing. When most people think about breathing, they think about the lungs, but not the involvement of the brain. Also, point out that each student's heart is beating. Although the heart is actually pumping the blood, the brain fulfills an important role in regulating the heartbeat. The involvement of the brain will be more obvious for some of the tasks than for others.

3. **After students deduce that the brain is involved in all of these activities, ask students to suggest how they think scientists investigate what happens in the human brain.**

   Students will provide a variety of answers, including watching a person's behavior, using various imaging techniques (such as PET scans, CT scans, or MRI), using animals (either living or dead) for research, and so forth.

Activity 2: Positron Emission Tomography and Brain Function

The following procedure describes how to conduct the Web version of this activity, which is the preferred method of instruction. Instructions for conducting the alternative print version follow the shaded Steps 1–5.

1. **Before starting the Web-based activity, inform students that they will be analyzing positron emission tomography (PET) images. PET is one technology scientists use to learn about the function of the living human brain. The PET images that the students will examine use radioactive glucose to identify parts of the brain that are active. Active brain areas use more glucose than less active areas and thus more of the labeled glucose is taken up into the active areas. PET images are color-coded by a computer. The most active brain areas are shown in red. Areas in yellow are less active than areas in red, but are more active than areas in green. The least active areas are shown in blue or purple. Students will see a color scale on the screen with the PET images for reference.**

   Students may have seen color-coded computer images on television weather reports. In weather radar images, areas encountering heavy storms appear in red and yellow, and areas experiencing milder weather disturbances appear in green or blue.

2. **Divide the class into groups of three students. Arrange for each group to work at a computer to complete the online activity *Analyzing Brain Images*. Give each group a copy of Master 1.2, *Interpreting PET Images*.**

   Go to the supplement's Web site. Select Lesson 1—*The Brain: What's Going On in There?*

3. **Instruct students to work with their group members to analyze the PET images and to answer the questions on Master 1.2. When students reach question 5, display a transparency of Master 1.3, *PET Image Tasks*, to provide the needed information.**

4. **After the groups complete the activity and write their answers to the questions on Master 1.2, discuss the answers to the questions as a class.**

Content Standard A: Formulate and revise scientific explanations and models using logic and evidence.

Content Standard A: Scientists rely on technology to enhance the gathering and manipulation of data.

Content Standard C: Organisms have behavioral responses to internal changes and to external stimuli.

Content Standard A:
Communicate and defend a scientific argument.

Sample Answers to Questions on Master 1.2

Question 1. When you look at the images that make up Set #1 (Master 1.1), how do the four images differ from each other?

The brain images are different sizes. The images show variation in the amount and pattern of the different colors.

Question 2. Why are four images shown in each set of PET images? Why would scientists need to examine more than one PET image taken of a subject's brain?

The four PET images in each set show the activity at different levels of the brain. If a scientist examines only a single image, he or she increases the chances of missing important information.

Question 3. When comparing the images in Set #1 with the images in Sets #2, 3, 4, 5, and 6, how is the activity of the brain in each of these sets different from Set #1's?

Set Number	Identify the image that shows the greatest change (a, b, c, or d)	Describe the change in brain activity
2	b	There is more red on the right side of the brain, mainly near the center in terms of front-to-back direction. There is also red on the left side, but it is not as strong as it is on the right side.
3	b	The main activation is in the back of the brain on both sides of the midline.
4	c	The main activation is at the front of the brain near the periphery on both sides of the midline.
5	d	The main activation is in four areas, two on each side of the brain. Two are very near the back of the brain, and two are farther forward.
6	a	The main areas of activation are a spot on the left side of the brain and a smaller spot near the front of the brain on the midline.

Question 4. The PET images shown in Set #1 show brain activity in a resting brain. The images in Sets #2–6 show activity in the brains of humans who are doing different tasks. When you look at the PET scans and the chart in question #3, what generalizations can you make about the activity of the brain when different tasks are performed?

The key points of this exercise are that different brain areas are activated during different tasks and different brain functions are localized to different brain areas.

Question 5. Compare the tasks that the subject performed during each of the PET scans (as shown on the overhead transparency) with the individual's brain activity. Use the information from the overhead and from the PET images to complete the following chart (Master 1.2b).

Set Number	Brain region that is more active in the PET image	This region is involved in processing information related to
2	auditory cortex	hearing
3	primary visual cortex	vision, sight
4	frontal cortex	thinking
5	hippocampus	memory
6	motor cortex	movement

5. **Instruct students to watch the online video *How PET Works*.**

   From the main menu, select Lesson 1—*The Brain: What's Going On in There?* Then click on *How Is PET Done*? This video expands students' understanding of PET. A scientist explains how PET imaging is done.

   After students have completed the activity, you may wish to challenge them by asking them to propose an explanation for why functions are localized to specific brain areas. Why would this be beneficial from an evolutionary standpoint? (See Background Information on pages 20–21.)

Content Standard E: Science often advances with the introduction of new technology.

The following procedure is for classes using the print version of the activity.

1. **Tell students that one of the ways that scientists investigate the function of the living human brain is by using positron emission tomography (PET). The PET images that the students will examine use radioactive glucose to identify parts of the brain that are active. Active brain areas use more glucose than less active areas and thus more of the labeled glucose is taken up into the active areas. PET scans are color-coded. The scale bar shown on Master 1.1, *Positron Emission Tomography (PET) Images*, provides a reference. The most active brain areas are shown in red. Areas in yellow are less active than areas in red, but are more active than areas in green. The least active areas are shown in blue or purple.**

   PET images are color-coded by computer to show activity in the brain. This is similar to color-coded images students may have seen on television weather reports. In weather radar images, areas encountering heavy storms appear in red and yellow, and areas experiencing milder weather disturbances appear in green or blue.

Content Standard A: Formulate and revise scientific explanations and models using logic and evidence.

Content Standard A: Scientists rely on technology to enhance the gathering and manipulation of data.

Content Standard C: Organisms have behavioral responses to internal changes and to external stimuli.

2. **Divide the class into groups of three students. Give each group a copy of Master 1.1, *Positron Emission Tomography (PET) Images*, and a copy of Master 1.2, *Interpreting PET Images*.**

3. **Help students understand how the PET images correlate to the orientation of the brain in the body.**

   The PET images show a cross-section of the brain. The four images in each set show four different levels of the brain. In these images, the front of the brain is toward the top (the subject's face is toward the top of the image). Have the students examine the PET scans and identify the regions that become active in response to each stimulus.

NSES

Content Standard A:
Communicate and defend a scientific argument.

4. **Instruct students to work with their group members to answer the questions on Master 1.2. When students reach question 5, display a transparency of Master 1.3, *PET Image Tasks*, to provide the needed information.**

5. **Discuss the answers to the questions on Master 1.2 as a class.**

   Sample answers for the questions on Master 1.2 are listed in the procedure for the online version of Activity 2 on pages 30–31.

Activity 3: Parts of the Brain

NSES

Content Standard C:
Cells can differentiate and complex multicellular organisms are formed as a highly organized arrangement of differentiated cells.

Note to teachers: This activity is intended for classes that want more information about the anatomy of the brain. Learning the names and functions of brain lobes and regions is not a major focus and could distract some students from the main concept, that brain functions are localized to specific brain areas. Understanding the main concept is critical for understanding how neurons communicate and how drugs of abuse affect neuronal function. These topics are covered in Lessons 2 and 3.

For classrooms using the Web version of this activity.

1. **Have students continue in their groups to conduct the online activity *What Does This Part of the Brain Do?***

   To access this activity, go to the supplement's Web site and select Lesson 1—*The Brain: What's Going On in There?* Then click on *What Does This Part of the Brain Do?*

2. **Ask students to take out their completed worksheet on Master 1.2. Review the tasks that the students performed in Step 1 of Activity 1 and ask students to identify the part of the brain that was active in each case.**

   From the information in question 5 on Master 1.2, students should be able to identify the brain area involved in some of the tasks performed in Step 1, but others were not covered in that question. Also, for some

of the activities listed, more than one function is involved. For example, reciting the Pledge of Allegiance requires both memory and speech. Be aware that this chart is very simplified. Virtually all mental functions involve more than one brain area.

The following procedure is for classes using the print version of this activity.

1. **Display transparencies of Master 1.4, *Major Regions of the Brain*, and Master 1.5, *Areas of the Cerebral Cortex and Their Function*.**

2. **Ask students to take out their completed worksheet on Master 1.2. Review the tasks that the students performed in Step 1 of Activity 1 and ask students to identify the part of the brain that was active in each case.**

   From the information in question 5 on Master 1.2, students should be able to identify the brain area involved in some of the tasks performed in Step 1 of Activity 1, but others were not covered in that question. Also, for some of the activities listed, more than one function is involved. For example, reciting the Pledge of Allegiance requires both memory and speech. Be aware that this chart is very simplified. Virtually all mental functions involve more than one brain area.

Remember, the names of the parts of the brain are not the important concepts that students need to learn. Rather, this is a way for students to relate what they have learned about localization of brain function to other activities and thus reinforce the concept that different brain regions control different functions.

Activity	General Functions Involved	Brain Area(s) Involved*
breathing		brainstem (medulla)
heart rate		brainstem (medulla)
waving hands in the air	movement	cerebrum—frontal lobe (motor cortex) cerebellum
hopping up and down on the right foot	movement	cerebrum—frontal lobe (motor cortex) cerebellum
walking around the classroom	movement	cerebrum—frontal lobe (motor cortex) cerebellum
looking out the window	vision	cerebrum—occipital lobe (primary visual cortex)
reciting the Pledge of Allegiance	speech, memory	cerebrum—frontal lobe hippocampus
doing an algebra problem	thinking	cerebrum—frontal lobe
remembering directions to get from the classroom to the school cafeteria	memory	hippocampus
reading a sentence aloud	speech	cerebrum—parietal lobe and frontal lobe

* This is very simplified. Most mental functions involve more than one area of the brain.

Content Standard A: Scientists rely on technology to enhance the gathering and manipulation of data.

Content Standard C: Multicellular animals have nervous systems that generate behavior.

Content Standard G: Usually, changes in scientific knowledge occur as small modifications in extant knowledge.

Activity 4: Who Was Phineas Gage?

1. **Give each student a copy of Master 1.6, *What Happened to Phineas Gage?* Instruct students to read the story and answer the questions.**

   Phineas Gage was injured in an accident in the 1800s. His recovery from the injury and the resulting change in personality and behavior gave scientists new insight into brain function.[8,9]

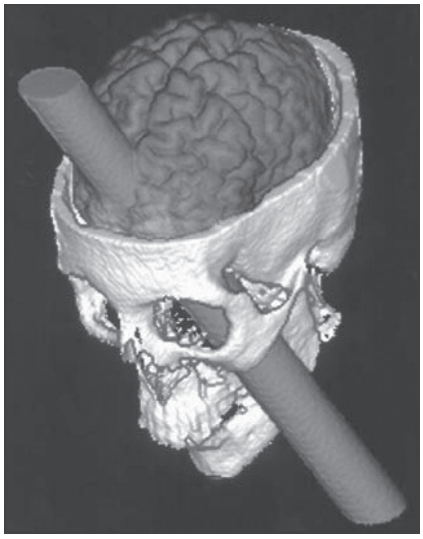


Figure 1.8: *Computer reconstruction of the skull of Phineas Gage illustrating the projection of the tamping rod through the brain. Reprinted with permission from Damasio, H., et al. 1994. The return of Phineas Gage: Clues about the brain from a famous patient.* Science *264:1102-05.*

Sample Answers to Questions on Master 1.6

Question 1. How did Phineas Gage change after the accident?

After the accident, Gage's personality changed. He was no longer the likeable and responsible person he was before the accident. Instead he was irresponsible and used profanity.

Question 2. How did Phineas Gage's accident change scientists' understanding of the brain?

Scientists learned that the brain does more than control language and movement. It also controls emotions and social behaviors. Equally important, scientists learned that the brain processes information for specific functions in specific brain areas.

Activity 5: Where Do Drugs Act?

1. **Now that students understand that different areas in the brain process specific types of stimuli, ask students to consider things that make them feel good, or are pleasurable. How might doing something pleasurable change brain activity?**

   If students understand, from Activity 2 of this lesson, that brain functions are localized to specific brain areas, they should suspect that things that make them feel pleasure will stimulate a specific brain region.

2. **Display the transparency of Master 1.7, *The Reward System*. Tell students that part of the brain produces and regulates feelings of pleasure, which scientists call reward. This brain region is called the reward system. The parts of the brain that make up the reward system are the ventral tegmental area (VTA), the nucleus accumbens, and part of the frontal region of the cerebral cortex. This brain region responds to life-sustaining activities such as eating and drinking, as well as species-sustaining sexual activity.**

3. **Introduce students to the idea that drugs of abuse activate the brain's reward system, or pleasure circuit. Drugs alter the way the reward system functions. Drugs also act on other regions of the brain, but their action in the reward system makes the person abusing drugs feel pleasure and want to continue taking drugs.**

   Students will learn more about how drugs exert these effects in the remaining lessons in this curriculum supplement.

4. **Ask students to hypothesize how PET images of a person's brain would change after taking drugs of abuse.**

   Students may predict an increase in activity in the reward system of the brain. Currently, though, PET technology is not sensitive enough to allow scientists to visualize this reward-system activation. The VTA and nucleus accumbens are too small for PET images to detect significant activity changes. Scientists have relied on other technologies to learn that drugs of abuse do activate these brain regions.

   Some students may hypothesize that PET images of the brain after drug abuse would also show changes in other regions of the brain. This is correct. Drugs do affect other regions of the brain, but it is the reward system that triggers the pleasurable feelings associated with drug use. More information on the more widespread effects of drugs on the brain is presented in Lesson 4.

Content Standard C:
Multicellular organisms have nervous systems that generate behavior.

Content Standard F:
An individual's mood and behavior may be modified by substances.

If students understand that PET images reveal changes in brain activity and that drugs activate the reward system in the brain, students should predict that the reward system (the VTA and nucleus accumbens) should be more active after an individual takes drugs. These brain areas should appear red or yellow in PET scans taken after drug use, whereas they would be purple or blue in PET images taken before drug use.

Lesson 1 Organizer: WEB VERSION

What the Teacher Does	Procedure Reference
Activity 1: *What Does the Brain Do?*	
Ask for six to eight volunteers to perform tasks written on the task cards you prepared.	Page 28 Step 1
Ask students to identify the part of the body involved in all of the tasks they just saw.	Page 28 Step 2
After students deduce that the brain is the part of the body involved, ask students to suggest how they think scientists investigate the human brain.	Page 28 Step 3
Activity 2: *Positron Emission Tomography and Brain Function*	
Inform students that they will analyze positron emission tomography (PET) images. Briefly explain that these PET images use radioactive glucose to identify areas of brain activity. Active brain areas use more glucose than less active areas. Introduce students to the color-coding added by a computer and the color-scale reference. Areas in red are the most active. Areas in blue or purple are the least active.	Page 29 Step 1
Divide the class into teams of three students. Have each group log onto a computer, go to the Student Activities page, and select Lesson 2—*The Brain: What's Going On in There?* and then *Analyzing Brain Images*. Give each team a copy of **Master 1.2**.	Page 29 Step 2
Allow time for student teams to analyze the PET images and answer questions on **Master 1.2**. Display a transparency of **Master 1.3** when students reach question 5.	Page 29 Step 3
Reconvene the class to discuss the answers to the questions on **Master 1.2**.	Pages 29–31 Step 4
Allow time for students to watch a segment online about PET imaging. From the Student Activities menu, ask students to select Lesson 1—*The Brain: What's Going On in There?* and click on *How Is PET Done?*	Page 31 Step 5

What the Teacher Does	Procedure Reference
Activity 3: *Parts of the Brain*	
Have students return to their teams to work on an online activity. From the Student Activities menu, select Lesson 1—*The Brain: What's Going On in There?* and then *What Does This Part of the Brain Do?*	Page 32 Step 1 
Instruct students to examine their completed **Master 1.2**. Review the tasks that the student volunteers performed in Step 1 of Activity 1. Have students identify the part of the brain that was active in each case.	Page 32 Step 2
Activity 4: *Who Was Phineas Gage?*	
Give each student a copy of **Master 1.6** and ask them to read the story and answer the questions.	Page 34 Step 1 
Activity 5: *Where Do Drugs Act?*	
Ask students to consider things that make them feel good or are pleasurable. Have them consider the question, How might doing something pleasurable change brain activity?	Page 35 Step 1
Display a transparency of **Master 1.7**. Tell students that part of the brain produces and regulates feelings of pleasure, which scientists call reward. Point out the parts of the brain that make up the reward system: the ventral tegmental area (VTA), the nucleus accumbens, and part of the frontal region of the cerebral cortex.	Page 35 Step 2 
Introduce students to the idea that drugs of abuse activate the brain's reward system. Specifically, introduce the idea that the action of drugs on the reward center is what makes the user feel pleasure and want to continue taking drugs.	Page 35 Step 3
Ask students to hypothesize how PET images of a person's brain would change after taking drugs of abuse. Inform them that they will learn more about how drugs affect the brain during the remaining lessons in this unit.	Page 35 Step 4

 = Involves using the Internet.

 = Involves copying a master.

 = Involves making a transparency.

Lesson 1 Organizer: PRINT VERSION

What the Teacher Does	Procedure Reference
Activity 1: *What Does the Brain Do?*	
Ask for six to eight volunteers to perform tasks written on the task cards you prepared.	Page 28 Step 1
Ask students to identify the part of the body involved in all of the tasks they just saw.	Page 28 Step 2
After students deduce that the brain is the part of the body involved, ask students to suggest how they think scientists investigate the human brain.	Page 28 Step 3
Activity 2: *Positron Emission Tomography and Brain Function*	
Inform students that they will analyze positron emission tomography (PET) images. Briefly explain that these PET images use radioactive glucose to identify areas of brain activity. Active brain areas use more glucose than less active areas. Introduce students to the color-coding added by a computer and the color-scale reference. Areas in red are the most active. Areas in blue or purple are least active.	Page 31 Step 1
Divide the class into groups of three students. Give each group a copy of **Master 1.1** and of **Master 1.2**. Help students understand how the images relate to the orientation of the brain in the body.	Page 32 Steps 2, 3 M
Allow time for student teams to analyze the PET images and answer questions on **Master 1.2**. Display a transparency of **Master 1.3** when students reach question 5.	Page 32 Step 4 T
Reconvene the class to discuss the answers to the questions on **Master 1.2**.	Page 32 Step 5

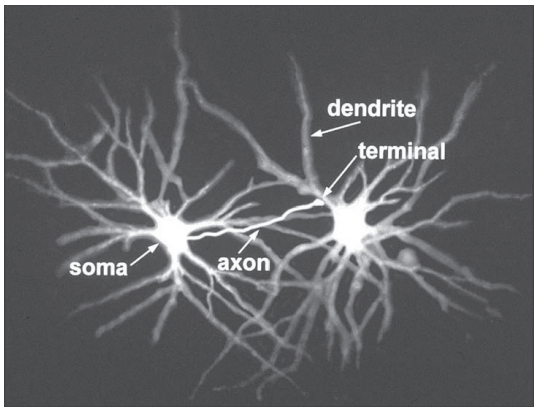
What the Teacher Does	Procedure Reference
Activity 3: *Parts of the Brain*	
Display a transparency of **Master 1.4** followed by a transparency of **Master 1.5**.	Page 33 Step 1 T
Instruct students to examine their completed **Master 1.2**. Review the tasks that the student volunteers performed in Step 1 of Activity 1. Have students identify the part of the brain that was active in each case.	Page 33 Step 2
Activity 4: *Who Was Phineas Gage?*	
Give each student a copy of **Master 1.6,** and ask them to read the story and answer the questions.	Page 34 Step 1 M
Activity 5: *Where Do Drugs Act?*	
Ask students to consider things that make them feel good or are pleasurable. Have them consider the question, How might doing something pleasurable change brain activity?	Page 35 Step 1
Display a transparency of **Master 1.7**. Tell students that part of the brain produces and regulates feelings of pleasure, which scientists call reward. Point out the parts of the brain that make up the reward system: the ventral tegmental area (VTA), the nucleus accumbens, and part of the frontal region of the cerebral cortex.	Page 35 Step 2 T
Introduce students to the idea that drugs of abuse activate the brain's reward system. Specifically, introduce the idea that the action of drugs on the reward center is what makes the user feel pleasure and want to continue taking drugs.	Page 35 Step 3
Ask students to hypothesize how PET images of a person's brain would change after taking drugs of abuse. Inform them that they will learn more about how drugs affect the brain during the remaining lessons in this unit.	Page 35 Step 4

M = Involves copying a master.

T = Involves making a transparency.

LESSON 2
Explore/Explain

Neurons, Brain Chemistry, and Neurotransmission



Source: NIDA. 1996. The Brain & the Actions of Cocaine, Opiates, and Marijuana. Slide Teaching Packet for Scientists.

At a Glance

Overview
Students learn that the neuron is the functional unit of the brain. To learn how neurons convey information, students analyze a sequence of illustrations and watch an animation. They see that neurons communicate using electrical signals and chemical messengers called neurotransmitters that either stimulate or inhibit the activity of a responding neuron. Students then use the information they have gained to deduce how one neuron influences the action of another.

Major Concept
Neurons convey information using electrical and chemical signals.

Objectives
By the end of these activities, the students will
- understand the hierarchical organization of the brain, neuron, and synapse;
- understand the sequence of events involved in communication at the synapse; and
- understand that synaptic transmission involves neurotransmitters that may be either excitatory or inhibitory.

Basic Science–Health Connection
Communication between neurons is the foundation for brain function. Understanding how neurotransmission occurs is crucial to understanding how the brain processes and integrates information. Interruption of neural communication causes changes in cognitive processes and behavior.

Background Information

The Brain Is Made Up of Nerve Cells and Glial Cells

The brain of an adult human weighs about 3 pounds and contains billions of cells. The two distinct classes of cells in the nervous system are **neurons** (nerve cells) and **glia** (glial cells).

The basic signaling unit of the nervous system is the neuron. The brain contains billions of neurons; the best estimates are that the adult human brain contains 10^{11} neurons. The interactions between neurons enable people to think, move, maintain homeostasis, and feel emotions. A neuron is a specialized cell that can produce different actions because of its precise connections with other neurons, sensory receptors, and muscle cells. A typical neuron has four morphologically defined regions: the cell body, dendrites, axons, and presynaptic, or axon, terminals.[1,2,3]

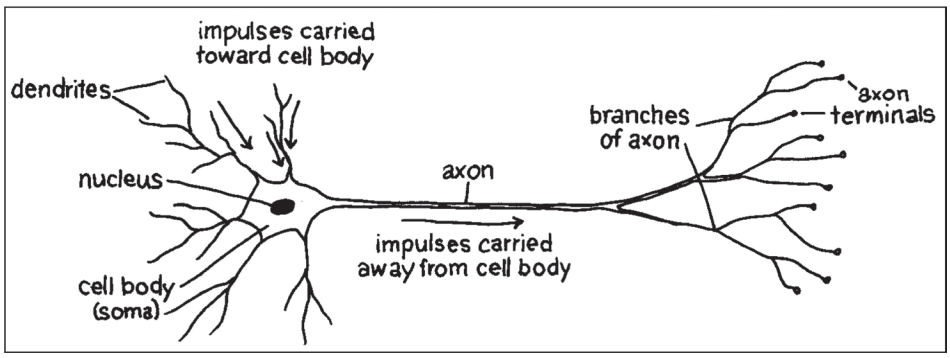


Figure 2.1: *The neuron, or nerve cell, is the functional unit of the nervous system. The neuron has processes called dendrites that receive signals and an axon that transmits signals to another neuron.*

The **cell body**, also called the **soma**, is the metabolic center of the neuron. The nucleus is located in the cell body, and most of the cell's protein synthesis occurs in the cell body.

A neuron usually has multiple processes, or fibers, called **dendrites** that extend from the cell body. These processes usually branch out somewhat like tree branches and serve as the main apparatus for receiving input into the neuron from other nerve cells.

The cell body also gives rise to the **axon**. Axons can be very long processes; in some cases, they may be up to 1 meter long. The axon is the part of the neuron that is specialized to carry messages away from the cell body and to relay messages to other cells. Some large axons are surrounded by a fatty insulating material called myelin, which enables the electrical signals to travel down the axon at higher speeds.

Near its end, the axon divides into many fine branches that have specialized swellings called axon, or presynaptic, terminals. These presynaptic terminals end in close proximity to the dendrites of another neuron. The dendrite of one neuron receives the message sent from the presynaptic terminal of another neuron.

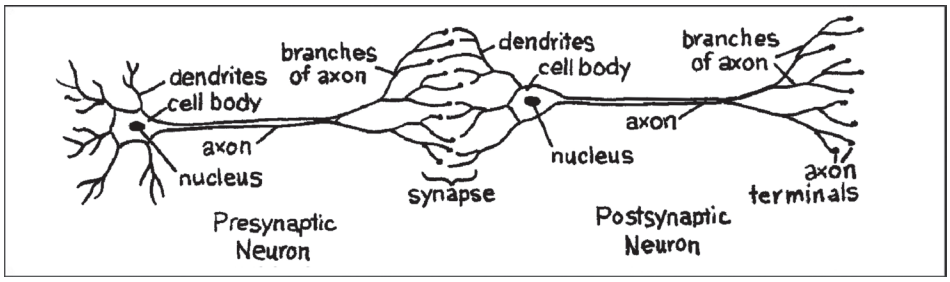


Figure 2.2: *Neurons transmit information to other neurons. Information passes from the axon of the presynaptic neuron to the dendrites of the postsynaptic neuron.*

The site where a presynaptic terminal ends in close proximity to a receiving dendrite is called the **synapse**. The cell that sends out information is called the **presynaptic** neuron, and the cell that receives the information is called the **postsynaptic** neuron. It is important to note that the synapse is *not* a physical connection between the two neurons; there is no cytoplasmic continuity between the two neurons. The intercellular space between the presynaptic and postsynaptic neurons is called the **synaptic space** or **synaptic cleft**. An average neuron forms approximately 1,000 synapses with other neurons. It has been estimated that there are more synapses in the human brain than there are stars in our galaxy. Furthermore, synaptic connections are not static. Neurons form new synapses or strengthen synaptic connections in response to life experiences. This dynamic change in neuronal connections is the basis of learning.

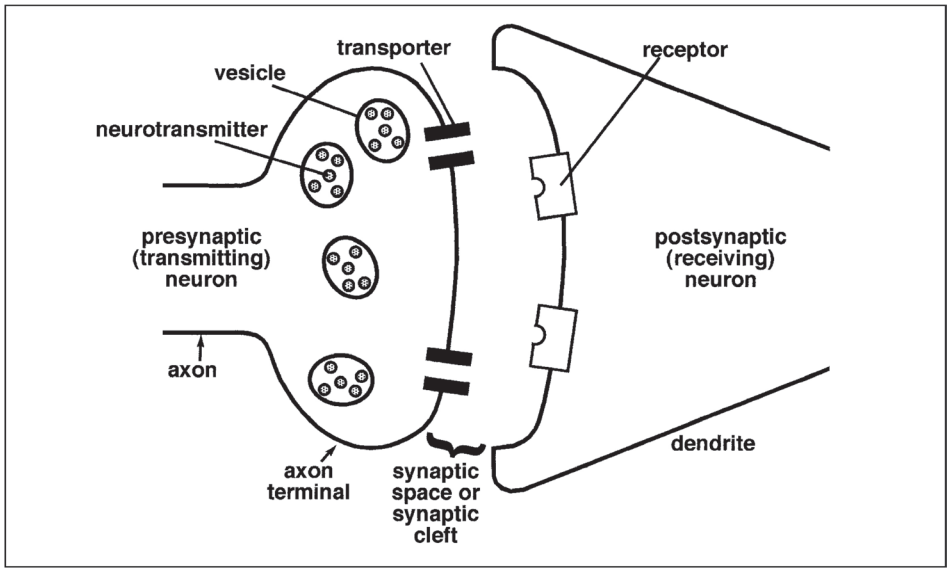


Figure 2.3: *The synapse is the site where chemical signals pass between neurons. Neurotransmitters are released from the presynaptic neuron terminals into the extracellular space, the synaptic cleft or synaptic space. The released neurotransmitter molecules can then bind to specific receptors on the postsynaptic neuron to elicit a response. Excess neurotransmitter can then be reabsorbed into the presynaptic neuron through the action of specific reuptake molecules called transporters. This process ensures that the signal is terminated when appropriate.*

The brain contains another class of cells called glia. There are as many as 10 to 50 times more glial cells than neurons in the central nervous system. Glial cells are categorized as microglia or macroglia. Microglia are phagocytic cells that are mobilized after injury, infection, or disease. They are derived from macrophages and are unrelated to other cell types in the nervous system. The three types of macroglia are oligodendrocytes, astrocytes, and Schwann cells. The oligodendrocytes and Schwann cells form the myelin sheaths that insulate axons and enhance conduction of electrical signals along the axons.

Scientists know less about the functions of glial cells than they do about the functions of neurons. Glial cells fulfill a variety of functions including as

- support elements in the nervous system, providing structure and separating and insulating groups of neurons;
- oligodendrocytes in the central nervous system and Schwann cells in the peripheral nervous system, which form myelin, the sheath that wraps around certain axons;
- scavengers that remove debris after injury or neuronal death;
- helpers in regulating the potassium ion (K^+) concentration in the extracellular space and taking up and removing chemical neurotransmitters from the extracellular space after synaptic transmission;
- guides for the migration of neurons and for the outgrowth of axons during development; and
- inducers of the formation of impermeable tight junctions in endothelial cells that line the capillaries and venules of the brain to form the blood-brain barrier.[3]

The Blood-Brain Barrier

The blood-brain barrier protects the neurons and glial cells in the brain from substances that could harm them. Endothelial cells that form the capillaries and venules make this barrier, forming impermeable tight junctions. Astrocytes surround the endothelial cells and induce them to form these junctions. Unlike blood vessels in other parts of the body that are relatively leaky to a variety of molecules, the blood-brain barrier keeps many substances, including toxins, away from the neurons and glia.

Most drugs do not get into the brain. Only drugs that are fat soluble can penetrate the blood-brain barrier. These include drugs of abuse as well as drugs that treat mental and neurological illness.

The blood-brain barrier is important for maintaining the environment of neurons in the brain, but it also presents challenges for scientists who are investigating new treatments for brain disorders. If a medication cannot get into the brain, it cannot be effective. Researchers attempt to circumvent the problems in different ways. Some techniques alter the structure of the drug to make it more lipid soluble. Other strategies attach potential therapeutic agents to molecules that pass through the blood-brain barrier, while others attempt to open the blood-brain barrier.[4]

Neurons Use Electrical and Chemical Signals to Transmit Information*

The billions of neurons that make up the brain coordinate thought, behavior, homeostasis, and more. How do all these neurons pass and receive information?

Neurons convey information by transmitting messages to other neurons or other types of cells, such as muscles. The following discussion focuses on how one neuron communicates with another neuron. Neurons employ electrical signals to relay information from one part of the neuron to another. The neuron converts the electrical signal to a chemical signal in order to pass the information to another neuron. The target neuron then converts the message back to an electrical impulse to continue the process.

Within a single neuron, information is conducted via electrical signaling. When a neuron is stimulated, an electrical impulse, called an **action potential**, moves along the neuron axon.[5] Action potentials enable signals to travel very rapidly along the neuron fiber. Action potentials last less than 2 milliseconds (1 millisecond = 0.001 second), and the fastest action potentials can travel the length of a football field in 1 second. Action potentials result from the flow of ions across the neuronal cell membrane. Neurons, like all cells, maintain a balance of ions inside the cell that differs from the balance outside the cell. This uneven distribution of ions creates an electrical potential across the cell membrane. This is called the resting membrane potential. In humans, the resting membrane potential ranges from –40 millivolts (mV) to –80 mV, with –65 mV as an average resting membrane potential. The resting membrane potential is, by convention, assigned a negative number because the inside of the neuron is more negatively charged than the outside of the neuron. This negative charge results from the unequal distribution of sodium ions (Na^+), potassium ions (K^+), chloride ions (Cl^-), and other organic ions. The resting membrane potential is maintained by an energy-dependent Na^+-K^+ pump that keeps Na^+ levels low inside the neuron and K^+ levels high inside the neuron. In addition, the neuronal membrane is more permeable to K^+ than it is to Na^+, so K^+ tends to leak out of the cell more readily than Na^+ diffuses into the cell.

A stimulus occurring at the cell body starts an electrical change that travels like a wave over the length of the neuron. This electrical change, the action potential, results from a change in the permeability of the neuronal membrane. Sodium ions rush into the neuron, and the inside of the cell becomes more positive. The Na^+-K^+ pump then restores the balance of sodium and potassium to resting levels. However, the influx of Na^+ ions in one area of the neuron fiber starts a similar change in the adjoining segment, and the impulse moves from the cell body toward the axon terminal. Action potentials are an **all-or-none phenomenon**. Regardless of the stimuli, the amplitude and duration of an action potential are the same. The action potential either occurs or it doesn't. The response of the neuron to an action potential depends on how many action potentials it transmits and their frequency.

* "Electrical signals" are not actually electric because ions travel down the axon, not electrons. For the sake of simplicity, though, we use "electrical."

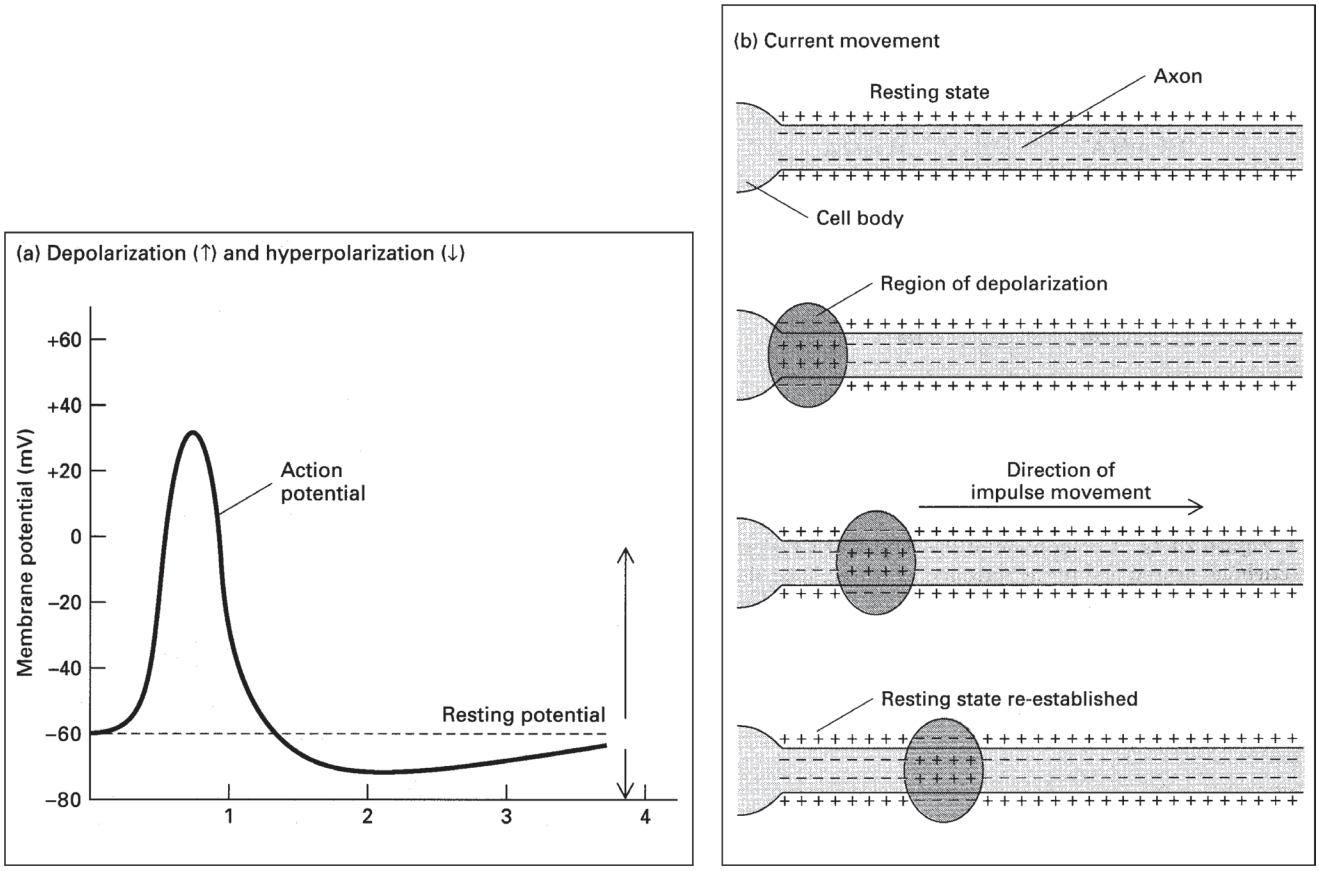


Figure 2.4: *(a) Recording of an action potential in an axon following stimulation due to changes in the permeability of the cell membrane to sodium and potassium ions. (b) The cell membrane of a resting neuron is more negative on the inside of the cell than on the outside. When the neuron is stimulated, the permeability of the membrane changes, allowing Na+ to rush into the cell. This causes the inside of the cell to become more positive. This local change starts a similar change in the adjoining segment of the neuron's membrane. In this manner, the electrical impulse moves along the neuron. From:* Molecular Cell Biology, *by Lodish et al. 1986, 1990 by Scientific American Books, Inc. Used with permission by W.H. Freeman and Company.*

Electrical signals carry information within a single neuron. Communication between neurons (with a few exceptions in mammals) is a chemical process. When the neuron is stimulated, the electrical signal (action potential) travels down the axon to the axon terminals. When the electrical signal reaches the end of the axon, it triggers a series of chemical changes in the axon terminal. Calcium ions (Ca^{++}) flow into the axon terminal, which then initiates the release of neurotransmitters. A **neurotransmitter** is a molecule that is released from a neuron to relay information to another cell. Neurotransmitter molecules are stored in membranous sacs called **vesicles** in the axon terminal. Each vesicle contains thousands of molecules of a given neurotransmitter. For neurons to release their neurotransmitter, the vesicles fuse with the neuronal membrane and then release their contents, the neurotransmitter, via exocytosis. The neurotransmitter molecules are released into the synaptic space and diffuse across the synaptic space to the postsynaptic neuron. A neurotransmitter molecule can then bind to a special receptor on the membrane of the postsynaptic neuron. **Receptors** are membrane proteins that are able to bind a specific chemical substance,

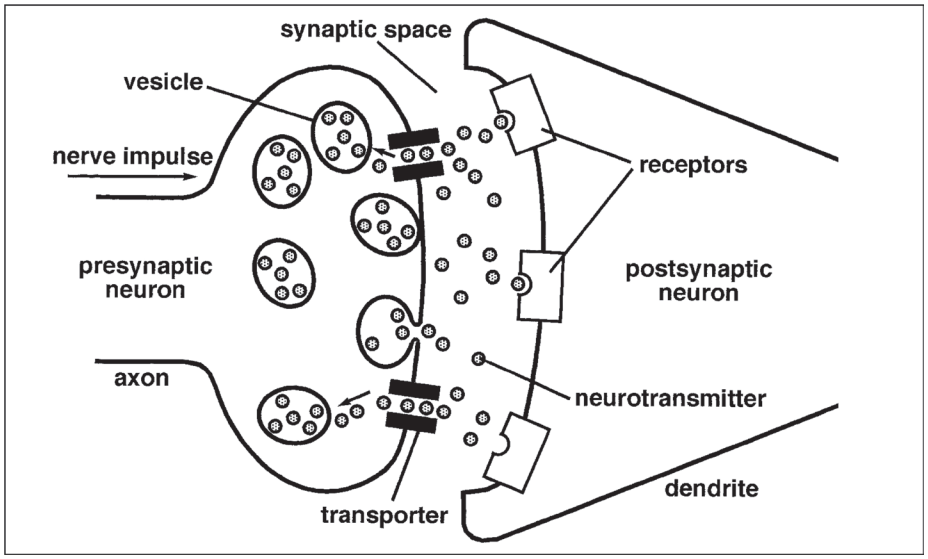


Figure 2.5: *Schematic diagram of a synapse. In response to an electrical impulse, neurotransmitter molecules released from the presynaptic axon terminal bind to the specific receptors for that neurotransmitter on the postsynaptic neuron. After binding to the receptor, the neurotransmitter molecules either may be taken back up into the presynaptic neuron through the transporter molecules for repackaging into vesicles or may be degraded by enzymes present in the synaptic space.*

such as a neurotransmitter. For example, the dopamine receptor binds the neurotransmitter dopamine but does not bind other neurotransmitters such as serotonin. The interaction of a receptor and neurotransmitter can be thought of as a lock-and-key for regulating neuronal function. Just as a key fits only a specific lock, a neurotransmitter only binds with high affinity to a specific receptor. The chemical binding of neurotransmitter and receptor initiates changes in the postsynaptic neuron that may facilitate or inhibit an action potential in the postsynaptic neuron. If it does trigger an action potential, the communication process continues.

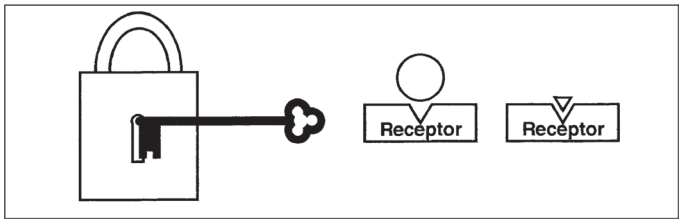


Figure 2.6: *Like a lock that will open only if the right key is used, a receptor will bind only a molecule that has the right chemical shape. Molecules that do not have the right "fit" will not bind to the receptor and will not cause a response.*

After a neurotransmitter molecule binds to its receptor on the postsynaptic neuron, it comes off (is released from) the receptor and diffuses back into the synaptic space. The released neurotransmitter, as well as any neurotransmitter that did not bind to a receptor, is either degraded by enzymes in the synaptic cleft or taken back up into the presynaptic axon terminal by active transport through a **transporter** or **reuptake**

pump. Once the neurotransmitter is back inside the axon terminal, it is either destroyed or repackaged into new vesicles that may be released the next time an electrical impulse reaches the axon terminal. Different neurotransmitters are inactivated in different ways.

Neurotransmitters Can Be Excitatory or Inhibitory

Different neurotransmitters fulfill different functions in the brain. Some neurotransmitters act to stimulate the firing of a postsynaptic neuron. Neurotransmitters that act this way are called **excitatory** neurotransmitters because they lead to changes that generate an action potential in the responding neuron.[1,6] Other neurotransmitters, called **inhibitory** neurotransmitters, tend to block the changes that cause an action potential to be generated in the responding cell. Table 2.1 lists some of the "classical neurotransmitters" used in the body and their major functions. In addition to the so-called classical neurotransmitters, there are many other peptide transmitters, sometimes called neuromodulators. They are similar to classical neurotransmitters in the way they are stored (in vesicles) and released, but they differ in how they are inactivated. Most neurons contain multiple transmitters, often a classical one (such as dopamine) and one or more peptides (such as neurotensin or endorphins).

The postsynaptic neuron often receives and integrates both excitatory and inhibitory messages. The response of the postsynaptic cell depends on which message is stronger. Keep in mind that a single neurotransmitter molecule cannot cause an action potential in the responding neuron. An action potential occurs when many neurotransmitter molecules bind to and activate their receptors. Each interaction contributes to the membrane permeability changes that generate the resultant action potential.

Table 2.1: Major Neurotransitters in the Body[1,6,7]

Neurotransmitter	Role in the body
Acetylcholine	Used by spinal cord motor neurons to cause muscle contraction and by many neurons in the brain to regulate memory. In most instances, acetylcholine is excitatory.
Dopamine	Produces feelings of pleasure when released by the brain reward system. Dopamine has multiple functions depending on where in the brain it acts. It is usually inhibitory.
GABA (gamma-aminobutyric acid)	The major inhibitory neurotransmitter in the brain. It is important in producing sleep, reducing anxiety, and forming memories.
Glutamate	The most common excitatory neurotransmitter in the brain. It is important in learning and memory.
Glycine	Used mainly by neurons in the spinal cord. It probably always acts as an inhibitory neurotransmitter.
Norepinephrine	Acts as a neurotransmitter and a hormone. In the peripheral nervous system, it is part of the fight-or-flight response. In the brain, it acts as a neurotransmitter regulating blood pressure and calmness. Norepinephrine is usually excitatory, but it is inhibitory in a few brain areas.
Serotonin	Involved in many functions including mood, appetite, and sensory perception. In the spinal cord, serotonin is inhibitory in pain pathways.

In Advance

Web-based Activities

Activity	Web Component?
1	No
2	Yes
3	Yes
4	Yes

Photocopies

For the class	For each group of 3 students	For each student
1 transparency of Master 2.1, *Anatomy of a Neuron* 1 transparency of Master 2.2, *Neurons Interact with Other Neurons Through Synapses* 1 transparency of Master 2.4, *Neurons Communicate by Neurotransmission* 1 transparency of Master 2.6, *Recording the Activity of a Neuron* 1 transparency of Master 1.7, *The Reward System (from Lesson 1)*	1 copy of Master 2.3, *How Do Neurons Communicate?*	1 copy of Master 2.5, *Neurotransmission* 1 copy of Master 2.7, *Neurotransmitter Actions* 1 copy of Master 2.8, *Neurons in Series*

Materials

Activity	Materials
Activity 1	overhead projector
Activity 2	computers or overhead projector
Activity 3	overhead projector
Activity 4	none

Preparation

Arrange for students to have access to the Internet for Activities 2, 3, and 4, if possible.

Procedure

Activity 1: Anatomy of a Neuron

Content Standard C: Cells have particular structures that underlie their functions.

Content Standard C: Cells can differentiate, and complex multicellular organisms are formed as a highly organized arrangement of differentiated cells.

1. **Remind students of the PET scans they examined in Activity 2 of Lesson 1. Ask students to think about the areas shown in red or yellow on a PET scan in response to a stimulus. What specifically composes those areas?**

   Students may respond correctly that the areas shown in red or yellow on the PET images are made up of brain cells that are more active than the cells in other regions. Students may even be able to say that the areas represent neurons in the brain that are activated. The goal is to reinforce that the brain is made up of billions of individual cells. The areas shown in the PET images are not just large amorphous masses.

2. **Display a transparency of Master 2.1, *Anatomy of a Neuron*. Explain to students that the basic functional unit of the brain and nervous system is the neuron. Point out the parts of a neuron and discuss their functions.**

   The cell body of the neuron is the metabolic center of the neuron. The nucleus is in the cell body. Most of the proteins are made in the cell body.

   Neurons have specialized cell processes, or fibers, that extend from the cell body. The dendrites are branched fibrous processes specialized to receive input and carry information *toward* the cell body.

   The axon is usually larger in diameter than the dendrites and is specialized to carry information *away* from the cell body. An axon may be very long. Some axons are over 1 meter long.

3. **Display the top half of a transparency of Master 2.2, *Neurons Interact with Other Neurons Through Synapses*. Point out that the axon terminals of one neuron end near the dendrites of another neuron.**

4. **Reveal the lower portion of Master 2.2 showing the synapse. Inform students that the connection between the two neurons is called a *synapse*. Explain the terms presynaptic and postsynaptic.**

   The **presynaptic** neuron is the neuron whose axon forms a synapse with the dendrite of another neuron. The presynaptic neuron sends out information.

   The **postsynaptic** neuron is the neuron whose dendrite forms a synapse with the axon of the presynaptic neuron. The postsynaptic neuron receives information.

   Note: Help students understand that there is no physical connection between the two neurons.

5. **When students understand that the brain is composed of neurons and neurons interact with other neurons, display the transparency of Master 1.7, *The Reward System* (used in Lesson 1), again and discuss the reward pathway in terms of the neurons.**

   The cell bodies of the neurons that drugs affect are located in the ventral tegmental area (VTA). Those cells extend their axons to nerve cells in an area of the brain called the nucleus accumbens. Some nerve fibers extend to part of the frontal region of the cerebral cortex.

Activity 2: How Do Neurons Communicate?

Content Standard A: Formulate and revise scientific explanations and models using logic and evidence.

Content Standard A: Communicate and defend a scientific argument.

Content Standard C: Cell functions are regulated.

Before doing this activity, students need to have a good understanding of the difference between an axon and a dendrite and the direction of information flow along these neuronal fibers. Remember that dendrites carry information toward the cell body and axons carry information away from the cell body. Also, students need to understand the terms presynaptic and postsynaptic.

In this activity, students will use the Internet to enhance what they deduce from a print-based activity. If students don't have access to the Internet, a print modification of the activity is also provided. The procedures for each version of the activity are the same except for Step 4. When you reach that point in the activity, select the appropriate step.

1. **Ask students to consider what purpose synapses serve.**

   Some students are likely to respond correctly that synapses serve to connect neurons (synapses do not connect neurons physically, but they do connect them functionally). This enables neurons to communicate by passing signals between them.

2. **Remind students that the brain is an organ that regulates body functions, behaviors, and emotions. Neurons are the cells that fulfill these functions. How do neurons do this?**

   Neurons control these functions by passing signals across the synapse from one neuron to the next. These signals dictate whether the receiving neuron is activated.

3. **Divide the class into groups of three students. Give each group a copy of Master 2.3, *How Do Neurons Communicate?* Ask students to look at and discuss the diagrams and, as a group, write a summary of how they believe the neurons are interacting at each step.**

   At this point, students will not know the correct terminology for the structures and molecules involved in neurotransmission. Encourage students to use whatever terms they wish to describe what is represented in the diagrams. The main point of this activity is for

students to begin to understand that specific events happen both within a neuron and between neurons during neurotransmission.

Sample Answers to Master 2.3

Students are likely to use a variety of terms in their responses. Although at this point the use of correct vocabulary is not the critical issue, some students will use the terms axon, dendrite, presynaptic, and postsynaptic that they learned in Activity 1.

Diagram #1 The presynaptic neuron ending has large circles in it. The large circles have smaller circles inside. There are two sets of bars that cross the end (membrane) of the presynaptic neuron. The postsynaptic neuron has two rectangular-shaped boxes on the end (membrane) of the neuron.

Diagram #2 Nothing has changed except that there is a lightning bolt (electrical signal) and an arrow indicating that the lightning bolt is moving toward the end of the presynaptic neuron.

Diagram #3 One of the larger circles is now in contact with the end of the presynaptic neuron. Another circle is now releasing the small circles into the space between the neurons.

Diagram #4 The small circles are in the space between the neurons and one small circle is now attached to the box-shaped figures on the end of the postsynaptic neuron.

Diagram #5 The lightning bolt symbol (electrical signal) is at the postsynaptic neuron now. The arrow indicates that it is moving away from the neuron ending.

Diagram #6 The small circles are no longer attached to the box-shaped figures on the postsynaptic neurons. The arrows seem to indicate that the small circles are now moving back into the presynaptic neuron and going back into the larger circles.

4. **Have the students watch the neurotransmission animation on the Web site or read Master 2.4 aloud.**

Students access the animation by going to the supplement's Web site and clicking on Lesson 2—*Neurons, Brain Chemistry, and Neurotransmission*. They may wish to view the animation several times because it is packed with information.

Now that students have explored neurotransmission by completing Master 2.3, the animation will help them incorporate the proper terminology and clarify any misunderstandings.

If computers are not available, display a copy of Master 2.4, *Neurons Communicate by Neurotransmission*. Read through the material with the students.

Students should not copy the information on Master 2.4. The goal is for students to listen to the reading to help them learn the proper terminology and clarify their understanding of neurotransmission.

5. **After the students have been introduced to the proper terminology by the animation or the reading, give each student a copy of Master 2.5, *Neurotransmission*. Ask them to revise their summary of neurotransmission using the appropriate terminology. Encourage students to discuss their answers with the other members of their group.**

   Students may wish to watch the animation or review the reading again while doing this step. The goal is not to have students copy the explanation, but to revise their understanding of neurotransmission, incorporate the appropriate terminology, and correct any misconceptions they had from Master 2.3.

Sample Answers to Master 2.5

Diagram #1 This diagram shows the component parts of the neurotransmission process between electrical impulses.

Diagram #2 An electrical impulse travels down the axon toward the presynaptic nerve terminals.

Diagram #3 The vesicles containing neurotransmitter move toward the neuron cell membrane at the end of the axon. The vesicles fuse to the membrane and then release their contents (neurotransmitter molecules) into the synaptic cleft.

Diagram #4 The neurotransmitter is in the synaptic cleft and binds to the receptor on the postsynaptic neuron's membrane.

Diagram #5 Neurotransmitter molecules are still bound to the receptors, and an electrical signal passes along the postsynaptic neuron away from the synapse.

Diagram #6 Neurotransmitter molecules are released from the receptors. Neurotransmitter molecules are taken back up into the presynaptic neuron through the transporter. Once inside the presynaptic neuron terminal, the neurotransmitter molecules are repackaged into vesicles.

6. **Once the groups have finished revising their summaries, hold a class discussion and put together a summary of how neurotransmission occurs. Inform students that the diagrams and Web animation are simplified models of neurotransmission. Many hundreds or thousands of receptors that can bind neurotransmitter are present in the dendrites of a postsynaptic neuron.**

7. **Remind students of the reward system. The neurons that make up the reward system use a neurotransmitter called *dopamine*. Dopamine neurotransmission occurs as the students learned in Masters 2.3, 2.4 (print alternative), and 2.5 and the Web animation.**

Activity 3: Do All Neurotransmitters Have the Same Effect?

Content Standard C:
Cell functions are regulated.

Now that students understand that neurotransmitters are the chemical messengers involved in communication between neurons, students will learn that different neurotransmitters can affect neurotransmission differently.

1. **Show an overhead transparency of Master 2.6, *Recording the Activity of a Neuron*. Explain that scientists study the activity of neurons by recording the electrical impulses that neurons generate when they are activated, or fire. These electrical impulses are called action potentials.**

   Master 2.6 shows a diagram of a microelectrode recording the electrical activity of a neuron in the brain. The action potentials are amplified and then analyzed by a computer that counts the number of spikes that occur during a period of time. The action potentials appear as vertical lines, or spikes, on the oscilloscope. If the recording were slowed down, the action potentials would appear similar to that shown in Figure 2.4 (see Background Information section). A signal is also sent to an audio amplifier that produces a click sound each time an action potential is generated in the neuron. The more frequently the spikes appear on the screen with accompanying audible clicks, the more frequently the neuron is firing.

2. **Divide the class into groups of three. Give each group a copy of Master 2.7, *Neurotransmitter Actions*. Tell students that they will analyze the effects of different neurotransmitters on the activity of a neuron. Have the groups answer the questions that follow the data analysis.**

   After the groups have completed the questions, discuss their answers to make sure that students understand that different neurotransmitters have different effects on neurons.

Sample Answers to Master 2.7

Question 1. Why is saline applied to the resting neuron?

The resting neuron is the control for the experiment. If a scientist wants to determine what effect applying a neurotransmitter has on a neuron, he or she must have a control. The neurotransmitter applied to the other neurons would be dissolved in a saline solution, so applying saline to the resting neuron provides information about how a neuron responds to the solvent solution (in this case, a weak salt solution). If the experimental neuron does not respond in the same way as the control neuron, this indicates that the neurotransmitter applied to those neurons is the cause for the response, not the saline itself, or the act of applying any solution to the neuron.

Question 2. When the neurotransmitter glutamate is applied to the neuron, how does its activity change?

Glutamate stimulates the neuron and causes it to generate more electrical impulses.

Question 3. How does the application of the two neurotransmitters, glutamate and GABA, change the activity of the neuron?

In this case, GABA is present in high enough concentrations to override the effects of glutamate.

Question 4. Predict how the activity of the neuron would change if only GABA was applied to the neuron.

If GABA can inhibit a neuron even when glutamate is added, GABA by itself should inhibit the neuron's activity.

Question 5. Do all neurotransmitters affect a neuron in the same way?

No, the neurotransmitters glutamate and GABA have opposite effects on the neuron's activity.

Question 6. How would the application of glutamate to a neuron change the amount of neurotransmitter that is released from that neuron? How would the application of GABA to a neuron change the amount of neurotransmitter that is released from that neuron?

If glutamate is applied to a neuron, it causes the neuron to generate more electrical impulses. This would increase the amount of neurotransmitter that the neuron releases from its axon terminals.

If GABA is applied to a neuron, it reduces the number of electrical impulses generated by that neuron. The decreased activity in the neuron would decrease the amount of neurotransmitter that the neuron releases from its axon terminals.

3. **Students can continue this activity using the simulation on the Web site of applying neurotransmitters to a neuron.**

   Go to the supplement's Web site. Click on Lesson 2—*Neurons, Brain Chemistry, and Neurotransmission* and then select *Neurotransmitter Actions*.

Activity 4: One Neuron Signals Another

Content Standard A: Formulate and revise scientific explanations and models using logic and evidence.
Content Standard A: Communicate and defend a scientific argument.
Content Standard C: Cell functions are regulated.

This activity is the most challenging one in the lesson. It requires students to integrate what they learned in Activities 2 and 3. If students successfully complete this activity, they will have a good understanding of how neurons communicate.

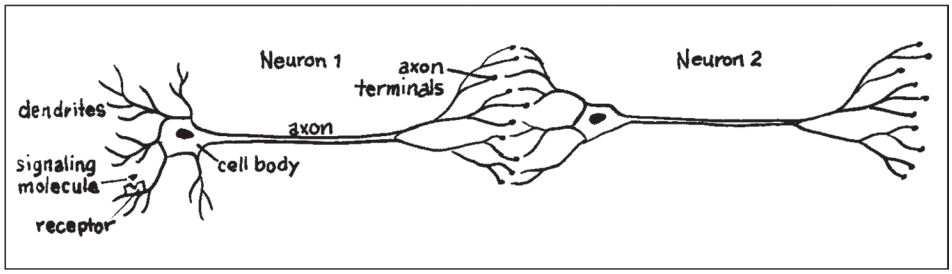
1. **Copy the chart from Master 2.8b, *Neurons in Series*, onto the board.**

2. **Now that students understand that neurotransmitters can either stimulate or inhibit the generation of action potentials in a neuron, they will continue to examine how one neuron signals another in a series. Give each student a copy of Master 2.8. As a class, work through Case A on the master to determine how the stimulatory and inhibitory neurotransmitter effects alter dopamine release from the last neuron in the series. Fill in the answers on the chart.**

   You may wish to use an up or down arrow to indicate an increase or decrease in the activity of the neuron or the amount of neurotransmitter released from a neuron. Students may find it helpful to refer to their work on Master 2.5.

   Case A

   The signal molecule that affects Neuron #1 in this case is inhibitory. It reduces the chances that Neuron #1 will fire. Thus, it acts to decrease the activity of Neuron #1. If Neuron #1 is less active, it releases less neurotransmitter. Neuron #1 produces glutamate, an excitatory neurotransmitter. The decreased level of neurotransmitter released from Neuron #1 leads to a decreased level of activity of Neuron #2. If Neuron #2 is less active, it will release less dopamine.



Case	Does the signal molecule excite or inhibit Neuron #1?	Does the activity of Neuron #1 increase or decrease?	Does the amount of neuro-transmitter released from Neuron #1 increase or decrease?	What is the name of the neuro-transmitter released from Neuron #1?	Is the neuro-transmitter released from Neuron #1 excitatory or inhibitory?	Does the activity of Neuron #2 increase or decrease?	Does the amount of dopamine released from Neuron #2 increase or decrease?
A	inhibit	↓	↓	glutamate	excitatory	↓	↓

Tip from the field test: Students sometimes became confused by the multiple neurotransmitters involved in each case. A common misconception was the same neurotransmitter that acted to stimulate or inhibit a neuron then passed through the neuron and was released from the axon terminals at the other end. Remind students what they learned in Activity 2 regarding the fate of a neurotransmitter after it binds to, and then comes off, its receptor. The released neurotransmitter is either degraded or taken back up into the axon terminal that released it.

For the purpose of this activity, the signal molecule is a neurotransmitter. In Lesson 3, students will learn that drugs of abuse can also act in a similar way to alter neurotransmission.

3. **After the students have worked through the first example as a class, ask them to work in their small groups to complete the chart for Cases B–D. Students will determine how inhibitory and excitatory inputs contribute to the activity of a neuron that is part of a series.**

   As a student group finishes one of the cases (B–D), have a group member come to the board and fill in the blanks for that problem. When all of the groups are finished, ask the group that completed each line on the board to explain its answers to the rest of the class. If another group disagrees with the answer, have that group explain its reasoning. As a class, resolve the discrepancies and reach a consensus explanation. In this way, students practice critical thinking and communication skills.

Listening to students explain their answers, defend their reasoning, and modify their responses after listening to other students explain their logic will help you assess students' understanding of neurotransmission.

Sample Answers for Master 2.8

Case A. The signaling molecule is inhibitory. Neuron #1 releases glutamate as its neurotransmitter. Neuron #2 releases dopamine as its neurotransmitter.

The inhibitory signal molecule decreases the activity of Neuron #1. If Neuron #1 is less active, it releases less neurotransmitter. Neuron #1 produces glutamate, an excitatory neurotransmitter. The decreased amount of neurotransmitter released from Neuron #1 leads to a decreased level of activity of Neuron #2. If Neuron #2 is less active, it will release less dopamine.

Case B. The signaling molecule is excitatory. Neuron #1 releases glutamate as its neurotransmitter. Neuron #2 releases dopamine as its neurotransmitter.

The excitatory signal molecule increases the activity of Neuron #1. If Neuron #1 is more active, it releases more neurotransmitter. Neuron #1 produces glutamate, an excitatory neurotransmitter. The increased amount of neurotransmitter released from Neuron #1 leads to an increase in the activity level of Neuron #2. If Neuron #2 is more active, it will release more dopamine.

Case C. The signaling molecule is inhibitory. Neuron #1 releases GABA as its neurotransmitter. Neuron #2 releases dopamine as its neurotransmitter.

The inhibitory signal molecule decreases the activity of Neuron #1. If Neuron #1 is less active, it releases less neurotransmitter. Neuron #1 produces GABA, an inhibitory neurotransmitter. The decreased amount of neurotransmitter released from Neuron #1 leads to an increase in the activity level of Neuron #2 (less GABA = less inhibition of Neuron #2). If Neuron #2 is more active, it will release more dopamine.

Case D. The signaling molecule is excitatory. Neuron #1 releases GABA as its neurotransmitter. Neuron #2 releases dopamine as its neurotransmitter.

The excitatory signal molecule increases the activity of Neuron #1. If Neuron #1 is more active, it releases more neurotransmitter. Neuron #1 produces GABA, an inhibitory neurotransmitter. The increased amount of neurotransmitter released from Neuron #1 leads to a decrease in the activity level of Neuron #2 (more GABA = stronger inhibition of Neuron #2). If Neuron #2 is less active, it will release less dopamine.

Case	Does the signal molecule excite or inhibit Neuron #1?	Does the activity of Neuron #1 increase or decrease?	Does the amount of neuro-transmitter released from Neuron #1 increase or decrease?	What is the name of the neuro-transmitter released from Neuron #1?	Is the neuro-transmitter released from Neuron #1 excitatory or inhibitory?	Does the activity of Neuron #2 increase or decrease?	Does the amount of dopamine released from Neuron #2 increase or decrease?
A	inhibit	↓	↓	glutamate	excitatory	↓	↓
B	excite	↑	↑	glutamate	excitatory	↑	↑
C	inhibit	↓	↓	GABA	inhibitory	↑	↑
D	excite	↑	↑	GABA	inhibitory	↓	↓

4. Ask students to keep their completed worksheets, Masters 2.5 and 2.8. Students will refer to these when they do activities in Lesson 3.

5. Students may continue to explore how signals from one neuron influence the target neuron by doing the online activity *Neurons in Series*.

To access the *Neurons in Series* activity, go to the supplement's Web site and click on Lesson 2—*Neurons, Brain Chemistry, and Neurotransmission*, and select the *Neurons in Series* tab.

Lesson 2 Organizer: WEB VERSION

What the Teacher Does	Procedure Reference
Activity 1: *Anatomy of a Neuron*	
Remind students of the PET images from Lesson 1. Ask students to think about what composes the differently colored areas.	Page 50 Step 1
Display a transparency of **Master 2.1**. Explain to students that the neuron is the basic functional unit of the brain and nervous system. Point out the parts of the neuron and their function.	Page 50 Step 2
Display the top half of a transparency of **Master 2.2**. Point out that axon terminals of one neuron end near the dendrites of another neuron.	Page 50 Step 3
Reveal the bottom half of the **Master 2.2** transparency. Inform students that the connection between the two neurons is called a synapse. Explain the terms presynaptic and postsynaptic.	Page 51 Step 4
Show the transparency of **Master 1.7** from Lesson 1. Discuss the reward system in terms of the neurons that form the reward system.	Page 51 Step 5
Activity 2: *How Do Neurons Communicate?*	
Ask students to consider what purpose synapses serve.	Page 51 Step 1
Remind students that the brain is an organ that regulates many functions. Ask, "How do neurons fulfill these diverse functions?"	Page 51 Step 2
Divide the class into groups of three. Give each group a copy of **Master 2.3**. Each group should work together to write descriptions of what is happening at each step.	Page 51 Step 3
Show the online animation *How Neurotransmission Works* to the class.	Page 52 Step 4
Reconvene the student groups. Give each student a copy of **Master 2.5**. Ask students to work individually to revise their description of neurotransmission using the appropriate terminology. After individuals have completed their descriptions, students can discuss them with their team members.	Page 53 Step 5

What the Teacher Does	Procedure Reference
Discuss the descriptions of neurotransmission as a class and generate a consensus summary of neurotransmission.	Page 54 Step 6
Remind students of the reward system and inform them that the neurons in the reward system use a neurotransmitter called dopamine.	Page 54 Step 7
Activity 3: *Do All Neurotransmitters Have the Same Effect?*	
Show a transparency of **Master 2.6**. Briefly explain that scientists study the activity of neurons by recording the electrical impulses that neurons generate when they are activated, or fire. Introduce the term action potential.	Page 54 Step 1 
Students return to their groups of three. Give each group a copy of **Master 2.7**. Ask students to work through the information and answer the questions.	Page 54 Step 2 
Allow time for students to work through the simulation on the Web site. To access the simulation, select Lesson 2—*Neurons, Brain Chemistry, and Neurotransmission* from the activities menu and then *Neurotransmitter Actions*.	Page 56 Step 3 
Activity 4: *One Neuron Signals Another*	
Copy the chart from **Master 2.8b** onto the board.	Page 56 Step 1
Give one copy of **Master 2.8** to each student. As a class, work through Case A to determine how stimulatory and inhibitory neurotransmitter effects alter dopamine release. Write the answers on the chart.	Page 56 Step 2 
Have students work through Cases B–D in their teams. As teams finish, ask for teams to volunteer to fill in the blanks for one of the cases on the chart on the board. Have teams explain the answers. If teams disagree, discuss how they arrived at their answer. Work through each case until there is consensus.	Pages 57–59 Step 3
Have students keep their copies of **Masters 2.5** and **2.8**. Students may then do the online activity *Neurons in Series*.	Page 59 Steps 4, 5 

 = Involves using the Internet.

 = Involves copying a master.

 = Involves making a transparency.

Lesson 2 Organizer: PRINT VERSION

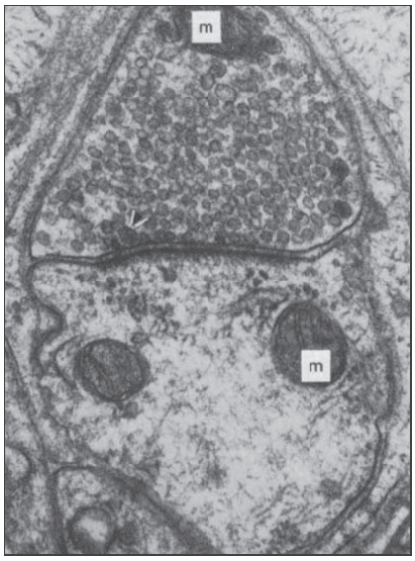
What the Teacher Does	Procedure Reference
Activity 1: *Anatomy of a Neuron*	
Remind students of the PET images from Lesson 1. Ask students to think about what composes the differently colored areas.	Page 50 Step 1
Display a transparency of **Master 2.1**. Explain that the neuron is the basic functional unit of the brain and nervous system. Point out the parts of the neuron and their function.	Page 50 Step 2 T
Display the top half of a transparency of **Master 2.2**. Point out that axon terminals of one neuron end near the dendrites of another neuron.	Page 50 Step 3 T
Reveal the bottom half of the **Master 2.2** transparency. Inform students that the connection between the two neurons is called a synapse. Explain the terms presynaptic and postsynaptic.	Page 51 Step 4 T
Show the transparency of **Master 1.7** from Lesson 1. Discuss the reward system in terms of the neurons that form the reward system.	Page 51 Step 5
Activity 2: *How Do Neurons Communicate?*	
Ask students to consider what purpose synapses serve.	Page 51 Step 1
Remind students that the brain is an organ that regulates many functions. Ask, "How do neurons fulfill these diverse functions?"	Page 51 Step 2
Divide the class into groups of three. Give each group a copy of **Master 2.3**. Each group should work together to write descriptions of what is happening at each step.	Page 51 Step 3 M
Display a transparency of **Master 2.4**. Read through the material with the students.	Page 52 Step 4 T
Reconvene the student groups. Give each student a copy of **Master 2.5**. Ask students to work individually to revise their description of neurotransmission using the appropriate terminology. After individuals have completed their descriptions, students can discuss them with their team members.	Page 53 Step 5 M

What the Teacher Does	Procedure Reference
Discuss the descriptions of neurotransmission as a class and generate a consensus summary of neurotransmission.	Page 54 Step 6
Remind students of the reward system and inform them that the neurons in the reward system use a neurotransmitter called dopamine.	Page 54 Step 7
Activity 3: *Do All Neurotransmitters Have the Same Effect?*	
Show a transparency of **Master 2.6**. Briefly explain that scientists study the activity of neurons by recording the electrical impulses that neurons generate when they are activated, or fire. Introduce the term action potential.	Page 54 Step 1 T
Students return to their teams of three. Give each team a copy of **Master 2.7**. Ask students to work through the information and answer the questions.	Page 54 Step 2 M
Activity 4: *One Neuron Signals Another*	
Copy the chart from **Master 2.8** onto the board.	Page 56 Step 1
Give one copy of **Master 2.8** to each student. As a class, work through Case A to determine how stimulatory and inhibitory neurotransmitter effects alter dopamine release. Write the answers on the chart.	Page 56 Step 2 M
Have students work through Cases B–D in their teams. As teams finish, ask for teams to volunteer to fill in the blanks for one of the cases on the chart on the board. Have teams explain the answers. If teams disagree, discuss how they arrived at their answer. Work through each case until there is consensus.	Pages 57–59 Step 3
Have students keep their copies of **Masters 2.5** and **2.8**.	Page 59 Step 4

M = Involves copying a master.

T = Involves making a transparency.

Drugs Change the Way Neurons Communicate



Source: Principles of Neural Science, *3rd edition, Eric R. Kandel, James H. Schwartz, and Thomas M. Jessell. ©The McGraw-Hill Companies. (m = mitochondria)*

At a Glance

Overview
Students build upon their understanding of neurotransmission by learning how different drugs of abuse disrupt communication between neurons. Students then conduct an activity investigating the effect of caffeine on their heart rate. Finally, students analyze data on how the way a drug is taken into the body influences its effect.

Major Concept
Drugs affect the biology and chemistry of the brain.

Objectives
By the end of these activities, the students will
- understand that certain drugs interfere selectively with neurotransmission and
- realize that the effect of a drug is dependent upon dosage and route of administration.

Basic Science–Health Connection
Drugs of abuse are valuable tools for investigations of brain function because they can mimic or block actions of neurotransmitters, and thus exert effects on homeostasis and behavior.

Background Information

Drugs Disrupt Neurotransmission

How do drugs cause their effects on the brain and behavior? Lesson 1 introduced students to the idea that a specific brain region, the reward system (part of the limbic system), regulates feelings of pleasure and that this region is activated by drugs of abuse. But what do drugs actually do in that brain region? Drugs interfere with neurotransmission. More specifically, drugs of abuse produce feelings of pleasure by altering neurotransmission by neurons in the reward system that release the neurotransmitter dopamine.[1,2] Thus, drugs of abuse alter the communication between neurons that is mediated by dopamine. Because the synapse is so complex, there is a variety of sites at which drugs may affect synaptic transmission. One way to affect synaptic transmission is to increase the amount of neurotransmitter released into the synaptic space. Drugs like alcohol, heroin, and nicotine indirectly excite the dopamine-containing neurons in the ventral tegmental area (VTA) so that they produce more action potentials.[1,2] As the number of action potentials increases, so does the amount of dopamine released into the synapse. Amphetamines (e.g., methamphetamine, crystal, crank) actually cause the release of dopamine from the vesicles. This is independent of the rate of action potentials and, depending on dose, can cause a relatively quick and prolonged rise of extracellular dopamine levels.

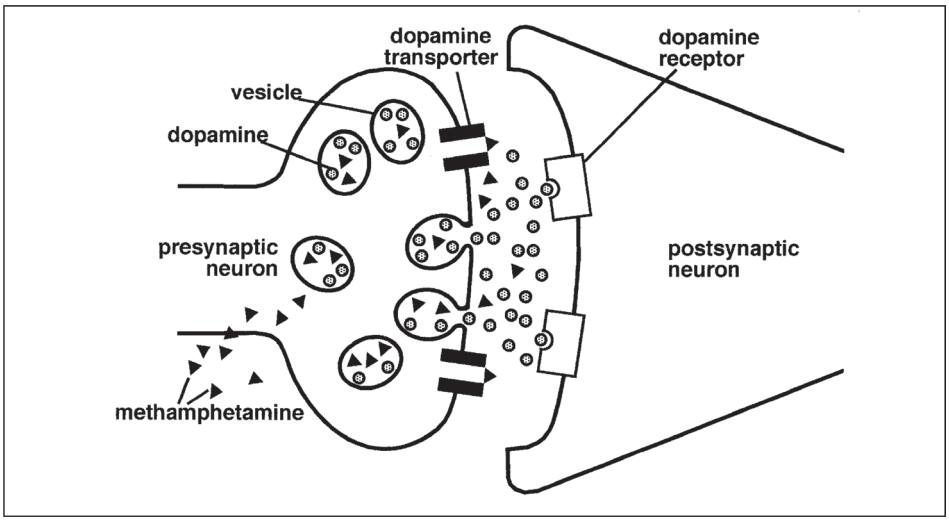


***Figure 3.1**: Methamphetamine alters dopamine neurotransmission in two ways. Methamphetamine enters the neuron by passing directly through nerve cell membranes. It is carried to the nerve cell terminals by transporter molecules that normally carry dopamine or norepinephrine. In the nerve terminal, methamphetamine enters the dopamine- or norepinephrine-containing vesicles and causes the release of neurotransmitter. Methamphetamine also blocks the dopamine transporter from pumping dopamine back into the transmitting neuron. Methamphetamine acts similarly to cocaine in this way.*

Nicotine not only acts at the cell body in the VTA to increase the number of action potentials and number of vesicles released from a neuron, but it also acts by another mechanism to alter dopamine release. When nicotine binds to nicotine receptors on the dopamine-containing axon terminals in the nucleus accumbens, more dopamine is released with each action potential.[1]

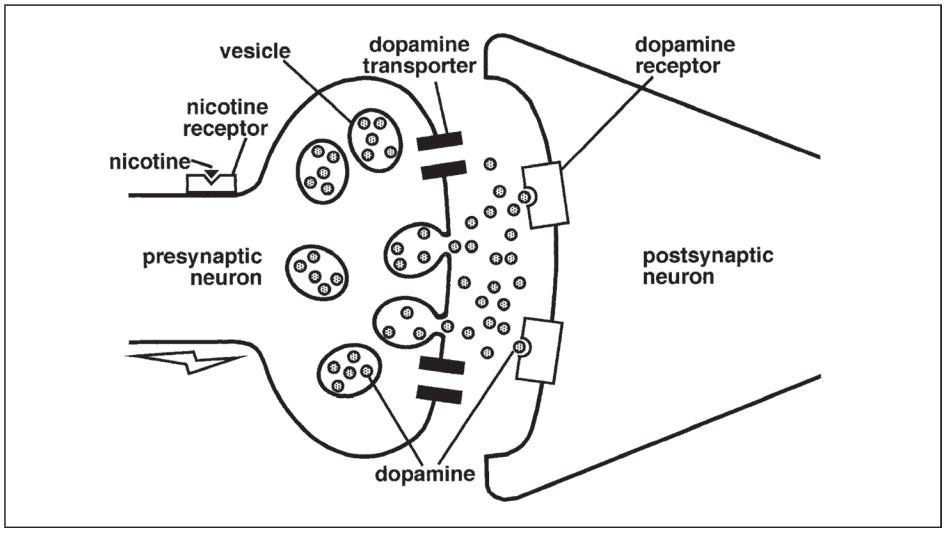


Figure 3.2: *Nicotine binds to specific receptors on the presynaptic neuron. When nicotine binds to receptors at the cell body, it excites the neuron so that it fires more action potentials (electrical signals, represented by jagged shape in lower left of figure) that move toward the synapse, causing more dopamine release (not shown in figure). When nicotine binds to nicotine receptors at the nerve terminal (shown above), the amount of dopamine released in response to an action potential is increased.*

Drugs may also alter synaptic transmission by directly affecting the post-synaptic receptors. Some drugs activate receptors, and others block them.

While THC (the main psychoactive chemical in marijuana) and morphine activate specific receptors, other drugs block specific receptors. Caffeine, the mild stimulant found in coffee and some soft drinks, exerts its effects by preventing a neurotransmitter/neuromodulator called adenosine from binding to its receptor. Normally, the binding of adenosine to its receptor causes sedation; it is a natural sleep-inducer. Instead of causing sedation, the blocking of the adenosine receptors with caffeine leads to an increase in activity and arousal levels.[1,3]

The actions of some drugs are very complex. LSD, for example, acts on serotonin receptors. Serotonin, an important neurotransmitter in many brain regions, is involved in regulating a wide variety of functions, including mood and basic survival functions such as sleeping and eating. Scientists continue to study how hallucinogens act, but apparently LSD activates some serotonin receptors (LSD acts as a receptor agonist) and blocks other serotonin receptors (LSD acts as a receptor antagonist).[1]

A third way to affect synaptic transmission is to alter the removal of neurotransmitters from the synapse. Cocaine and amphetamines work this way (this is the second way amphetamines can alter neurotransmission).[1,3] Both drugs block the dopamine transporter (reuptake pump) that removes dopamine from the synapse. The result is a fairly rapid and persistent rise of dopamine in the synapse, leading to feelings of euphoria and well-being. Most drugs of abuse don't block enzymatic destruction of neurotransmitters, although smoking has been shown to reduce levels of an enzyme that breaks down neurotransmitters, monoamineoxidase.

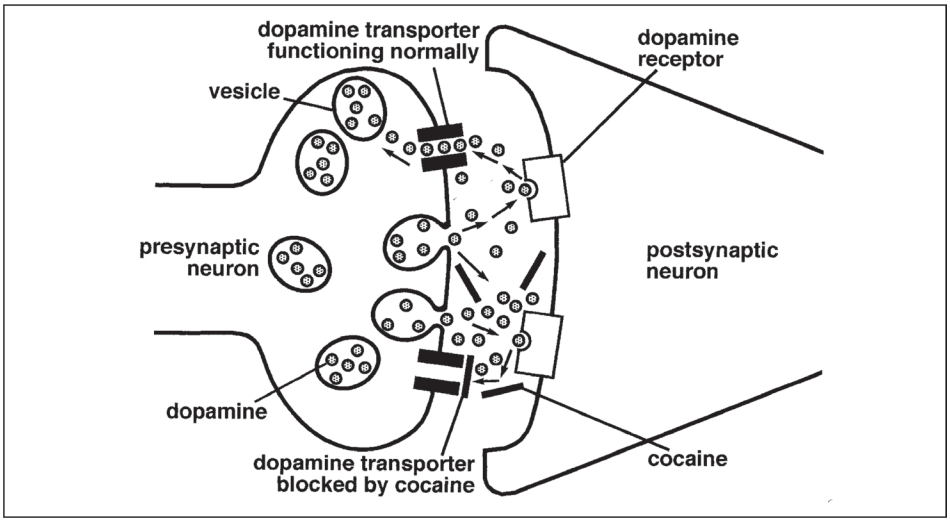


***Figure 3.3**: When cocaine enters the brain, it blocks the dopamine transporter from pumping dopamine back into the transmitting neuron, flooding the synapse with dopamine. This intensifies and prolongs the stimulation of receiving neurons in the brain's pleasure circuits, causing a cocaine high.*

Alcohol affects the brain's neurons in several ways. It alters their membranes and ion channels, enzymes, and receptors, and it also binds directly to the receptors for acetylcholine, serotonin, and GABA and the NMDA receptors for glutamate. GABA normally reduces the activity of neurons by allowing chloride ions to enter the postsynaptic neurons. This effect is amplified when alcohol binds to the GABA receptor and the neuron's activity is further diminished, which explains the sedative effect of alcohol.

Alcohol also reduces glutamate's excitatory effect by blocking the receptor activated by glutamate, the NMDA receptor. NMDA receptors are known to be involved in synaptic plasticity, a cellular mechanism for learning and memory. However, chronic consumption of alcohol gradually makes the NMDA receptors *hypersensitive* to glutamate while desensitizing the GABA receptors.

Alcohol also helps increase the release of dopamine, by a process that is still poorly understood but that appears to involve curtailing the activity of the enzyme that breaks dopamine down.

Drugs Mimic Natural Body Chemicals

The ability of drugs to interrupt normal synaptic transmission may seem odd. After all, if receptors have such great specificity for a single type of binding partner, how can drugs disrupt the process? The answer lies in the similarity in conformation, or structure, of the drugs to natural body chemicals. For example, the receptors in the brain that bind morphine and other opioids recognize natural opioid peptides called endorphins and enkephalins that are made by our brains and used as neurotransmitters.[4] It is an evolutionary coincidence that these receptors recognize a plant-derived chemical (drug) as well. This coincidence is a double-edged sword. Opioid compounds that come from plants are both the most potent analgesics (pain relievers) available and some of the most potent addictive drugs as well. Morphine continues to be one of the most effective drugs to relieve the pain associated with many chronic diseases. When abused, opioids are often taken at higher-than-prescribed doses or in ways other than as prescribed (for example, injected vs. orally), which, by stimulating the dopamine cells in the VTA, can cause profound feelings of pleasure (euphoria). Tetrahydocannabinol (THC), the active ingredient in marijuana, binds to specific receptors in the brain called cannabinoid receptors, which were discovered because scientists were trying to understand how marijuana works. Subsequently, natural (endogenous) transmitters that bind these receptors were identified—one of which is called anandamide. The cannabinoid system is distributed widely in the brain and the body and is thought to play a role in a wide variety of physiological activities, including memory, appetite, pain perception, and immune regulation. The discovery of this system may enable scientists to develop medications (without the abuse and other health liabilities of marijuana) for a variety of diseases, including obesity, schizophrenia, multiple sclerosis, and addiction.

Drugs of abuse share a common action: they act on the brain's reward system. Within that system, they all (except perhaps for LSD) share the ability to increase the levels of dopamine in the nucleus accumbens. This almost certainly accounts for the rewarding (pleasurable) effects of abused drugs.

The effects of drugs are not limited to the reward pathway in the brain. Drugs can act in various regions of the brain to exert their effects, but their ability to alter dopamine neurotransmission in the ventral tegmental area (VTA) and the nucleus accumbens is the initial and one of the most important factors driving continued drug use.

Many factors determine how a drug affects an individual. Some of these are biological. For example, genetics can affect a person's sensitivity to a drug or how quickly the drug is metabolized and cleared from the body. But environmental factors can also be important—stress or trauma can alter a person's experience with drugs. Two factors that are especially important are the dose of the drug and the route of administration, which affects how fast it reaches the brain.

The Dose Changes the Drug's Effects

For a drug to work, it must be taken into the body, absorbed in the bloodstream, and delivered to the brain. Drugs can be taken in a range of doses—from low, having no detectable effect, to moderate, producing the drug's desired effect, to large and unpleasant, or even toxic (Figure 3.4). Not everyone will respond the same way to a given drug dose—many factors can influence this, including those mentioned above, as well as age,

gender, and the person's history of using that drug or other related drugs. However, most drugs, when taken at high doses, produce effects that are both undesirable and potentially harmful to health (overdose).

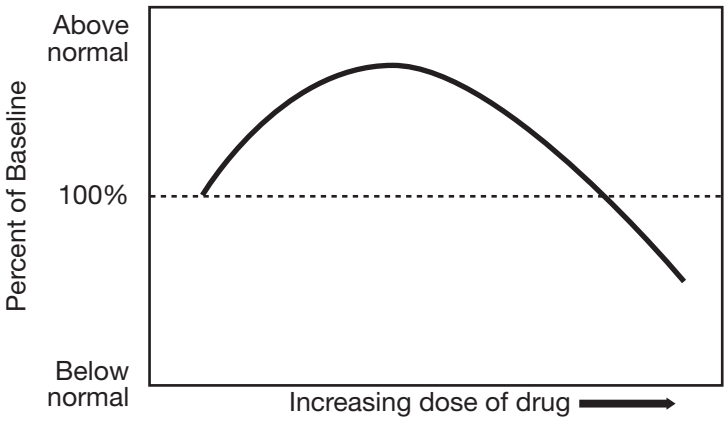


***Figure 3.4**: Effects of a drug depend on the dose.*

Drugs Enter the Brain in Different Ways

In addition to dose, the manner in which a drug is taken can profoundly alter the response to the drug. A drug that is inhaled (smoked) reaches the brain very quickly. The inhaled drugs go directly from the lungs into the left side of the heart, where they enter the arterial circulation that carries them to the brain. Marijuana and nicotine are examples of drugs that are commonly taken into the body by inhalation (smoking). The intensity of the effect of inhaled drugs may be slightly less than that for injected drugs because less of the drug gets into the brain; some of the drug will be exhaled with the rest of the components of the smoke. A drug that is injected intravenously also travels quickly to the brain, where it can exert its effects. The rapid passage of injected heroin, for example, brings a high risk of overdose. In some cases, the heroin can reach lethal levels faster than medical help can be obtained to reverse the overdose. A third route of drug administration is by snorting or snuffing. A drug that is snorted or snuffed is taken in through the nose, where it is absorbed through the

Routes of Administration

Ingestion
Inhalation
Injection
Snorting/Snuffing
Through the skin

***Figure 3.5:** Drugs enter the brain by different routes.*

mucous membranes lining the nasal passages. Television and movies often depict cocaine being snorted. The effects of drugs taken by this method will be less intense than by injection or inhalation because it takes longer for the drug to get into the brain.

Another route of administration is by oral ingestion. Most people are familiar with taking a medicine, either as a solid or a liquid, by mouth. People can also take drugs of abuse this way. Drugs commonly taken orally include stimulants and depressants. Drugs taken orally enter the bloodstream more slowly than by any of the other routes. The drugs that are swallowed reach the stomach and intestine, where they are absorbed into the bloodstream. Not only do they take longer to act, but the body begins to metabolize them before they can act on the brain. Enzymes in the stomach, intestines, and liver begin breaking down the drugs so they can be cleared from the body.

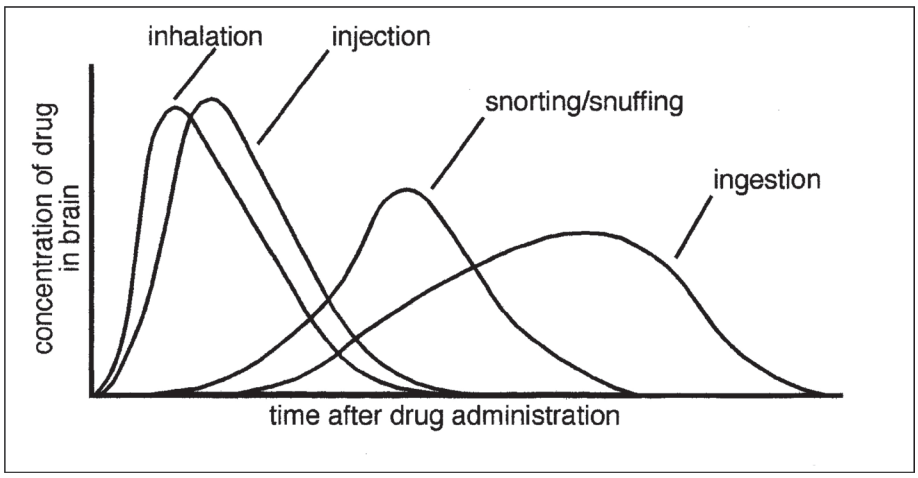


Figure 3.6: *Drugs of abuse enter the body by different routes. The intensity of a drug's effect depends on how the drug is taken.*

As shown in Figure 3.6, the route of administration causes dramatic differences in the onset, intensity, and duration of a drug's effect. Methamphetamine, for example, can be smoked, snorted, ingested orally, or injected. If the drug is smoked or injected, the user almost immediately experiences an intense rush or "flash" that lasts a few minutes. Snorting methamphetamine produces feelings of euphoria within three to five minutes, while oral ingestion produces effects within 15 to 20 minutes. The high resulting from snorting or ingestion is not as intense as that resulting from injecting or smoking the drug.[5]

In Advance

Web-Based Activities

Activity	Web Component?
1	Yes
2	No
3	Yes

Photocopies

For the class	For each student
1 transparency of Master 3.1, *Cocaine Alters Neurotransmission* 1 transparency of Master 3.2, *Methamphetamine and Nicotine Disrupt Neurotransmission* 1 transparency of Master 3.3, *How Does Alcohol Affect Neurotransmission?* 1 transparency of Master 3.7, *What Should the Doctor Do?*	1 copy of Master 3.4, *Parent Letter* 1 copy of Master 3.5, *Caffeine: How Does Your Heart Respond?* 1 copy of Master 3.6, *How Do Drugs Get Into the Brain?*

Materials

Activity	Materials
Activity 1	overhead projector computers
Activity 2	soft drinks, caffeinated and caffeine-free (see Preparation, below) 1 watch or classroom clock with a second hand
Activity 3	computers

Preparation

Arrange for students to have access to the Internet for Activities 1 and 3, if possible.

At least one week before conducting Activity 2, send a copy of Master 3.4, *Parent Letter*, home with each student to inform parents of the activity and get permission for the students to consume a caffeinated or a caffeine-free soft drink during science class. You can also use the letter to ask each student to bring in his or her own can of the designated soft drink. Students who don't drink soda can drink water as another control.

Decide on a brand of soft drink that is available with and without caffeine to use in the activity. Students should drink the same brand of soft drink because each brand contains a different amount of caffeine. If students drank different brands or flavors, the results would be difficult to interpret because each student who drank a caffeinated soft drink would ingest a

different dose. You will need approximately half of the students to drink a caffeinated soft drink and half the students to drink a caffeine-free soft drink. Students who do not get parental permission can participate by drinking water, thereby providing a comparison to the control group. You may obtain the necessary soft drinks through one of the following ways:

- purchase all the soft drinks yourself through your school budget,
- ask for parent or business donations to cover the cost, or
- request that each student bring in one can of soft drink, labeled with his or her name, for his or her consumption only. (If you use this approach, you will need to specify which drink each student brings to class.)

Before the day of Activity 2, have students practice taking a resting heart rate so they are used to finding their pulse, counting the beats for 15 seconds, and multiplying that number by four to get a resting heart rate for one minute (see Activity 2).

Activity 1: Drugs Alter Neurotransmission

Procedure

1. **Review neurotransmission with the students. It may be helpful to have the class watch the online animation of neurotransmission to refresh their memories. Have students refer to the summary of neurotransmission that they completed on Master 2.5.**

After going to the supplement's Web site, click on Lesson 2—*Neurons, Brain Chemistry, and Neurotransmission*.

2. **Create a chart with the following headings on the board:**

Change in neurotransmission	Effect on neurotransmitter release or availability

3. **Ask students if they think there are ways that neurotransmission could be altered. As students propose ideas, fill in the chart on the board. Probe for ideas by asking questions such as**

   - What would happen if certain components in the process increased or decreased in amount?
   - How would that change affect the response in the responding neuron?

   Students may suggest a variety of ways in which neurotransmission can be altered. For example, maybe less neurotransmitter gets released, which would result in reduced (fewer) firings in the responding (postsynaptic) neuron. The postsynaptic neuron might have either more or fewer receptors; changing the number of

Content Standard A: Formulate and revise scientific explanations and models using logic and evidence.

Content Standard C: Cell functions are regulated.

Content Standard C: Organisms have behavioral responses to internal changes and to external stimuli.

receptors would cause an increased or decreased chance of postsynaptic neuron firing. The following chart outlines potential changes and their responses. Omit the third column on the chart at this time; you will complete that part in Step 4.

Change in neurotransmission	Effect on neurotransmitter release or availability	Drug that acts this way
increase the number of impulses	increased neurotransmitter release	nicotine, alcohol,* opioids,* marijuana (THC)*
release neurotransmitter from vesicles with or without impulses	increased neurotransmitter release	amphetamines methamphetamine
release more neurotransmitter in response to an impulse	increased neurotransmitter release	nicotine
block reuptake	more neurotransmitter present in synaptic cleft	cocaine, amphetamine
produce less neurotransmitter	less neurotransmitter in synaptic cleft	no drug example
prevent vesicles from releasing neurotransmitter	less neurotransmitter released	no drug example
block receptor with another molecule, or neurotransmitter cannot bind to its receptor on postsynaptic neuron	no change in amount of neurotransmitter released	LSD, caffeine

* These drugs cause an increase in dopamine release. However, both alcohol and opioids act indirectly. See Steps 10 and 11 on pages 76–77 for a more complete explanation of their actions.

4. **When you have the first two columns completed on the chart, inform students that certain drugs may cause the changes in the neurons that they have suggested. Write the name of the drug next to the change as indicated in the third column on the chart.**

   Students will begin to see that drugs of abuse interfere with and disrupt the process of neurotransmission. When neurons do not communicate normally, the brain does not function normally, either.

5. **Display a transparency of Master 3.1, *Cocaine Alters Neurotransmission*, showing cocaine's effect on dopamine neurotransmission. Point out that cocaine blocks the dopamine transporters. Ask the following questions:**

   - How does this blocking action of cocaine affect dopamine levels?
   - What is the effect on the responding postsynaptic neuron?

   Cocaine blocks the dopamine reuptake pumps (also called dopamine transporters). Students should recall that transporters, or reuptake pumps, carry neurotransmitter, dopamine in this case, back into the presynaptic neuron, where it is repackaged into new vesicles. If the reuptake pumps cannot function, more dopamine will be present in

the synaptic space, where it can cause a greater stimulation of the postsynaptic neuron.

6. **After the students understand how blocking the dopamine transporters alters neurotransmission, show the animation on the Web of cocaine's effect on neurotransmission to the class, if possible.**

To view the animation, go to the supplement's Web site. Select Lesson 3—*Drugs Change the Way Neurons Communicate*.

7. **Discuss the actions of another type of drug, methamphetamine, with the class. Display a transparency of Master 3.2, *Methamphetamine and Nicotine Disrupt Neurotransmission* (top half only). Explain that methamphetamine can act similarly to cocaine in blocking dopamine transporters (reuptake pumps). Methamphetamine also acts in another way to alter neurotransmission. Methamphetamine passes directly through the neuron cell membrane and is carried to the axon terminals. In the terminals, methamphetamine enters the vesicles that contain dopamine. This then triggers the vesicles to be released, even without an electrical signal (action potential) to cause vesicle release. Ask students how this affects the postsynaptic neuron.**

   Methamphetamine acts in two ways to change dopamine neurotransmission. Both actions lead to an increase in the amount of dopamine in the synaptic cleft. When more dopamine is present in the synaptic cleft, it is more likely to bind to the dopamine receptors on the postsynaptic neuron.

8. **Continue to assess the students' understanding of how drugs can alter neurotransmission by asking them to consider how nicotine interferes with dopamine neurotransmission in the brain. Display a transparency of Master 3.2 (bottom half). Explain that nicotine binds to receptors on the transmitting (presynaptic) neuron and causes the neuron to release more neurotransmitter each time an electrical impulse (action potential) occurs. How does this affect the activity of the postsynaptic (receiving) neuron?**

   Nicotine binds to nicotine receptors on the presynaptic neuron. The binding of nicotine to its receptor stimulates the generation of action potentials in the neuron that cause dopamine to be released from the neuron. The released dopamine can then bind to its receptor on the postsynaptic neuron. Nicotine also changes the amount of dopamine that is released. When the presynaptic neuron fires an action potential, more dopamine is released than normal. The increased amount of dopamine in the synaptic cleft will bind to dopamine receptors on the postsynaptic neuron.

Now that students have expanded their understanding of neurotransmission to include how drugs of abuse can alter the process, they should be able to determine how another drug, alcohol, changes neurotransmission.

9. **Display a transparency of Master 3.3, *How Does Alcohol Affect Neurotransmission?* Inform the students that in the presence of alcohol, GABA activity is enhanced, resulting in greater Cl^- influx into the postsynaptic neuron and, consequently, greater inhibition of the neuron. Ask students what other inhibitory signal they have learned.**

   This exercise is similar to Activity 4 in Lesson 2. Although the activity in Lesson 2 limited the signal molecules to being neurotransmitters, drugs can also be signal molecules that affect neuron activity.

   Students may benefit from reviewing their work on Masters 2.7 and 2.8. Students have learned previously that GABA is an inhibitory neurotransmitter.

10. **Ask students to use what they have learned about neurotransmission to answer the following questions:**

    - **How does alcohol affect the activity of the neurons?**

    Alcohol affects the brain's neurons in several ways, most of which are not fully understood. It alters their membranes as well as their ion channels, enzymes, and receptors.

    GABA's effect is to reduce neural activity by allowing Cl^- ions to enter the postsynaptic neuron. These ions have a negative electrical charge, which helps make the neuron less excitable. This physiological effect is amplified when alcohol binds to the GABA receptor, probably because it enables the ion channel to stay open longer and thus let more Cl^- ions into the cell. The neuron's activity would be further diminished, thus explaining the sedative effect of alcohol. This effect is accentuated because alcohol also reduces glutamate's excitatory effect on NMDA receptors.

    In addition to these GABA-mediated effects, alcohol may bind to other receptors. It also helps increase the release of dopamine, by a process that is still poorly understood but that appears to involve curtailing the activity of the enzyme that breaks down dopamine.

    - **If the presynaptic neuron releases GABA as its neurotransmitter, does the amount of GABA released increase or decrease when alcohol is present in the body?**

    If the activity of the presynaptic neuron is decreased, it releases less neurotransmitter.

    - **How does this affect the release of dopamine from the postsynaptic neuron?**

    Because GABA is an inhibitory neurotransmitter, smaller quantities of it in the synaptic space create less inhibition of the postsynaptic neuron. Therefore, the activity of the postsynaptic neuron increases and more dopamine is released when alcohol is present.

If you complete a line for alcohol on the chart like the one on Master 2.8b, it would appear as follows:

Does the signal molecule excite or inhibit Neuron #1?	Does the activity of Neuron #1 increase or decrease?	Does the amount of neuro-transmitter released from Neuron #1 increase or decrease?	What is the name of the neuro-transmitter released from Neuron #1?	Is the neuro-transmitter released from Neuron #1 excitatory or inhibitory?	Does the activity of Neuron #2 increase or decrease?	Does the amount of dopamine released from Neuron #2 increase or decrease?
inhibit	↓	↓	GABA	inhibitory	↑	↑

11. **Now that students understand how alcohol affects neurotransmission in the brain, ask them to compare how alcohol and cocaine change neurotransmission. Use the following questions to guide the discussion.**

    - **How does the way alcohol alters dopamine neurotransmission differ from the way cocaine changes dopamine neurotransmission?**

    Unlike cocaine, alcohol does not act directly on the dopamine-producing neuron. Alcohol acts on another neuron that regulates the activity of a dopamine-producing neuron. In other words, alcohol acts indirectly on dopamine neurotransmission, whereas cocaine acts directly on the neuron that produces dopamine. (Opioids and tetrahydrocannabinol (THC), the active ingredient in marijuana, act by a mechanism similar to that of alcohol.)

    - **Are there any similarities in how alcohol and cocaine change neurotransmission?**

    Both alcohol and cocaine change dopamine neurotransmission and increase the amount of dopamine present in the synaptic cleft. The increased amount of dopamine can inhibit or excite the activity of the postsynaptic neuron depending on the type of dopamine receptor present on the postsynaptic neuron.

Activity 2: How Does Caffeine Affect You?

In Activity 1, students learned that drugs change the communication between neurons. However, hands-on classroom investigations of drugs' effects on the brain are impossible. The following activity is an exercise that students can do to learn more about how a drug, caffeine, affects their body.

Note: Before beginning this investigation, be sure to have permission forms signed by parents or guardians for the students to drink either a caffeinated or caffeine-free soft drink (use Master 3.4, *Parent Letter*). Those students who do not have permission can participate in the investigation by drinking water, thereby providing a comparison or second control for the activity.

NSES

Content Standard A: Design and conduct scientific investigations.

Content Standard A: Mathematics is essential in scientific inquiry.

Content Standard C: Organisms have behavioral responses to internal changes and to external stimuli.

1. **Several days prior to conducting Activity 2, decide which students will be in the group that drinks a caffeinated soft drink and which students will be in the group that drinks a caffeine-free soft drink. Tell students which group they will be a part of if you are asking them to bring a can of soft drink to class. Make sure students understand the need to bring only the specified type of drink.**

   Approximately half of the class should be assigned to each group. You should have permission letters specifying the type of drink for both of these groups. Any student who does not have parental permission can participate in the activity by drinking water.

   Tip from the field test: Knowing which beverage they are consuming may influence students' results. To avoid this possibility, you can prepare cups of soda in advance. Cups labeled "A" could contain a noncaffeinated soft drink, and cups labeled "B" could contain a caffeinated soft drink. Reveal which cups contain each beverage type only after students have collected their data.

2. **Because their heart rates might be elevated from their walk to class, spend several minutes allowing students to rest and talk quietly. Find out what students know about caffeine.**

   Caffeine is a mild stimulant contained in coffee and some soft drinks. People often report that mild doses of caffeine increase their alertness and their ability to concentrate. Higher doses can cause a person to feel jittery or nervous. High doses can cause sleeplessness.

   Related chemicals theophylline (found in tea) and theobromine (found in cocoa and tea) are very mild stimulants also.

3. **If you have not already done so, teach students how to find their pulse, count their heartbeats, and calculate their resting heart rate.**

   A student can find his or her pulse most easily by pressing two fingers against the artery in the neck or on the inside of the wrist. It is easiest to count for 15 seconds and then multiply that number by four to obtain the resting heart rate for one minute. Students should repeat the process several times until they get a consistent resting heart rate.

4. **Distribute one copy of Master 3.5, *Caffeine: How Does Your Heart Respond?*, to each student. On your signal, ask students to measure their heartbeats one more time for 15 seconds, stopping when you call time. Instruct students to calculate their resting heart rate for one minute by multiplying the number they counted by four. Direct them to record it on the data table on the master.**

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

6. **When all the students have filled in their data tables and calculated the difference between their resting heart rate and their heart rate after drinking a soft drink, discuss their findings by asking:**

   - **Did your heart rate go up, down, or stay the same after you drank a caffeinated soft drink?**
   - **If you drank a caffeine-free soft drink, how did your heart rate change?**
   - **What happened if you drank water?**

   On average, most students should have seen their heart rate go up after drinking the caffeinated soft drink. Drinking a caffeinated soft drink increased the heart rate of students in a field-test class by an average of 15 beats per minute. Drinking either a caffeine-free soft drink or water should not change the heart rate significantly.

   Scientists don't know exactly how caffeine increases heart rate, but it is likely to work in two ways:

   – It acts on parts of the brain that regulate the heart rate.
   – It acts directly on the heart.

   - **Why was it important that some students drink the same amount of a caffeine-free soft drink? Why did some students drink water?**

   These questions address the need for controls in scientific investigations. Students will recognize that they are interested in determining the effect of caffeine on their heart rate. Because caffeine-free soft drinks generally contain the same ingredients as caffeinated varieties except for the caffeine, the caffeine-free soft drink serves as a control to ensure that the response is due to the caffeine in the soft drink rather than some other ingredient. Water is a second control; it ensures that the effect on the heart rate of drinking a soft drink is not caused by an ingredient other than caffeine or by simply drinking something.

   - **How long did the effect of caffeine last?**

   Most students will find that their heart rates are either back to the resting rate or very close to it after one hour.

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

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

- **Why do people respond differently to caffeine?**

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

- **What could your results from the caffeine investigation tell you about how individuals respond to drugs of abuse?**

Just as individuals vary in their response to caffeine, individuals will vary in their response to drugs of abuse. The same factors—gender, body size, frequency of use (development of tolerance), genetics, and the individual's metabolic rate—will influence a person's response.

7. **If you are conducting this activity in several classes, you may wish to pool the data from all classes to have a larger sample size.**

8. **Discuss the last item on the master that asks students to consider how different doses of caffeine might affect the response. Encourage students to design an experiment to investigate this.**

   Students likely will propose that drinking a small amount of soft drink will cause only a slight increase, if any, in a person's heart rate, while drinking a large volume of soft drink will cause a larger increase in heart rate. This leads students to consider the concept of dose.

   To investigate the effect of dose on the body's response to caffeine, students may propose that different groups of students drink different amounts of caffeinated soft drink. For example, students could drink 1 ounce, 2 ounces, 4 ounces, 8 ounces, or 16 ounces of soft drink. The design should include appropriate controls. Caffeine-free soft drink again could serve as the control if it is consumed in equal amounts to the caffeinated variety.

Many soft drinks popular among youth contain caffeine. The accompanying table lists some soft drinks and the amounts of caffeine a 12-ounce size contains.

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

Caffeine in Soft Drinks

Soft Drink	Milligrams in 12 ounces
Red Bull	117 mg
Jolt Cola	72 mg
Code Red	54 mg
Mountain Dew	54 mg
Mellow Yellow	53 mg
Diet Coke	47 mg
Coca-Cola Classic	35 mg
Dr Pepper	41 mg
Pepsi Cola	38 mg
Diet Pepsi	36 mg
Coke Zero	35 mg
Barq's Root Beer	23 mg
Mug Root Beer	0 mg
Sprite	0 mg
Sierra Mist	0 mg

Source: Center for Science in the Public Interest. Caffeine Content of Food and Drugs.

Activity 3: Routes of Administration

1. **Give students the opportunity to view the segment *Pathways to the Brain* online, if possible. If not possible, move to Step 2.**

Go to the supplement's Web site. Select Lesson 3—*Drugs Change the Way Neurons Communicate* and then *Pathways to the Brain*.

2. **Give each student a copy of Master 3.6, *How Do Drugs Get Into the Brain*? Students may work in groups of three to analyze the graph and answer the questions.**

   Note to teachers: The graph shown on Master 3.6 is a generalized representation of the speed and intensity of response to drugs. Very few, if any, drugs are commonly taken by all of the different routes.

Content Standard A:
Communicate and defend a scientific argument.

Sample Answers to Questions on Master 3.6

Question 1. Four people who abuse drugs each take a drug. One person injects 100 milligrams of a drug into a vein, one person smokes 100 milligrams of the drug, one person snorts 100 milligrams of the drug, and one person swallows or ingests 100 milligrams of the drug. Who will experience the greatest effect of the drug? The individual with the greatest concentration of drug in the brain will have the greatest effect.

The graph indicates that the individuals who inhale the drug or inject the drug into a vein will experience the greatest effect from the drug. These individuals will have a higher concentration of the drug in the brain than the people who snort (absorption through the mucous membranes) or ingest the drug. The concentration of drug in the brain will be slightly lower for inhalation than injection because some of the smoked drug is exhaled in the smoke.

Question 2. Who will experience the quickest effect from the drug?

The person who inhales the drug will experience the quickest effect from the drug (assuming the person inhales the whole 100 mg). The inhaled drug goes through the lungs and into the left side of the heart and then enters the arterial circulation to the brain, while injected drugs enter the venous circulation that returns the blood to the right side of the heart. The drug that enters the venous system takes longer to exert its effect because the blood must go to the lungs and then to the left side of the heart before it is pumped to the brain and the rest of the body.

Question 3. Who will experience the least behavioral effect from the drug?

The person who ingests, or swallows, the drug will experience the least effect.

Question 4. Who will experience the slowest effect from the drug?

The person who ingests, or swallows, the drug will also have the slowest effect.

Question 5. Tobacco smokers can use nicotine patches to help them quit smoking. The nicotine patches help the smoker slowly lower the amount of nicotine that enters the body. How does the nicotine in the patch enter the body?

Nicotine enters the body by absorption through the skin into capillaries.

Question 6. Explain why the different ways of taking drugs cause different behavioral responses.

Taking drugs by inhalation causes a very rapid increase in the level of drug in the brain. Inhaled drugs are absorbed into the arterial bloodstream in the lungs and then pumped to all parts of the body including the brain. Taking drugs by intravenous (IV) injection also causes a rapid increase in the drug level in the brain. It is slightly slower than inhalation because the drug goes first to the right side of the heart, is then pumped to the lungs where the blood is oxygenated, then goes back to the left side of the heart, and finally to the brain and body. Absorption through the skin or mucous membranes would be even slower because the drug has a longer path to travel before being circulated throughout the body. Drug response would be the slowest after ingestion because the drug goes into the digestive tract and then must pass through the walls of the stomach and intestine to enter the blood capillaries.

3. **Display a transparency of Master 3.7, *What Should the Doctor Do?* Discuss the reasons why one action may be more appropriate than others.**

If students understand that taking drugs into the body by different routes causes different responses, they should be able to explain that the different ways of administering drugs can have advantages and disadvantages. Use this scenario to evaluate students' understanding.

On the basis of what you have learned about how drugs act in the body, how should morphine be given to the patient? Should the morphine be given as a pill, a shot, or an inhalant? Consider each alternative and explain why the different methods should or should not be chosen.

The question concerning how morphine should be administered to a patient to relieve pain is designed to assess whether students understand how different ways of getting drugs into the body changes their effects. The doctor's goal is to relieve the patient's pain quickly so that the fracture can be set.

On the basis of the graph that students analyzed on Master 3.6, the doctor should elect to give morphine as an inhalant or an injection. In each case, the drug reaches the brain quickly. Inhaled drugs can reach the brain even faster than injected drugs. Perhaps the main disadvantage of giving the morphine as an inhaled drug is the amount of drug that actually enters the bloodstream is more variable. If the drug is injected, all of the drug is delivered into the bloodstream. The doctor knows how much morphine enters the bloodstream. Giving a pill to the patient would be less effective than the other means for pain relief because it would take longer for the drug to act and its concentration in the bloodstream would be lower.

Lesson 3 Organizer: WEB VERSION

What the Teacher Does	Procedure Reference
Activity 1: *Drugs Alter Neurotransmission*	
Review neurotransmission with students. If helpful, have students watch the animation from Lesson 2 again.	Page 73 Step 1
Draw a chart on the board with the column headings: "Change in neurotransmission" and "Effect on neurotransmitter release or availability."	Page 73 Step 2
Ask students if they can think of ways that neurotransmission could be altered. Fill in the chart. Ask questions such as • What would happen if the amount of certain components in the process increased or decreased? • How would that change affect the responding neuron?	Pages 73–74 Step 3
Add a third column to the chart with the heading "Drug that acts this way." Write the name of the drug next to the appropriate change.	Page 74 Step 4
Display a transparency of **Master 3.1**. Point out that cocaine blocks the dopamine transporters. Ask, • "How does this blocking action affect dopamine levels in the synaptic cleft?" • "What is the effect on the postsynaptic neuron?"	Pages 74–75 Step 5
Show the online animation of how cocaine acts. Select Lesson 3—*Drugs Change the Way Neurons Communicate*.	Page 75 Step 6
Display the top half of a transparency of **Master 3.2**. Explain how methamphetamine acts by blocking dopamine transporters and by passing through the neuron cell membrane to trigger vesicle release. Ask how these actions affect the postsynaptic neuron.	Page 75 Step 7
Show the bottom half of **Master 3.2**. Explain that nicotine binds to nicotine receptors on the presynaptic neuron and causes the neuron to release more neurotransmitter with each action potential. Ask how this activity affects the postsynaptic neuron.	Page 75 Step 8

What the Teacher Does	Procedure Reference
Display a transparency of **Master 3.3**. Explain that in the presence of alcohol, GABA activity is enhanced, resulting in greater Cl^- influx into the presynaptic neuron and, consequently, greater inhibition of the neuron. Use the following questions to help students understand how alcohol affects neurotransmission. • How does alcohol affect the activity of the neurons? • If the presynaptic neuron releases GABA as its neurotransmitter, does the amount of GABA released increase or decrease when alcohol is present in the body? • How does this affect the release of dopamine from the postsynaptic neuron? Complete a summary by completing a line for alcohol on the chart on **Master 2.8b**.	Page 76 Steps 9–10 T
Have students compare the actions of alcohol and cocaine on neurotransmission. Use the following questions to guide the discussion. • How does the way alcohol alters dopamine neurotransmission differ from the way cocaine changes dopamine neurotransmission? • Are there any similarities in how alcohol and cocaine change neurotransmission?	Page 77 Step 11
Activity 2: *How Does Caffeine Affect You?*	
Several days before this activity, assign students to the caffeinated or caffeine-free group. Remind students to bring the appropriate can of soft drink and a signed permission form (**Master 3.4**).	Page 78 Step 1 M
Have students spend several minutes sitting quietly so their heart rates are at a resting level. Probe students' knowledge about caffeine.	Page 78 Step 2
Teach students how to find their pulse, count their heartbeat, and calculate their resting heart rate.	Page 78 Step 3
Distribute one copy of **Master 3.5** to each student. Ask students to count their heartbeats for 15 seconds while you time them. Have students calculate their resting heart rate and enter the number in the data table on the master.	Page 78 Step 4 M
Ask students to work in pairs. Distribute cans of soft drink. Allow students time to work through the instructions on the master.	Page 79 Step 5

What the Teacher Does	Procedure Reference
Discuss the results of the investigation with the class. Use the following questions to guide the discussion. • Did your heart rate go up, down, or stay the same after you drank a caffeinated soft drink? • If you drank a caffeine-free soft drink, how did your heart rate change? • What happened if you drank water? • Why was it important that some students drink the same amount of a caffeine-free soft drink? Why did some students drink water? • How long did the effect of caffeine last? • Did all the members of the class have exactly the same results when they drank a caffeinated soft drink? • Why do people respond differently to caffeine? • What could your results from the caffeine investigation tell you about how individuals respond to drugs of abuse?	Pages 79–80 Step 6
If you have several classes, you may wish to pool data to have a larger sample size for analysis.	Page 80 Step 7
Discuss how the dose of caffeine may affect the response. Encourage students to design an experiment to investigate this.	Page 80 Step 8
Activity 3: *Routes of Administration*	
Give students the opportunity to view the appropriate online segment. To access the segment, click on Lesson 3—*Drugs Change the Way the Neurons Communicate* from the activities menu. Then select *Pathways to the Brain*.	Page 81 Step 1 
Give each student one copy of **Master 3.6**. Have students work in groups of three for this step.	Pages 81–83 Step 2 
Display a transparency of **Master 3.7**. Discuss as a class why one action may be more appropriate than others.	Page 83 Step 3 

 = Involves using the Internet.

 = Involves copying a master.

 = Involves making a transparency.

Lesson 3 Organizer: PRINT VERSION

What the Teacher Does	Procedure Reference
Activity 1: *Drugs Alter Neurotransmission*	
Review neurotransmission with students.	Page 73 Step 1
Draw a chart on the board with the column headings: "Change in neurotransmission" and "Effect on neurotransmitter release or availability."	Page 73 Step 2
Ask students if they can think of ways that neurotransmission could be altered. Fill in the chart. Ask questions such as • What would happen if the amount of certain components in the process increased or decreased? • How would that change affect the responding neuron?	Pages 73–74 Step 3
Add a third column to the chart with the heading "Drug that acts this way." Write the name of the drug next to the appropriate change.	Page 74 Step 4
Display a transparency of **Master 3.1**. Point out that cocaine blocks the dopamine transporters. Ask, • "How does this blocking action affect dopamine levels in the synaptic cleft?" • "What is the effect on the postsynaptic neuron?"	Pages 74–75 Step 5 (skip Step 6)
Display the top half of a transparency of **Master 3.2**. Explain how methamphetamine acts by blocking dopamine transporters and by passing through the neuron cell membrane to trigger vesicle release. Ask how these actions affect the postsynaptic neuron.	Page 75 Step 7
Show the bottom half of **Master 3.2**. Explain that nicotine binds to nicotine receptors on the presynaptic neuron and causes the neuron to release more neurotransmitter with each action potential. Ask how this activity affects the postsynaptic neuron.	Page 75 Step 8

What the Teacher Does	Procedure Reference
Display a transparency of **Master 3.3**. Explain that in the presence of alcohol, GABA activity is enhanced, resulting in greater Cl^- influx into the presynaptic neuron and, consequently, greater inhibition of the neuron. Use the following questions to help students understand how alcohol affects neurotransmission. • How does alcohol affect the activity of the neurons? • If the presynaptic neuron releases GABA as its neurotransmitter, does the amount of GABA released increase or decrease when alcohol is present in the body? • How does this affect the release of dopamine from the postsynaptic neuron? Complete a summary by completing a line for alcohol on the chart on **Master 2.8b**.	Page 76 Steps 9–10 T
Have students compare the actions of alcohol and cocaine on neurotransmission. Use the following questions to guide the discussion. • How does the way alcohol alters dopamine neurotransmission differ from the way cocaine changes dopamine neurotransmission? • Are there any similarities in how alcohol and cocaine change neurotransmission?	Page 77 Step 11
Activity 2: *How Does Caffeine Affect You?*	
Several days before this activity, assign students to the caffeinated or caffeine-free group. Remind students to bring the appropriate can of soft drink and a signed permission form (**Master 3.4**).	Page 78 Step 1 M
Have students spend several minutes sitting quietly so their heart rates are at a resting level. Probe students' knowledge about caffeine.	Page 78 Step 2
Teach students how to find their pulse, count their heartbeat, and calculate their resting heart rate.	Page 78 Step 3
Distribute one copy of **Master 3.5** to each student. Ask students to count their heartbeats for 15 seconds while you time them. Have students calculate their resting heart rate and enter the number in the data table on the master.	Page 78 Step 4 M
Ask students to work in pairs. Distribute cans of soft drink. Allow students time to work through the instructions on the master.	Page 79 Step 5

What the Teacher Does	Procedure Reference
Discuss the results of the investigation with the class. Use the following questions to guide the discussion. • Did your heart rate go up, down, or stay the same after you drank a caffeinated soft drink? • If you drank a caffeine-free soft drink, how did your heart rate change? • What happened if you drank water? • Why was it important that some students drink the same amount of a caffeine-free soft drink? Why did some students drink water? • How long did the effect of caffeine last? • Did all the members of the class have exactly the same results when they drank a caffeinated soft drink? • Why do people respond differently to caffeine? • What could your results from the caffeine investigation tell you about how individuals respond to drugs of abuse?	Pages 79–80 Step 6
If you have several classes, you may wish to pool data to have a larger sample size for analysis.	Page 80 Step 7
Discuss how the dose of caffeine may affect the response. Encourage students to design an experiment to investigate this.	Page 80 Step 8
Activity 3: *Routes of Administration*	
Give each student one copy of **Master 3.6**. Have students work in groups of three for this step.	Pages 81–83 Steps 1–2 M
Display a transparency of **Master 3.7**. Discuss as a class why one action may be more appropriate than others.	Page 83 Step 3 T

M = Involves copying a master.

T = Involves making a transparency.

LESSON 4
Explain/Elaborate

Drug Abuse and Addiction

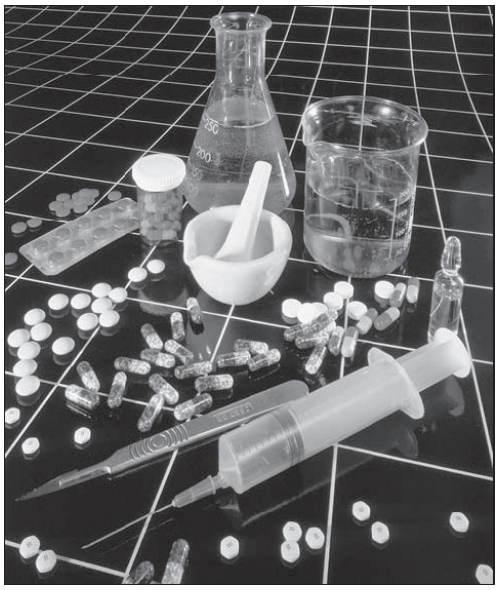


Photo: Corel

At a Glance

Overview

Students examine data from animal experiments, play a card game, and examine a case study. They learn that although the initial decision to take drugs of abuse is voluntary, continued use may lead to addiction, which is the continued compulsive abuse of drugs despite adverse consequences. Students then watch a minidocumentary online to learn how drugs cause long-term changes in the brain.

Major Concept

Addiction is a brain disease.

Objectives

By the end of these activities, the students will

- understand that drug abuse initially is a voluntary behavior,
- be able to define drug addiction as the continued compulsive drug abuse despite known adverse health or social consequences,
- understand that drug abuse and addiction are associated with long-term physical and functional changes in the brain, and
- recognize that addiction is influenced by biological factors (for example, genetics and age) and by the social and behavioral context of drug use.

Basic Science–Health Connection

Drug addiction is a complex brain disease. Preventing drug abuse and addiction and treating the disease effectively require understanding the biological, genetic, social, psychological, and environmental factors that predispose individuals to drug addiction.

Background Information

Individuals make choices to begin using drugs. Some people begin using drugs to relieve a medical condition and then continue to use the drugs after the medical need is over. Children or teens who are depressed or who have another psychiatric disorder sometimes begin using illicit drugs in an attempt to self-medicate. Other people begin taking drugs to feel pleasure, to escape the pressures of life, or to alter their view of reality. This voluntary initiation into the world of addictive drugs has strongly influenced society's view of drug abuse and drug addiction and their treatment.

When does drug abuse become drug addiction? It rarely happens with the first use of a drug. Drug abuse and drug addiction can be thought of as points along a continuum. Any use of a mind-altering drug or the inappropriate use of medication (either prescription or over-the-counter drugs) is **drug abuse**, but the point when drug abuse becomes drug addiction is less clear. Different people may reach the point of addiction at different stages. Scientists continue to investigate the factors that contribute to the transition to drug addiction.

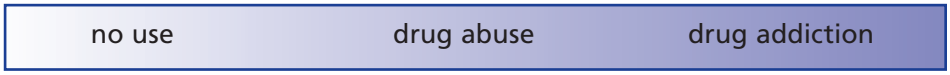


Figure 4.1: *The continuum of drug abuse and addiction.*

Drug addiction is defined as the continued compulsive use of drugs despite adverse health or social consequences.[1] Drug-addicted people have lost control of their drug use. Individuals who are addicted to drugs often become isolated from family or friends, have difficulty at work or school, may commit crimes, and become involved with the criminal justice system. For a person addicted to drugs, continuing to take them becomes the primary focus in life.

Certain drugs, including opioids and alcohol, cause strong physical reactions in the body when drug use stops. When a person addicted to heroin stops taking heroin, he or she can experience a variety of symptoms ranging from watery eyes and a runny nose to irritability and loss of appetite and then diarrhea, shivering, sweating, abdominal cramps, increased sensitivity to pain, and sleep problems.[2] In general, withdrawal from heroin makes people feel miserable. Withdrawal from alcohol can cause serious effects such as seizures and even death. Withdrawal from other drugs, such as cocaine and amphetamines, does not lead to strong physical reactions, but it may make the person feel depressed or lethargic. For most drugs, physical withdrawal symptoms can usually be controlled effectively with medications. Even though withdrawal from some drugs does not cause the person abusing them to have physical reactions, stopping drug use is difficult because of the changes the drugs have caused in the brain. Once the drugs stop, the person will have **cravings**, or intense desire for the drugs.[3] Craving arises from the brain's need to maintain a state of homeostasis that now relies on the presence of the drug. A person may experience cravings at any stage of drug abuse or addiction, even early

in the experimentation phase of drug abuse. Cravings have a physical basis in the brain. Using PET imaging, scientists have shown that just seeing images of drug paraphernalia can stimulate the amygdala (part of the brain involved in emotional memory) in an addicted person.[4]

Drugs of addiction do not merely cause short-term changes in an individual's cognitive skill and behavior. A drug "high" lasts a short time, ranging from less than an hour to 12 hours, depending on the drug, dose, and route of administration. The changes in the brain that result from continued drug use, however, can last a long time. Scientists believe that some of these changes disappear when drug use stops; some disappear within a short time after drug use stops, and other changes are potentially permanent. One of the first changes in the brain that may occur in response to repeated drug abuse is tolerance. **Tolerance** develops when a person needs increasing doses of a drug to achieve the same high or "rush" that previously resulted from a lower dose of the drug. Two primary mechanisms underlie the development of tolerance.[3] First, the body may become more efficient at metabolizing the drug, thereby reducing the amount that enters the brain. Second, the cells of the body and brain may become more resistant to the effect of the drug. For example, after continued cocaine use, neurons decrease the number of dopamine receptors, which results in decreasing cocaine's stimulatory effect. Opioids, on the other hand, do not cause a change in the number of receptors. Instead the opioid receptors become less efficient in activating associated cellular processes, thus reducing the effects of the opioids.

Drugs can cause other long-term changes in the anatomy and physiology of the brain's neurons. Alcohol, methamphetamine, and MDMA (ecstasy) have been shown to be neurotoxic in animal studies.[3] Unlike other types of cells in the body, neurons in many parts of the brain have little or no capacity to regenerate. (Recent studies have shown that the adult human brain can generate new neurons in the hippocampus, a part of the brain important for learning and memory.[5] Other parts of the brain have not been shown to have this ability.) Alcohol kills neurons in a part of the brain that helps create new memories (the hippocampus and mammillary bodies). If those neurons die, the capacity for learning decreases. Methamphetamine is toxic to dopamine-containing neurons in animals and possibly in humans as well.[6] MDMA has been shown in animal studies to damage the axon terminals of neurons that produce another neurotransmitter called serotonin.[7] In addition to neurotoxic effects, drugs can significantly alter the activity of the brain. PET scans of people addicted to cocaine show that the metabolism of glucose, the primary fuel for cells, is drastically reduced in the brain; this decrease in metabolism can last for many months after drug abuse stops.[8]

In addition to the functional and anatomical changes in the brain, drug abuse puts people at higher risk for other health problems. For example, inhalant abuse can lead to disruption of heart rhythms, and snorting cocaine can lead to ulcerations in the mucous membranes of the nose. In addition, injection drug users (IDUs) are at higher risk of contracting HIV through the sharing of potentially contaminated needles. Similarly,

hepatitis B and hepatitis C are much more common among drug addicts than the general population. Tuberculosis is another concern. Drug abuse and addiction also are contributing factors in motor vehicle accidents.

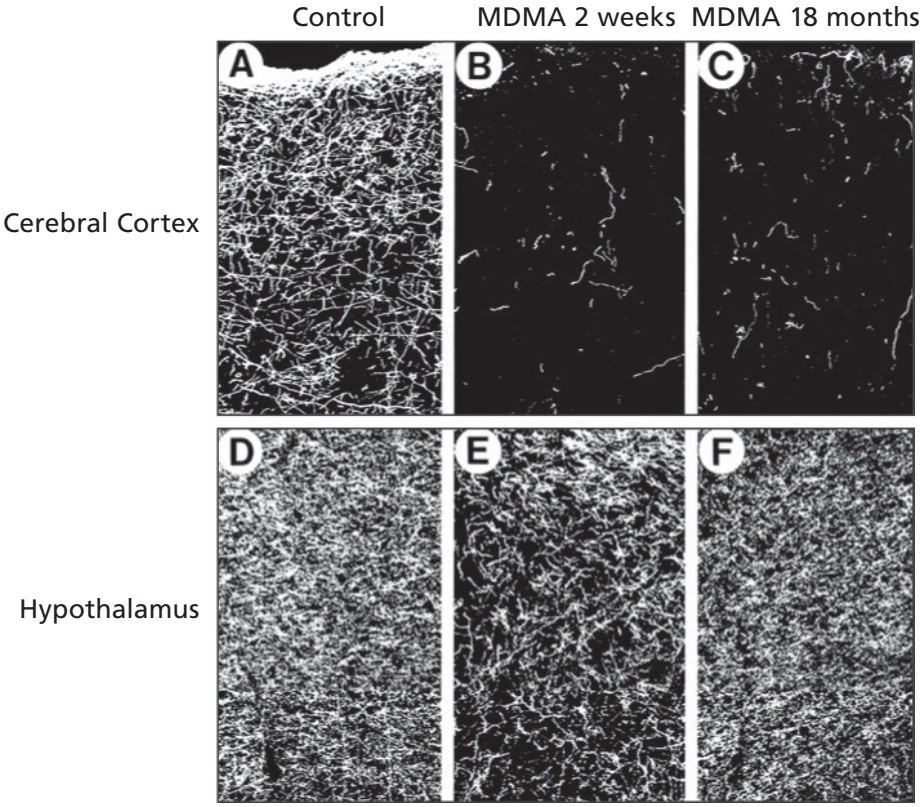


***Figure 4.2**: Photographs of serotonin axons in the cerebral cortex of nonhuman primates labeled with a fluorescent marker. The number of serotonin-labeled axons is dramatically reduced in the cerebral cortex at 2 weeks (B) and 18 months (C) after the last drug exposure. The brain of the control animal that did not receive MDMA (A) shows the dense network of labeled axons. Images E and F show changes caused by MDMA use on a different brain region, the hypothalamus. The control showing the hypothalamus in the absence of MDMA is shown in D. Photographs courtesy of G.A. Ricaurte, with the permission of the* Journal of Neuroscience.

Genetic, Behavioral, and Environmental Influences on Drug Addiction

Drug addiction is not simply continuous drug abuse. Many more individuals will try an addictive drug than will become addicted. Most people know of situations in which two people use the same amount of alcohol or tobacco, but have very different responses to them. Environmental, social, behavioral, and genetic factors also contribute to the development of drug addiction.[9] Stress can increase the susceptibility to addiction.

Scientists continue to investigate the factors that place one individual at greater risk of becoming addicted than another individual with a similar pattern of drug use. Individuals who have developed strong coping skills to deal with life's pressures have less risk of becoming addicted to drugs. The younger a person is when he or she begins using drugs, the more likely he or she is to become addicted. This may be true because younger individuals have not developed the coping skills necessary to deal with life's ups and downs. Additionally, the frontal cortex of the adolescent brain isn't fully mature until age 24.[10] This area of the brain is responsible for judgment and for inhibiting impulsivity and risk-taking behavior. In addition, genetic factors probably influence who engages in higher-risk behaviors.

The context in which a person uses an addictive drug greatly contributes to its behavioral effects and the risk of abuse and addiction. For example, some cancer patients take relatively large doses of morphine for extended periods to control pain without becoming addicted. It has been proposed that addiction is rare in these patients because, in contrast to addicted individuals, these patients are motivated not by a compulsive urge to seek a high but by a physiologic need to ease their pain and improve their quality of life.

Medical Uses of Addictive Drugs

It is well known that otherwise safe medications can turn harmful if abused or taken without prescription or supervision. The other side of this coin is that many drugs of abuse are themselves, or have been found to contain, active ingredients that can be therapeutic. A good example is morphine. During the Civil War, doctors gave morphine to wounded soldiers to relieve the pain of injuries. Doctors didn't realize how addictive injected morphine was until many soldiers became addicted to the drug.[2] Morphine addiction became known as "soldiers' disease." Today, morphine is a valuable medicine to relieve pain when administered with the appropriate medical supervision. Patients in hospitals receive morphine to ease their pain after surgery and during cancer and burn treatment. Very few of these patients become addicted to morphine even though they may take it for extended periods of time.

Another drug that has received considerable attention for its potential medical benefits is marijuana. Television and newspaper reports periodically present stories on the use of marijuana by terminal cancer or AIDS patients to ease their discomfort and pain. Following up on such anecdotal evidence, several scientific studies have been able to corroborate at least some of the claims about marijuana's beneficial effects on appetite, nausea, and certain types of pain. However, marijuana's addictive properties and its usual delivery by smoke inhalation—which exposes the lungs to many toxic chemicals—make it an unappealing candidate for medications development. Rather, it is likely that our understanding of the biology of marijuana's active ingredients, such as tetrahydrocannabinol (THC), will lead to improved medications for a variety of conditions, ranging from obesity and addiction to neuropathic pain in multiple sclerosis (MS) patients, chronic pain in advanced cancer patients, nausea, and wasting syndrome.[11]

The risk of becoming addicted to prescription pain medications is minimal in patients who are treated on a short-term basis; however, the risk for those with chronic pain is less well understood. Some studies have shown that those most vulnerable to becoming addicted to prescription pain medications have a history of psychological disorders, prior substance abuse problems, or a family history of these disorders. Pain management for patients who have substance abuse disorders is particularly challenging for the medical profession. However, these patients can still be successfully treated with opioid pain medications, although they may need to be admitted to a treatment or recovery program and monitored closely if controlled substances are prescribed for pain.

In the 1970s, news media reported the use of marijuana and heroin by soldiers who were serving in Vietnam. Combat stress, the easy availability of drugs, and the relaxation of taboos against drug use at the time all contributed to the problem. Although many soldiers did have drug problems while in Vietnam, 95 percent were not addicted to drugs after they returned to the United States.[12] This illustrates the profound effect that environmental circumstances can have on drug taking and drug addiction.

In addition, scientists are working to identify genetic factors that contribute to drug abuse and addiction. Studies of identical twins indicate that as much as half of an individual's risk of becoming addicted to nicotine, alcohol, or other drugs depends on his or her genes. Recent technical advances in DNA analysis have enabled researchers to untangle complex genetic interactions by examining a person's entire genome at once. A series of studies has identified a certain variant in the gene for a nicotinic receptor subunit that more than doubles the risk for addiction among smokers, as well as increasing their vulnerability to lung cancer and peripheral arterial disease.

Animals as Research Models

Why do scientists study the brains of laboratory animals? Scientists use animals in research studies because the use of humans is either impossible or unethical. For example, when scientists investigate the effects of drugs of abuse on brain function, either the question they are asking cannot be answered in a living human or it would be inappropriate to give a person the drugs.

The use of animals as subjects in scientific research has contributed to many important advances in scientific and medical knowledge. Scientists must analyze the goals of their experiments in order to select an animal species that is appropriate. Scientists often use fruit flies (*Drosophila melanogaster*) when they want to learn more about genetics. However, fruit flies are not a very good model if a scientist is investigating muscle physiology or behavior; a mouse may be a better model for those experiments. Although scientists strive to develop nonanimal models for research, these models often do not duplicate the complex animal or human body. Continued progress toward a more complete understanding of human and animal health depends on the use of living animals.

Guidelines for the Use of Animals in Scientific Research

Scientists who use animals as research subjects must abide by federal policies that govern the use and care of vertebrate animals in research. The Public Health Service established a policy that dictates specific requirements for animal care and use in research. This policy conforms to the Health Research Extension Act of 1985 (Public Law 99-158) and applies to all research, research training, biological testing, and other activities that involve animals.[13] The principles for using and caring for vertebrate animals in research and testing are as follows:

- The transportation, care, and use of animals should be in accordance with the Animal Welfare Act and other applicable federal laws, guidelines, and policies.
- Procedures involving animals should be designed with consideration of their relevance to human or animal health, the advancement of knowledge, or the good of society.
- The animals selected should be of an appropriate species and quality and the minimum number required to obtain valid results. Methods such as mathematical models, computer simulation, and in vitro biological systems should be considered.
- Procedures should minimize discomfort, distress, and pain to the animals.
- Procedures that may cause more than momentary or slight pain should be performed with appropriate sedation, analgesia, or anesthesia.
- Animals that would suffer severe or chronic pain or distress that cannot be relieved should be painlessly killed.
- The living conditions of animals should be appropriate for the species. The housing, feeding, and care of animals must be directed by a veterinarian or a trained, experienced scientist.
- Investigators who work with animals must be appropriately qualified and trained for conducting procedures on living animals.
- Exceptions to any of these principles must be reviewed and approved by an appropriate committee prior to the procedure.
- An Institutional Animal Care and Use Committee (IACUC) oversees all animal use in each institution where animal research is conducted. The IACUC must give approval for the research plan and species to be used. IACUCs include both scientists and nonscientists from outside the institution. Nonscientists are often representatives of humane organizations.

In Advance

Web-Based Activities

Activity	Web Component?
1	No
2	No
3	No
4	No
5	Yes

Photocopies

For the class	For each student
1 transparency of Master 4.4, *Playing the Game* 1 transparency of Master 4.5, *Who Is Addicted?*	1 copy of Master 4.1, *Data for Rat Self-administration Experiment* 1 copy of Master 4.2, *Worksheet for Rat Experiment Data* 1 copy of Master 4.3, *Evaluating the Experiment* 1 copy of Master 4.6, *Long-Term Effects of Drugs on the Brain* (only if not using the Web-based version)

Materials

Activity	Materials
Activity 1	none
Activity 2	colored pencils, overhead projector, transparency
Activity 3	playing cards (one deck for each group of 3 students; see Preparation section), overhead projector
Activity 4	overhead projector
Activity 5	computer

Preparation

Gather decks of playing cards for use in Activity 3. Each group of three students can share one deck of cards. Separate the face cards (jacks, queens, and kings) and place them in one pile. Place the aces and number cards in another pile.

Arrange for students to have access to computers for viewing the minidocumentary online in Activity 5.

Activity 1: How Does Drug Abuse Begin?

Procedure

Content Standard F: An individual's mood and behavior may be modified by substances.

1. **Begin the activity by holding a class discussion. Ask students, "What is a drug?" Write their answers on the chalkboard or on an overhead transparency. Give students the opportunity to present differing views.**

   Students will respond with a variety of answers. Some will give examples of illegal drugs, such as marijuana or cocaine, others may give the names of prescription medications. If so, prompt students to think about a definition for the word drug. Some students will describe a drug either as an illegal substance that harms a person's health or as a chemical that a person takes to treat a disease or illness. At this point, based on students' knowledge, both definitions are correct.

   Several terms will be introduced in this lesson. It is very important to use these terms according to the definitions provided.

2. **Write the following definitions for *drug* and *medication* on the board or transparency and inform students that, for this discussion, you will use the terms according to the following definitions.**

   - **A *medication* is a drug that is used to treat an illness or disease according to established medical guidelines.**
   - **A *drug* is a chemical compound or substance that can alter the structure and function of the body. Psychoactive drugs affect the function of the brain, and some of these may be illegal to use and possess.**

3. **If the students didn't do this in the previous question, ask them to consider examples for both medications and drugs. List each response in the proper category as a medication or a drug.**

   According to these definitions, all medications are drugs, but not all drugs are medications. This module uses the word "drug" to refer to psychoactive drugs, or drugs of abuse. Drug abuse refers to the use of illicit drugs or to the inappropriate use of a legal drug or substance, such as alcohol, nicotine, prescription drugs, or inhalants.

   Societal and political factors sometimes influence into which category a substance falls. Alcohol and nicotine (tobacco) are drugs that are illegal to use and possess if the individual is below legal age, but not for adults to possess and use responsibly. Also, inhalants (paints, glues, and sprays, for example) are not illegal to possess when they are used for their intended purposes. However, they are drugs when used improperly to alter brain function.

Some students will raise the idea that medications can also be drugs if they are used inappropriately. For example, overuse of a prescription medication, such as a sedative, is inappropriate and wouldn't be considered a medication in that case. Alternatively, students may indicate that morphine is an illegal drug when used without medical supervision, but is a valuable medicine when used appropriately in a hospital, or at home, to relieve pain associated with various diseases. Students may also propose that marijuana can be a medication to relieve the pain that accompanies various diseases. (In some states, marijuana is legal as a medication, but is illegal according to federal law.) If students bring this up, point out to them that scientists need to continue studying marijuana or its active ingredients to determine if it may be effective as a medicine. Marijuana contains hundreds of chemical compounds; the effects of most of these compounds in the body are unknown. Marijuana also poses many problems outside of the brain—for the lungs, for example, because it is usually smoked. Use this as an opportunity to inform students that scientific research is being done to determine whether marijuana or other cannabinoid-based medications are more effective than other medicines (see the Background Information section).

4. **Ask students to respond to the question, Why do people start abusing drugs?**

   Students may provide a wide range of answers to this question including peer pressure, experimentation, boredom, or fun. Some students may also respond that people take drugs to escape from life's pressures.

Activity 2: Drug Abuse Is Voluntary; Addiction Is Compulsive

Content Standard A: Mathematics is essential in scientific inquiry.
Content Standard A: Scientists rely on technology to enhance the gathering and manipulation of data.
Content Standard C: Organisms have behavioral responses to internal changes and to external stimuli.
Content Standard F: An individual's mood and behavior may be modified by substances.

1. **For this activity, students will work in groups of four. Before you have students divide into their small groups, set the stage for the activity. Tell students they will be analyzing data from experiments using rats. For the experiments, each rat was placed in a cage with two levers that the rat could press. If the rat pressed the food lever, a pellet of food was released. If the stimulus lever was pressed, the rat received an injection or an electrical stimulus.**

   Students may ask what substance was injected in response to the press of the stimulus lever. Tell students that the answer to that question will be revealed during the activity.

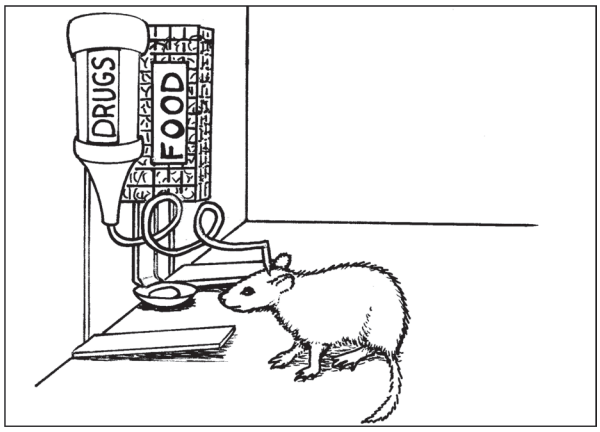


Figure 4.3 *Diagram of a rat in a cage during a drug self-administration experiment.*

2. **Give each student a copy of Masters 4.1, *Data for Rat Self-administration Experiment*, and 4.2, *Worksheet for Rat Experiment Data*. Each student will graph on Master 4.2 the data for only one of the rats. Instruct the teams to decide which member will graph the data for Rats A, B, C, and D. The students will plot the total number of times that the rat presses the stimulus lever vs. time and the total number of times that the rat presses the food lever vs. time.**

   The graph of the data for each rat will have two lines, one for the stimulus lever and one for the food lever. Students can use a different color of pencil for plotting each set of data, or they can use a solid line and a dashed line to distinguish between the two graph lines.

3. **After students have completed their graphs, give each student a copy of Master 4.3, *Evaluating the Experiment*. Each student should share his or her graph with the other members of the group. Group members then discuss the similarities and differences among the rats' responses and answer the questions on Master 4.3.**

4. **When the groups are finished answering the questions, hold a class discussion to ensure that each group has come to the appropriate conclusions.**

Sample Answers to Questions on Master 4.3

Question 1. Why do the rats press a lever the first time?

The rats initially press a lever while they are exploring the cage. A rat may even press the lever by accident. Whether a rat presses the food lever or the stimulus lever first is usually random.

Question 2. Compare the lever-pressing behaviors of the four different rats. Which rat pressed the stimulus lever the most? Which one pressed the stimulus lever the least? Which rat pressed the food lever the most? Which one pressed the food lever the least?

Rats A and C pressed the stimulus lever about the same number of times and many more times than either Rat B or Rat D. Rats B and D did not press the stimulus lever very many times, but they pressed the food lever more times than Rats A and C did. Overall, Rats A and C behaved similarly and Rats B and D behaved similarly.

Question 3. Rat A was injected with cocaine each time it pressed the stimulus lever. Can you use this fact to explain why Rat A behaved the way it did?

The cocaine activated the reward system in the brain and caused the rat to continue its stimulus-lever-pressing behavior. If necessary, remind students that the reward system is the part of the brain stimulated by drugs to cause feelings of pleasure.

Question 4. Based on the data you analyzed, do you think Rat B was injected with cocaine when it pressed the stimulus lever? From what you have learned so far in this unit, do you think Rat B was injected with a different addictive drug when it pressed the stimulus lever? Why?

It appears that Rat B was not injected with cocaine when it pressed the stimulus lever because its behavior was very different from Rat A. If Rat B was injected with cocaine or another addictive drug, it should display behavior similar to Rat A.

(Rat B actually received a saline injection when it pressed the stimulus lever.)

Question 5. Do you think Rat C received cocaine when it pressed the stimulus lever? Why?

It is possible that Rat C received cocaine when it pressed the stimulus lever because its behavior was very similar to that of Rat A. However, you cannot be sure that it was cocaine.

Question 6. Rat C did not receive an injection of cocaine when it pressed the stimulus lever. When Rat C pressed the stimulus lever, it received a mild electrical stimulation in the brain. On the basis of what you have learned, can you predict what part of the brain was stimulated?

The reward system (ventral tegmental area or nucleus accumbens) is the part of the brain stimulated. Stimulation in that area of the brain caused the rat to continue pressing the stimulus lever.

Question 7. Rat D also received a mild electrical stimulation in the brain when it pressed the stimulus lever. Do you think the same part of the brain was stimulated in Rat D as was stimulated in Rat C? Why?

Rat D did not receive an electrical stimulation in the same part of the brain that was stimulated in Rat C. If the same part of the brain, the reward system, was stimulated, Rat D should behave similarly to Rat C.

(Rat D received an electrical shock in the cerebellum, which is not part of the reward pathway.)

Question 8. Why did Rats A and C press the stimulus lever more than the food lever?

Rats A and C received a greater "reward" when they pressed the stimulus lever than they did when they pressed the food lever.

Question 9. Why did Rats B and D press the food lever more than the stimulus lever?

Rats B and D received greater "reward" when they pressed the food lever than they did when they pressed the stimulus lever.

Question 10. Why did the scientists who conducted this experiment include Rats B, C, and D? How did the data from those rats help scientists understand more about how cocaine acts in the brain?

Rats B, C, and D were used as controls in this experiment. Rat B received a saline injection after pressing the stimulus lever. (The cocaine that Rat A received was dissolved in a saline solution.) Because Rat B's behavior differed from Rat A's behavior, this suggests that the cocaine that Rat A received caused the frequent stimulus-lever-pressing behavior. Because both rats had a canula inserted to deliver the solution, the process of inserting the canula is not sufficient to cause Rat A's behavior.

The data from Rat C reveal that electrical stimulation of the VTA elicits behavior similar to that caused by cocaine injection. Because cocaine is known to act on neurons in the VTA, these data reinforce the findings from Rat A that the cocaine acting on the VTA neurons causes the frequent stimulus-lever-pressing behavior.

Rat D received electrical stimulation in the cerebellum after pressing the stimulus lever. The cerebellum is not part of the reward system. These data show that stimulation to a discrete brain area, the reward system, causes Rat C's behavior. Inserting the electrode into other areas of the brain is not sufficient to elicit the rapid stimulus-lever-pressing behavior observed in Rat C.

Question 11. Do you think that Rats A and C will stop pressing the stimulus lever if they continue to receive the same stimulation each time they press it? Why?

On basis of the data, it does not seem likely that Rats A and C would stop pressing the stimulus lever because the number of times it is pressed continues to increase within each five-minute period. Students may notice that Rat A pressed the stimulus lever more times during the last five-minute period of the experiment than it did during the first five-minute period.

Question 12. On the basis of what you learned from these data, what might this investigation tell you about drug use by humans? Explain your view.

The data from the rat experiment show that the use of addictive drugs is reinforcing. Rats who are given cocaine want more cocaine. Because rats are mammals just as humans are and many of their organs function in ways similar to those in humans, the data suggest that drug use in humans is likely to be reinforcing as well: humans who take drugs will probably want to continue taking drugs.

5. **Have students consider the question, Why do humans continue to abuse drugs?**

   People who are addicted to drugs continue to take drugs despite negative consequences. They know that their family, social, or career interactions are disrupted by their drug abuse, but they cannot stop. Drug-taking becomes *compulsive*. Rats A and C became conditioned to the activation of the reward system by the administration of cocaine or electrical stimulation in the VTA in response to a lever press. Those rats continued to press the stimulus bar in their cages and ignored the food lever. The cocaine or electrical stimulation in the VTA was a bigger reward for the rats than was the food. In humans, drugs cause a compulsive need for more drugs.

6. **Write the following definition of *addiction* on the chalkboard or overhead transparency.**

   - ***Addiction* is a chronic, relapsing brain disease characterized by compulsive drug-taking despite adverse health, social, or legal consequences.**

7. **Ask students to consider what they learned from the data concerning the continued use of cocaine by Rat A and the continued stimulation of the reward pathway in Rat C. Did Rat A and Rat C experience any adverse effects from their treatments? What adverse consequences do drug-addicted humans experience?**

Although it is not appropriate to refer to the rats as addicted to cocaine, those rats would have experienced adverse effects if the experiment continued for a long time. If the experiment continued and the rats continued to push only the stimulus lever, the lack of food and water would lead to adverse health consequences. If the scientists did not stop the experiment, the rats would have continued to press the stimulus lever until they died from a cocaine overdose.

Humans addicted to drugs are most concerned with their next drug use. Because of this, they often eat little or poorly and consequently suffer the adverse health consequences of poor nutrition.

8. **Ask students to consider the distinction between drug abuse and drug addiction in humans.**

   - **When does abuse become addiction?**
   - **What causes abuse to become addiction?**
   - **Does the change from abuse to addiction occur at the same level (amount of drug taken, duration of drug abuse) of drug abuse for different individuals?**

   Students should be able to use the previously given definition of addiction and the results of the cocaine self-administration experiments with rats to differentiate between drug abuse and addiction. Abuse is voluntary; addiction is the continued compulsive drug use despite adverse health or social consequences.

   Scientists do not know what causes a person who is abusing drugs to become addicted. Continuing research is attempting to answer this question.

Activity 3: When Does Abuse Become Addiction?

Note: The power of this activity lies in the discussion it elicits. Without the discussion, the activity could allow misconceptions to persist. If you don't have enough class time for discussion, please skip this activity.

Content Standard F: Personal choice concerning fitness and health involves multiple factors.

1. **Divide the class into groups of three students. Give each group a deck of cards that have been divided into two piles. Tell the students that the small pile contains the face cards and the larger pile has the aces and number cards.**

2. **Display a transparency of Master 4.4, *Playing the Game*, showing the instructions for the game. Have students play through the game. Each student in the group will play individually, but the group members share the deck of cards.**

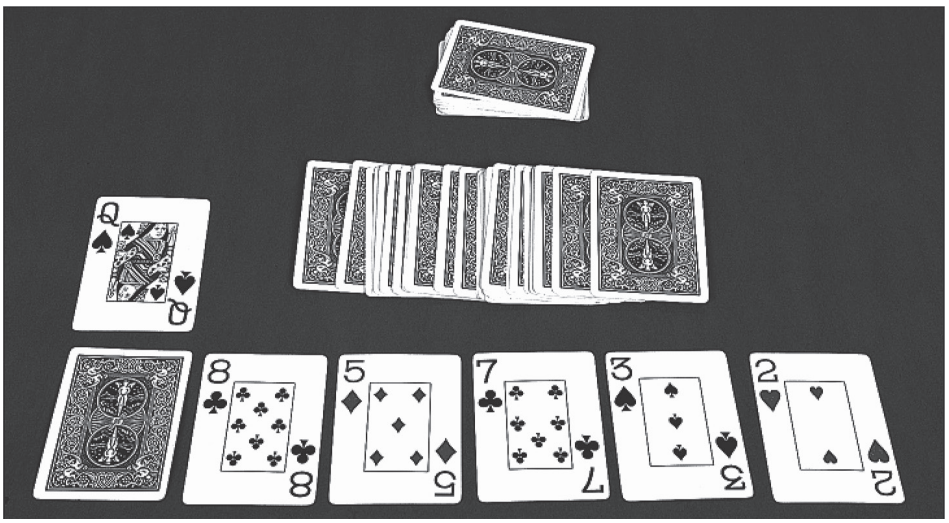


Figure 4.4: *The arrangement of cards during the game.*

3. **When all the groups have finished the game, discuss the game and the results of the game with them. The value of this activity lies in the discussion and questions that it may generate. The following sample questions can guide the discussion.**

   - **How many choice cards did each person pick?**

   Students will draw different numbers of cards before they decide to stop.

   - **How many people equaled or went over the value of the switch card?**

   Some students will decide to play it safe, whereas other students will risk going over the transition, or switch, value.

   - **How does this game relate to drug abuse and drug addiction?**

   This game relates to abuse and addiction in that each person who continues to abuse drugs will reach some point that, if surpassed, will change the person (and the person's brain) from abusing drugs to being addicted to them. Each person has risk factors, and each person can make choices about abusing drugs.

   - **What does the transition, or switch, card mean in regard to drug addiction?**

   Drug abuse causes changes in the brain that lead to the compulsive use of drugs despite negative consequences. Scientists do not know what factors control the transition from drug abuse to addiction.

- **Is everyone's transition, or switch, level the same?**

In the card game, students choose one of three cards, each assigned an arbitrary value, as their *switch* card. In life, a person does not know when he or she will reach the point where drug abuse becomes drug addiction. For some people, that change will occur earlier in their drug abuse, while other people will abuse drugs extensively before they become addicted.

- **What does the risk card mean?**

The risk card symbolizes that there are factors that influence the outcome. An individual does not know what all the risks are or how great their influence is.

- **Is everyone's risk card the same?**

Different students will have different risk cards. In life, people who abuse drugs have different risks of becoming addicted.

- **Why is the risk card face down?**

The risk card is face down because a person often does not know the magnitude of the risk factors that he or she carries. For example, a person may know that genes play a role in determining whether a person will become addicted, but a person doesn't know whether he or she carries the genes that will place them at risk for addiction or to what degree the gene's influence increases the risk.

- **What factors influence a person's risk of becoming addicted to drugs?**

Many factors influence whether a person becomes addicted to drugs. Some of these include genetics, family influence, influence of friends, age at which drug abuse begins (a person who begins using drugs early in life is more likely to become addicted), context of drug use, and the development of coping skills.

- **What do the choice cards represent?**

Each choice card in this model represents an episode of drug use.

Students likely will try to assign meaning to the numbers on the choice cards. For example, they may equate a 2 with drinking a low-alcohol beer and a 10 with heroin injection. These correlations are difficult to make with any accuracy. For example, a person may smoke a small amount of marijuana believing that it contains a low dose of THC. If that marijuana is of a potent strain that contains a high level of THC, the individual could receive a higher dose than if he or she smoked a larger dose of a less potent strain of marijuana.

Like most models, this one has imperfections. The discussion that this issue may generate among students can be valuable because it causes them to question drug abuse.

- **If a total score that equals or goes over the switch value indicates addiction, did anyone become addicted to drugs with the first drug use?**

The point values in the game have been assigned so that the player cannot reach the switch value after drawing one choice card. This correlates with addiction; becoming addicted with one episode of drug abuse rarely happens.

Important note: This is true with the outcome of the game being *drug addiction* if the switch value is reached. This is not true if the designated outcome is death if the switch value is reached. A person can die from the first episode of drug abuse. After one use, drugs do not change the brain sufficiently to cause addiction. However, drugs can affect other body systems and cause them to fail. See Step 9 (on page 111) for a modification of the game to address this. Also, although a person does not become addicted to drugs after one use, one episode can cause some changes to start occurring in the brain. For example, one use of crack cocaine can cause a person to experience cravings for the drug.

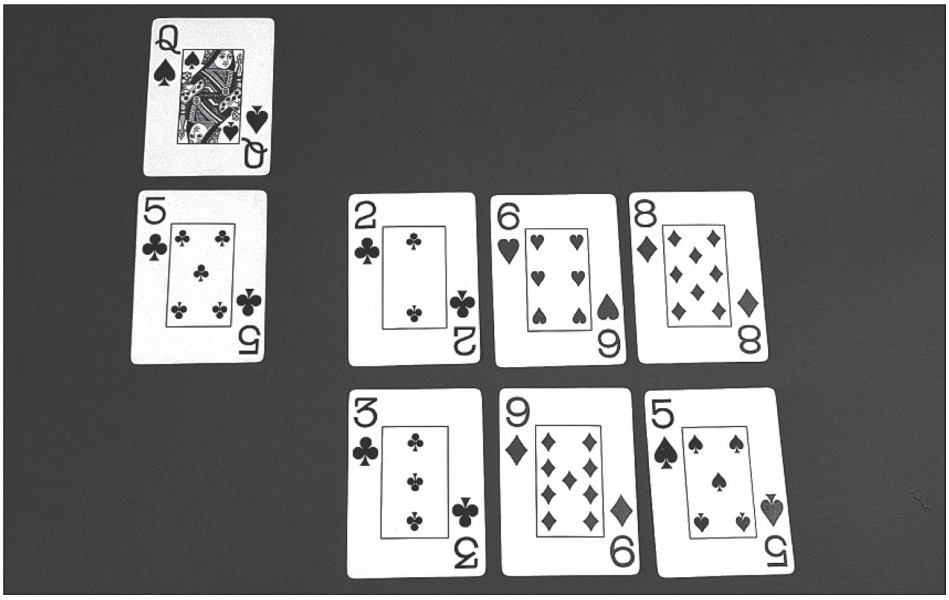


Figure 4.5: *Sample card hand #1. The player had a moderate switch value (the switch card is a queen). The student elected to draw six choice cards totaling 33 points before finding out that the risk card had a value of 5. The 38-point total put the score over the switch value (35), signifying addiction.*

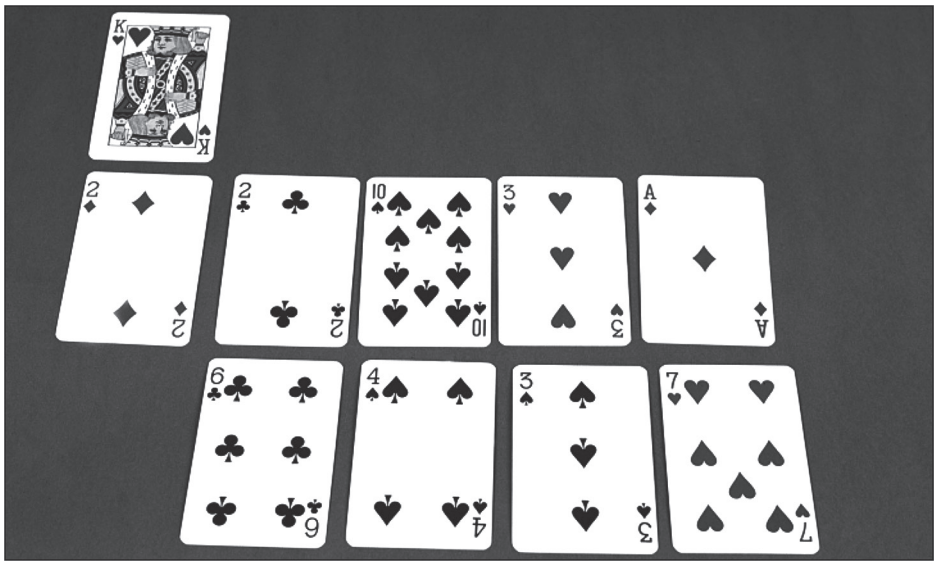


Figure 4.6: *Sample card hand #2. The player had a higher switch card (king = 45 points) and elected to draw eight choice cards totaling 36 points. Because the risk card was low (a 2), the 38-point total was still below the switch value, signifying drug abuse.*

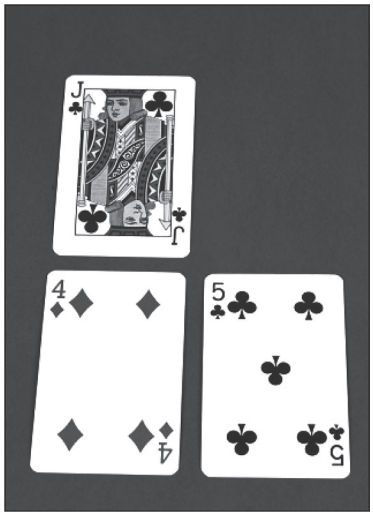


Figure 4.7: *Sample card hand #3. The player elected to draw only one choice card, a 5, to ensure that the total of risk (which turned out to be a 4) and choice cards remained below the switch value of 25 points (jack = 25 points).*

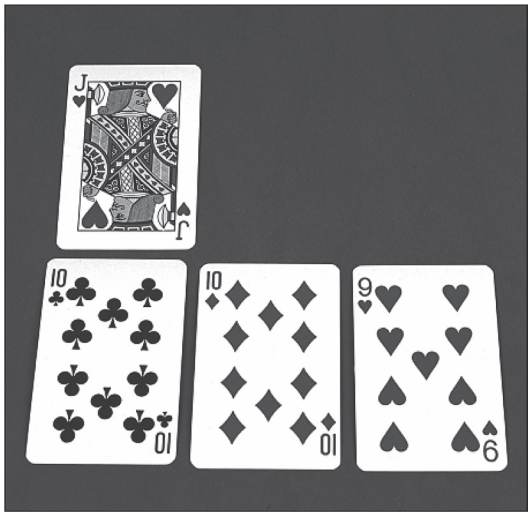


Figure 4.8: *Sample card hand #4. The player drew a low switch card (a jack = 25 points) and a high risk card (a 10). Because the choice cards have high point values, the total of just two cards totaled more than the switch value, signifying drug addiction.*

4. **Have the students play the game again now that they can relate it to the issues of drug abuse and drug addiction.**

5. **Ask students if they played the game any differently this time. Did they make different choices?**

   Some students will continue to risk drawing more choice cards and get closer to the switch value. Other students may elect not to draw any choice cards.

   Some students might bring up questions relating to a hand containing a high switch card, a low risk card, and some low choice cards so that they can continue to draw more cards. Students may feel that this scenario would lead them to continue to experiment with drugs. You can respond by asking them what choices they would make if they drew a low switch card and a high risk card. (Perhaps the numbers on the cards are lower or higher than the assigned values. For example, what if the switch card had a value of 22 points and the risk card had a value of 12 points? Would this change the decision about drawing additional cards?) This scenario leads into the next step of the activity, in which students consider that the switch point really is unknown.

6. **Discuss the idea of the switch card with students. Does anyone really know at what point in drug abuse the brain changes and the person shifts from abusing to being addicted to a drug? How could you modify the card game to account for this?**

   In life, a person does not know when he or she will reach the point at which drug abuse becomes drug addiction. To reflect this in the card game, students can play the game leaving the switch card face down.

7. **When the students play the game this time, they will not look at the switch card. Have them keep the switch card face down and continue the game as before.**

8. **Continue the discussion of the game and its relation to drug abuse and drug addiction.**

   The main points that students should learn through this activity are

   - Drug abuse involves choice.
   - The point at which a person's brain is changed and drug abuse becomes drug addiction is different and unknown for each individual.
   - Everyone has risk factors.
   - A person does not become addicted to drugs after one episode of abuse.

9. **(Optional) A person does not become addicted to drugs after one episode of abuse, but a person can die as a result of one episode of drug abuse. The drugs can act on the brain or other body systems with a lethal outcome, such as by suppressing respiration. If you want to modify the game to add this scenario, insert the jokers into each pile of choice cards and have the students play the game a fourth time. If a student draws a joker, the game is over for that student.**

   If you decide to do this optional modification to the game, make sure that students understand that the joker does *not* indicate addiction. The joker would, perhaps, represent a batch of drugs that contain a lethal contaminant that would cause some body organ to fail and, thus, cause the person using them to die. Another person, for example, takes a large enough dose of opioids to completely inhibit the neurons in the brain that control respiration; those neurons no longer stimulate the lungs to contract, causing death. Sometimes a drug can produce a fatal response for unknown reasons; it could be due to a mutation in a gene that reduces the body's ability to metabolize a drug, leading to an increased, possibly toxic, level of the drug in the body.

Activity 4: Environmental, Behavioral, and Social Influences on Drug Abuse and Addiction

Note to teachers: This activity, as described in the following steps, is designed as a class discussion. An alternative approach is to have individual students write their answers to the questions and then discuss the questions as a class.

NSES

Content Standard C:
An individual's mood and behavior may be modified by substances.

Content Standard F:
Personal choice concerning fitness and health involves multiple factors.

1. **Display a transparency of Master 4.5, *Who Is Addicted?*, showing only the top section (to the first horizontal line). Ask students to answer the question.**

   Students may respond differently to the question about who is addicted to morphine. At this stage, any answer is acceptable if the student can explain the reasoning underlying his or her answer. Some students will say that Chris is addicted because of the higher dose of morphine being taken over a longer period of time. Some students will say Pat because this could be a larger dose than what Chris is taking (if Chris is at 50 mg per day). Students could also believe that both individuals are addicted because of their continued drug abuse. Conversely, students could respond that possibly neither one is addicted and more information is needed before a judgment could be made.

2. **Reveal the next section on Master 4.5 (to the next horizontal line). Again have students answer the question and discuss the responses.**

   Students may respond in a variety of ways. Answers could involve aspects of genetics, dose, or even random chance.

3. **Reveal the remaining section of Master 4.5 and have students read the case studies.**

4. **Discuss the cases with the class. Use the following questions to guide the discussion.**

   - **Why did these two individuals begin taking morphine and then continue to take morphine?**

   Pat began abusing morphine basically for social reasons. Chris began taking morphine for medical reasons.

   - **What are the differences in how Chris and Pat take morphine?**

   Pat takes an injection of morphine one time each day. Chris also receives morphine through injection, but he receives a dose many times each day.

   - **How may these differences have influenced whether addiction develops?**

   Although Chris receives a higher total dose of morphine during a day, each single injection is a smaller dose. The smaller single dose does not lead to the same high that results from a larger dose. Perhaps the fact that Chris does not feel the euphoria when he receives the morphine is important in keeping him from being addicted. (It is acceptable for students to propose answers here even if they cannot be sure.)

   - **Is a larger dose of a drug the only factor to consider when thinking about the causes of drug addiction? Explain your answer based on the case studies.**

   No, because Chris took a larger dose and did not become addicted.

   - **Is the length of time that someone has been taking drugs enough to determine whether addiction will develop? Explain your answer based on the case studies.**

   No, because Chris took morphine for a longer period of time and did not become addicted while Pat took morphine for a shorter period of time and did become addicted.

   - **What factors other than the amount (dose) of the drug taken and the period of time for which the drug is taken may contribute to addiction?**

   The expectation of feeling a rush may be a factor. A person getting morphine in a hospital would not be taking morphine to get that feeling. The context of drug (medication) use influences whether a person becomes addicted. Pat's use of drugs to escape problems contributed to the development of drug addiction.

The cases should reveal to the students that a high dose of a drug is not enough to cause addiction. The behaviors and motivations for taking drugs are important factors in the development of addiction. The addicted street person was using drugs with the expectation of a rush, or high, and trying to escape life. The patient was taking drugs without the expectation of a high. The patient experiencing pain uses drugs in order to function normally. Scientists do not completely understand why pain patients do not become addicted after drug use, but the statistics clearly show that these individuals are at very low risk of becoming addicted.

You may also want to discuss the case of Vietnam veterans with students. For many years, the media portrayed Vietnam veterans as hopelessly drug-addicted individuals. Although drug addiction was a problem for some veterans while in Vietnam, the vast majority of those veterans have had no problems with drug addiction since returning to the United States. They may have started using drugs (and subsequently became addicted) to relieve the stress of combat, to rebel against society, or even to relieve boredom, but once they were back in a "normal" environment, they were able to function without drugs.

Activity 5: Long-Term Effects of Drug Abuse and Addiction

Having students view the minidocumentary on the long-term effects of drugs on the brain is the strongly preferred approach for this activity. If the Internet is not available, follow the procedure for the alternate version of the activity (on page 114).

For classes using the Web version of this activity.

1. **Have students view the minidocumentary, *Long-Term Effects of Drugs on the Brain*, online.**

   To view the minidocumentary, which takes about five minutes, go to the supplement's Web site. From the activities menu, select Lesson 4—*Drug Abuse and Addiction*.

2. **After viewing the minidocumentary, ask students to write brief answers to the following questions.**

   - **What was the most surprising thing you learned about the effect of drugs?**
   - **What makes this fact surprising to you?**
   - **On the basis of what you have learned through the rat experiment analysis, the card game, and the minidocumentary, would you say that drug addiction is a disease? Justify your answer.**

   Students should be encouraged to relate what they learned in Activities 1 through 4 to what they learned from the minidocumentary.

Content Standard A: Scientists rely on technology to enhance the gathering and manipulation of data.

Having students write their answers to the questions encourages them to organize their thoughts and reflect on what they have learned. Listening to students explain their view about drug addiction as a disease will help you evaluate their understanding.

3. **After students have completed their answers to the questions, discuss the questions as a class.**

   Drug addiction is a disease that causes physical and functional changes in the brain. This is similar to other diseases in which a part of the body does not function properly.

4. **Encourage students to learn about how drugs affect other body systems by doing library or Internet searches.**

   Because the focus of this unit is the brain, the curriculum supplement does not address how drugs act on other parts of the body. However, a great deal of additional information is available online. See the section *Additional Resources for Teachers* for some informative Web sites.

The following procedure is for classes using the print version of the activity.

1. **Give each student a copy of Master 4.6. Instruct students to read the handout *Long-Term Effects of Drugs on the Brain* and answer the questions.**

   After students finish reading and answering the questions, discuss the responses as a class.

Sample Answers to Questions on Master 4.6

Question 1. What are some of the ways that drugs cause long-term changes in the brain?

The continued use of drugs may cause the brain to become resistant to the effects of the drug (tolerance). Some drugs, such as alcohol, methamphetamine, and MDMA, are neurotoxic; that is, they can damage or kill brain cells. Cocaine and amphetamine can cause the activity level of the brain to decrease for a long period of time after drug use is stopped.

Question 2. How does the brain adapt to the presence of drugs?

The brain adapts to the presence of drugs through various alterations in cellular, molecular, and genetic processes that affect its function. The decrease in the number of dopamine receptors in the reward areas is one example of a brain adaptation. Changes in the brain can lead to the development of tolerance—a person needing more of a drug to achieve the desired effect—and to cravings for the drug when drug use has stopped.

Question 3. How may the abuse of drugs relate to the plasticity of the brain?

Plasticity means that the brain can modify connections (synapses) in response to experiences. Drugs that damage or kill neurons can decrease the plasticity of the brain because neurons are not present to form new connections and because existing connections are lost. Drugs also hijack the learning and memory systems of the brain so that cues (people, places, or things) that are associated with the drug experience become powerful motivators of craving and drug use. In fact, addiction is sometimes described as a disease of learning and memory.

Question 4. What are some problems that scientists have when they investigate the effects of drugs on the brain?

Scientists have difficulty investigating the effects of drugs on the brain because many people who abuse drugs abuse more than one drug. Scientists must understand how each drug affects the brain and body because drugs taken in combination may have different effects. Also, many people who abuse drugs have other medical conditions that make it difficult for scientists to determine what effects are due to the drug and what effects are due to those conditions. Scientists also don't know what someone's brain was like before they used drugs. This makes it hard to determine whether drug use caused the changes or a vulnerability existed before drugs were used that made someone susceptible to addiction.

2. **If students want to learn more about how drugs affect other parts of the body, encourage them to do library or Internet searches for additional information.**

   Because this unit focuses on the brain, it does not address how drugs act on other parts of the body. A great deal of information is available online. See the section *Additional Resources for Teachers* (page 143) for some informative Web sites.

Lesson 4 Organizer: WEB VERSION

What the Teacher Does	Procedure Reference
Activity 1: *How Does Drug Abuse Begin?*	
Ask the class, "What is a drug?" Write responses on the board or a transparency. Allow differing views to be discussed.	Page 99 Step 1
Write the following definitions for *drug* and *medication* on the board or transparency. Inform students that, for this discussion, you will use the terms according to these definitions. • A *medication* is a drug that is used to treat an illness or disease according to established medical guidelines. • A *drug* is a chemical compound or substance that can alter the structure and function of the body. Psychoactive drugs affect the function of the brain, and some of these may be illegal to use and possess.	Page 99 Step 2
Ask students to list examples of both medications and drugs.	Pages 99–100 Step 3
Continue the class discussion by asking, "Why do people start abusing drugs?" Accept reasonable answers.	Page 100 Step 4
Activity 2: *Drug Abuse Is Voluntary; Addiction Is Compulsive*	
Organize students into groups of four. Explain how the rats in the experiment were in cages that had two levers. Depending on which lever the rat pressed, it receives a food reward or either an injection or electrical stimulus.	Page 100 Step 1
Give each student a copy of **Masters 4.1** and **4.2**. Instruct groups to choose one rat's data to graph.	Page 101 Step 2 M
Give each student a copy of **Master 4.3**. Ask groups to compare the graphs and discuss the similarities and differences among the rats' responses. Instruct students to answer the questions on Master 4.3.	Page 101 Step 3 M
Have a class discussion about the questions.	Pages 101–104 Step 4
Ask students to consider the question, Why do humans continue to abuse drugs?	Page 104 Step 5

What the Teacher Does	Procedure Reference
Write the definition of *addiction* on the board or overhead transparency. • *Addiction* is a chronic, relapsing brain disease characterized by compulsive drug-taking despite adverse health, social, or legal consequences.	Page 104 Step 6
Ask students to consider whether Rat A (continued cocaine use) and Rat C (continued stimulation of reward pathway) experienced any adverse effects. What adverse effects do drug-addicted humans experience?	Pages 104–105 Step 7
Prompt students to consider the distinction between abuse and addiction in humans by asking the following questions. • When does abuse become addiction? • What causes abuse to become addiction? • Does the change from abuse to addiction occur at the same level (amount of drug taken, duration of drug abuse) of drug abuse for different individuals?	Page 105 Step 8
Activity 3: *When Does Abuse Become Addiction?*	
Divide the class into groups of three students. Give each group a deck of cards that have been divided into two piles. Tell the students that the small pile contains the face cards and the larger pile has the aces and number cards.	Page 105 Step 1
Display a transparency of **Master 4.4**. Have students play through the game. Each student should play individually, but the group members will share the deck of cards.	Page 105 Step 2 
As a class, discuss the game and the results. Guide the discussion with the following questions. • How many choice cards did each person pick? • How many people equaled or went over the value of the switch card? • How does this game relate to drug abuse and drug addiction? • What does the transition, or switch, card mean in regard to drug addiction? • Is everyone's transition, or switch, level the same? • What does the risk card mean? • Is everyone's risk card the same? • Why is the risk card face down? • What factors influence a person's risk of becoming addicted to drugs? • What do the choice cards represent? • If a total score that equals or goes over the switch value indicates addiction, did anyone become addicted to drugs with the first drug use?	Pages 106–109 Step 3

What the Teacher Does	Procedure Reference
Have students play the game again now that they can relate it to the issues of drug abuse and drug addiction.	Page 110 Step 4
Ask students if they played the game any differently this time. Did they make different choices?	Page 110 Step 5
Discuss the idea of the switch card. Does anyone really know at what point in drug abuse the brain changes and the person who is abusing drugs the abuser becomes an addict? How could you modify the card game to account for this?	Page 110 Step 6
Have the students play the game again, but leave the switch card face down this time.	Page 110 Step 7
Continue the discussion of the game and its relationship to drug abuse and addiction. Ask students to summarize the main points that the game conveys: • Drug abuse involves choice. • The point at which a person's brain is changed and drug abuse becomes addiction is different and unknown for each individual. • Everyone has risk factors. • A person does not become addicted to drugs after one episode of abuse.	Page 110 Step 8
To model the fact that one episode of drug abuse can result in lethal consequences (which is different from addiction), insert the jokers into the pile of choice cards. Have the students play the game again. If a student draws a joker, the game is over for that student.	Page 111 Step 9 (optional)
Activity 4: *Environmental, Behavioral, and Social Influences on Drug Abuse and Addiction*	
Display the top section of a transparency of **Master 4.5**. Ask students to answer the question.	Page 111 Step 1
Reveal the next section of **Master 4.5**. Again have students answer the question and discuss the responses.	Page 111 Step 2
Reveal the remaining section of **Master 4.5** and have students read the case studies.	Page 112 Step 3

What the Teacher Does	Procedure Reference
Discuss the cases with the class using the following questions to guide the discussion. • Why did these two individuals begin taking morphine and then continue to take morphine? • What are the differences in how Chris and Pat take morphine? • How may these differences have influenced whether addiction develops? • Is a larger dose of a drug the only factor to consider when thinking about the causes of drug addiction? • Is the length of time that someone has been taking drugs enough to determine if addiction will develop? • What factors other than the amount (dose) of the drug taken and the period of time for which the drug is taken may contribute to addiction?	Pages 112–113 Step 4
Activity 5: *Long-Term Effects of Drug Abuse and Addiction*	
Ask the students to watch the minidocumentary online. From the activities menu, select Lesson 4—*Drug Abuse and Addiction*.	Page 113 Step 1 
Ask students to write answers to the following questions before discussing the questions as a class. • What was the most surprising thing you learned about the effects of drugs? • What makes this fact surprising to you? • On the basis of what you have learned through analyzing the rat experiment, the card game, and the minidocumentary, would you say that addiction is a disease?	Pages 113–114 Steps 2–3
Encourage students to learn about how drugs affect other body systems by doing library or Internet searches.	Page 114 Step 4

 = Involves using the Internet.

 = Involves copying a master.

 = Involves making a transparency.

Lesson 4 Organizer: PRINT VERSION

What the Teacher Does	Procedure Reference
Activity 1: *How Does Drug Abuse Begin?*	
Ask the class, "What is a drug?" Write responses on the board or a transparency. Allow differing views to be discussed.	Page 99 Step 1
Write the following definitions for *drug* and *medication* on the board or transparency. Inform students that, for this discussion, you will use the terms according to these definitions. • A *medication* is a drug that is used to treat an illness or disease according to established medical guidelines. • A *drug* is a chemical compound or substance that can alter the structure and function of the body. Psychoactive drugs affect the function of the brain, and some of these may be illegal to use and possess.	Page 99 Step 2
Ask students to list examples of both medications and drugs.	Pages 99–100 Step 3
Continue the class discussion by asking, "Why do people start abusing drugs?" Accept reasonable answers.	Page 100 Step 4
Activity 2: *Drug Abuse Is Voluntary; Addiction Is Compulsive*	
Organize students into groups of four. Explain how the rats in the experiment were in cages that had two levers. Depending on which lever the rat pressed, it receives a food reward or either an injection or electrical stimulus.	Page 100 Step 1
Give each student a copy of **Masters 4.1** and **4.2**. Instruct groups to choose one rat's data to graph.	Page 101 Step 2
Give each student a copy of **Master 4.3**. Ask groups to compare the graphs and discuss the similarities and differences among the rats' responses. Instruct students to answer the questions on Master 4.3.	Page 101 Step 3
Have a class discussion about the questions.	Pages 101–104 Step 4
Ask students to consider the question, Why do humans continue to abuse drugs?	Page 104 Step 5

What the Teacher Does	Procedure Reference
Write the definition of *addiction* on the board or overhead transparency. • *Addiction* is a chronic, relapsing brain disease characterized by compulsive drug-taking despite adverse health, social, or legal consequences.	Page 104 Step 6
Ask students to consider whether Rat A (continued cocaine use) and Rat C (continued stimulation of reward pathway) experienced any adverse effects. What adverse effects do human drug addicts experience?	Pages 104–105 Step 7
Prompt students to consider the distinction between abuse and addiction in humans by asking the following questions. • When does abuse become addiction? • What causes abuse to become addiction? • Does the change from abuse to addiction occur at the same level (amount of drug taken, duration of drug abuse) of drug abuse for different individuals?	Page 105 Step 8
Activity 3: *When Does Abuse Become Addiction?*	
Divide the class into groups of three students. Give each group a deck of cards that have been divided into two piles. Tell the students that the small pile contains the face cards and the larger pile has the aces and number cards.	Page 105 Step 1
Display a transparency of **Master 4.4**. Have students play through the game. Each student should play individually, but the group members will share the deck of cards.	Page 105 Step 2 
As a class, discuss the game and the results. Guide the discussion with the following questions. • How many choice cards did each person pick? • How many people equaled or went over the value of the switch card? • How does this game relate to drug abuse and drug addiction? • What does the transition, or switch, card mean in regard to drug addiction? • Is everyone's transition, or switch, level the same? • What does the risk card mean? • Is everyone's risk card the same? • Why is the risk card face down? • What factors influence a person's risk of becoming addicted to drugs? • What do the choice cards represent? • If a total score that equals or goes over the switch value indicates addiction, did anyone become addicted to drugs with the first drug use?	Pages 106–109 Step 3

What the Teacher Does	Procedure Reference
Have students play the game again now that they can relate it to the issues of drug abuse and drug addiction.	Page 110 Step 4
Ask students if they played the game any differently this time. Did they make different choices?	Page 110 Step 5
Discuss the idea of the switch card. Does anyone really know at what point in drug abuse the brain changes and the abuser becomes an addict? How could you modify the card game to account for this?	Page 110 Step 6
Have the students play the game again, but leave the switch card face down this time.	Page 110 Step 7
Continue the discussion of the game and its relationship to drug abuse and addiction. Ask students to summarize the main points that the game conveys: • Drug abuse involves choice. • The point at which a person's brain is changed and drug abuse becomes addiction is different and unknown for each individual. • Everyone has risk factors. • A person does not become addicted to drugs after one episode of abuse.	Page 110 Step 8
To model the fact that one episode of drug abuse can result in lethal consequences (which is different from addiction), insert the jokers into the pile of choice cards. Have the students play the game again. If a student draws a joker, the game is over for that student.	Page 111 Step 9 (optional)
Activity 4: *Environmental, Behavioral, and Social Influences on Drug Abuse and Addiction*	
Display the top section of a transparency of **Master 4.5**. Ask students to answer the question.	Page 111 Step 1 
Reveal the next section of **Master 4.5**. Again have students answer the question and discuss the responses.	Page 111 Step 2
Reveal the remaining section of **Master 4.5** and have students read the case studies.	Page 112 Step 3

What the Teacher Does	Procedure Reference
Discuss the cases with the class using the following questions to guide the discussion. • Why did these two individuals begin taking morphine and then continue to take morphine? • What are the differences in how Chris and Pat take morphine? • How may these differences have influenced whether addiction develops? • Is a larger dose of a drug the only factor to consider when thinking about the causes of drug addiction? • Is the length of time that someone has been taking drugs enough to determine if addiction will develop? • What factors other than the amount (dose) of the drug taken and the period of time for which the drug is taken may contribute to addiction?	Pages 112–113 Step 4
Activity 5: *Long-Term Effects of Drug Abuse and Addiction*	
Give each student a copy of **Master 4.6**. Allow time for students to read the information and answer the questions. Discuss the questions as a class.	Page 114 Step 1 M
Encourage students to learn about how drugs affect other body systems by doing library or Internet searches.	Page 115 Step 2

M = Involves copying a master.

T = Involves making a transparency.

Drug Addiction Is a Disease—So What Do We Do about It?

Photo courtesy of Gray Wolf Ranch Wilderness Recovery Lodge.

At a Glance

Overview
Students make predictions about the success rate for treatment of addiction compared with treatment for other chronic diseases. Then students evaluate case studies of individuals with different diseases to compare and contrast how the diseases are similar to, or different from, the others.

Major Concept
Drug addiction is a recurring chronic disease that can be treated effectively, similar to other chronic diseases.

Objectives
By the end of these activities, the students will
- understand that addiction is a chronic disease that is likely to recur;
- recognize that treatment is most effective when it combines medication and behavioral treatments;
- be able to explain how treatment for addiction is similar to that for other chronic diseases, such as diabetes or heart disease; and
- recognize that even though we may think that treatment could be more effective when people who are addicted to drugs, like people with other chronic diseases, choose to participate actively in their treatment, research shows that treatment can be very effective even when it is compulsory.

Basic Science–Health Connection
Addiction has many dimensions and disrupts many aspects of a person's life. Scientific research and clinical practice have yielded a variety of effective approaches to treatment for addiction to certain drugs, such as heroin. Continuing research is yielding new approaches to developing medications to treat addiction to other drugs, such as cocaine, for which no medications are currently available.

Background Information

Drug abuse and addiction lead to long-term changes in the brain's chemistry and physiology. The changes in the brain cause drug-addicted people not only to lose the ability to control their drug use, but their addiction also changes all aspects of their lives. People with drug addiction often become isolated from family and friends and have trouble in school or work. In addition, the compulsive need for drugs can lead to significant legal problems. While the biological foundation for drug addiction does not absolve an individual from the responsibility of his or her actions, the stigma of drug addiction needs to be lifted so individuals may receive proper medical treatment, similar to that for other chronic diseases.[1]

Addiction is a recurring chronic disease. No cure is available at this time, but addiction can often be treated effectively. Drug addiction is often viewed as a lapse in moral character. This value judgment influences how society deals with the disease, both socially and medically. Unfortunately, because people, including physicians, have often viewed addiction as a self-inflicted condition, drug-addicted people have not always received the medical treatment common for other chronic diseases. Treating addiction requires more than a "just say no" approach.[2]

Treatment for addiction can be very effective. Treatment is successful when the addicted person reduces or abstains from drug use, improves his or her personal health or social function, and becomes less of a threat to public health and safety.[3] Certain addictions, such as heroin addiction, can be treated with medications.[4,5] Methadone, the most common medication, prevents craving and withdrawal symptoms in heroin addiction. Methadone is an opioid-receptor agonist. That is, methadone binds to the opioid receptor just as heroin does. Methadone, however, does not produce the euphoria or "high" that results from heroin use. When taken orally as indicated, it does not produce the rapid increase in opioid-receptor occupancy that comes from injecting or snorting heroin, but it does maintain sufficient opioid-receptor activity to prevent withdrawal and cravings for opioids.

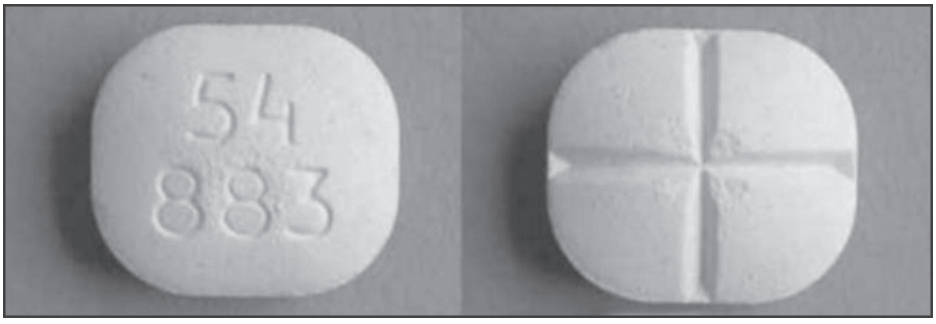


Figure 5.1: *Methadone can be part of an effective treatment plan for addiction to opiates. Photograph of pills by, and used with permission of, Roxane Laboratories, Inc. All Rights Reserved.*

A second medication prescribed for heroin addiction is naltrexone. Unlike methadone, naltrexone is an opioid-receptor antagonist. Instead of competing with or mimicking heroin for the opioid receptor, naltrexone prevents heroin from binding to the receptor, thereby preventing heroin

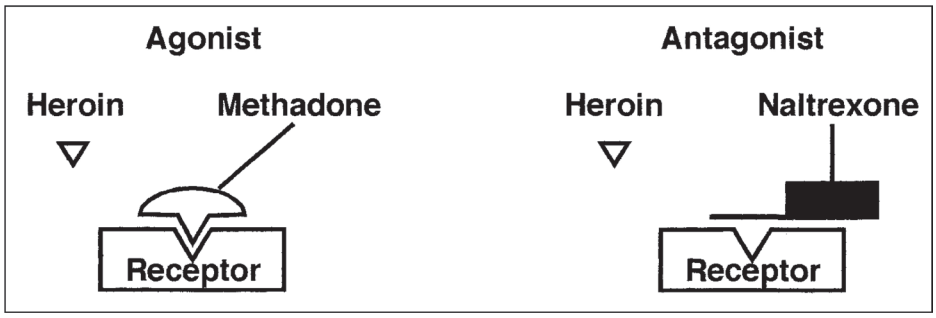


Figure 5.2: *Agonists are chemicals that bind to a specific receptor to elicit a response, such as excitation or inhibition of action potentials. Methadone is an agonist that, like heroin, binds to opioid receptors. Unlike heroin, however, methadone does not produce the same level of euphoria. Buprenorphine is a partial agonist that also binds to opioid receptors. Partial agonists are chemicals that are similar to full agonists, but at higher doses their effect is not as great as a full agonist's. Buprenorphine does not produce the euphoria seen with heroin. Antagonists are chemicals that bind to a receptor and block it, producing no response and preventing other chemicals (drugs or receptor agonists) from binding or attaching to the receptor. Naltrexone is an antagonist that binds to the opioid receptor and blocks heroin from binding.*

from eliciting the euphoric high (see Figure 5.2). Buprenorphine is also used to treat heroin addiction. It is a long-acting partial opioid-receptor agonist. It acts on the same receptors as heroin but does not produce the same intense "high" or dangerous side effects. Buprenorphine has some advantages over other medications for treating heroin addiction. Unlike methadone, buprenorphine can be prescribed in physicians' offices. It is also less likely to be toxic or abused than methadone.

Table 5.1 outlines the different medications used to treat addiction. The development of medications to treat drug addiction has been difficult because the brain, the main target of addictive drugs, is such a complex organ. Until scientists understand how drugs affect the chemistry of the brain, they cannot develop medicines that will alter their effects.

Table 5.1: Medications for Addiction[4]

Medication	Treatment for addiction to	Mechanism
Methadone	Heroin	Opioid-receptor agonist
Naltrexone	Heroin	Opioid-receptor antagonist
Naloxone	Heroin, alcohol	Opioid-receptor antagonist
Buprenorphine	Heroin	Mixed opioid-receptor agonist and antagonist
Nicotine gum, patches	Nicotine	Provide low doses of nicotine

Medication, if available, is rarely sufficient for effective treatment. Behavioral treatment in combination with medication is the most effective way to treat drug addiction.[6,7] People recovering from drug addiction need to address the behavioral and social consequences of their drug use and learn to cope with the social and environmental factors that contribute to their illness.[7] Behavioral treatments can be provided either individually or as a group.

Principles of Effective Drug Addiction Treatment

1. **Addiction is a complex but treatable disease that affects brain function and behavior.** Drugs of abuse alter the brain's structure and function, resulting in changes that persist long after drug use has ceased. This may explain why drug abusers are at risk for relapse even after long periods of abstinence and despite the potentially devastating consequences.

2. **No single treatment is appropriate for everyone.** Matching treatment settings, interventions, and services to an individual's particular problems and needs is critical to his or her ultimate success in returning to productive functioning in the family, workplace, and society.

3. **Treatment needs to be readily available.** Because drug-addicted individuals may be uncertain about entering treatment, taking advantage of available services the moment people are ready for treatment is critical. Potential patients can be lost if treatment is not immediately available or readily accessible. As with other chronic diseases, the earlier treatment is offered in the disease process, the greater the likelihood of positive outcomes.

4. **Effective treatment attends to multiple needs of the individual, not just his or her drug abuse.** To be effective, treatment must address the individual's drug abuse and any associated medical, psychological, social, vocational, and legal problems. It is also important that treatment be appropriate to the individual's age, gender, ethnicity, and culture.

5. **Remaining in treatment for an adequate period of time is critical.** The appropriate duration for an individual depends on the type and degree of his or her problems and needs. Research indicates that most addicted individuals need at least 3 months in treatment to significantly reduce or stop their drug use and that the best outcomes occur with longer durations of treatment. Recovery from drug addiction is a longterm process and frequently requires multiple episodes of treatment. As with other chronic illnesses, relapses to drug abuse can occur and should signal a need for treatment to be reinstated or adjusted. Because individuals often leave treatment prematurely, programs should include strategies to engage and keep patients in treatment.

6. **Counseling—individual and/or group—and other behavioral therapies are the most commonly used forms of drug abuse treatment.** Behavioral therapies vary in their focus and may involve addressing a patient's motivation to change, providing incentives for abstinence, building skills to resist drug use, replacing drug-using activities with constructive and rewarding activities, improving problemsolving skills, and facilitating better interpersonal relationships. Also, participation in group therapy and other peer support programs during and following treatment can help maintain abstinence.

7. **Medications are an important element of treatment for many patients, especially when combined with counseling and other behavioral therapies.** For example, methadone and buprenorphine are effective in helping individuals addicted to heroin or other opioids stabilize their lives and reduce their illicit drug use. Naltrexone is also an effective medication for some opioid-addicted individuals and some patients with alcohol dependence. Other medications for alcohol dependence include acamprosate, disulfiram, and topiramate. For persons addicted to nicotine, a nicotine replacement product (such as patches, gum, or lozenges) or an oral medication (such as bupropion or varenicline) can be an effective component of treatment when part of a comprehensive behavioral treatment program.

8. **An individual's treatment and services plan must be assessed continually and modified as necessary to ensure that it meets his or her changing needs.** A patient may require varying combinations of services and treatment components during the course of treatment and recovery. In addition to counseling or psychotherapy, a patient may require medication, medical services, family therapy, parenting instruction, vocational rehabilitation, and/or social and legal services. For many patients, a continuing care approach provides the best results, with the treatment intensity varying according to a person's changing needs.

9. **Many drug-addicted individuals also have other mental disorders.** Because drug abuse and addiction—both of which are mental disorders—often co-occur with other mental illnesses, patients presenting with one condition should be assessed for the other(s). And when these problems co-occur, treatment should address both (or all), including the use of medications as appropriate.

10. **Medically assisted detoxification is only the first stage of addiction treatment and by itself does little to change long-term drug abuse.** Although medically assisted detoxification can safely manage the acute physical symptoms of withdrawal and, for some, can pave the way for effective long-term addiction treatment, detoxification alone is rarely sufficient to help addicted individuals achieve long-term abstinence. Thus, patients should be encouraged to continue drug treatment following detoxification. Motivational enhancement and incentive strategies, begun at initial patient intake, can improve treatment engagement.

11. **Treatment does not need to be voluntary to be effective.** Sanctions or enticements from family, employment settings, and/or the criminal justice system can significantly increase treatment entry, retention rates, and the ultimate success of drug treatment interventions.

12. **Drug use during treatment must be monitored continuously, as lapses during treatment do occur.** Knowing their drug use is being monitored can be a powerful incentive for patients and can help them withstand urges to use drugs. Monitoring also provides an early indication of a return to drug use, signaling a possible need to adjust an individual's treatment plan to better meet his or her needs.

13. **Treatment programs should assess patients for the presence of HIV/ AIDS, hepatitis B and C, tuberculosis, and other infectious diseases as well as provide targeted risk-reduction counseling to help patients modify or change behaviors that place them at risk of contracting or spreading infectious diseases.** Typically, drug abuse treatment addresses some of the drug-related behaviors that put people at risk of infectious diseases. Targeted counseling specifically focused on reducing infectious disease risk can help patients further reduce or avoid substance-related and other high-risk behaviors. Counseling can also help those who are already infected to manage their illness. Moreover, engaging in substance abuse treatment can facilitate adherence to other medical treatments. Patients may be reluctant to accept screening for HIV (and other infectious diseases); therefore, it is incumbent upon treatment providers to encourage and support HIV screening and inform patients that highly active antiretroviral therapy (HAART) has proven effective in combating HIV, including among drugabusing populations.

Source: NIDA. 2009. *Principles of Drug Addiction Treatment: A Research-based Guide*, *2nd edition*. 2009. National Institute on Drug Abuse.

Relapse is a common event for people recovering form drug addiction. In many ways, relapse should be thought of as a normal part of the recovery process. A person in recovery is more likely to experience a relapse if he or she also has other psychiatric conditions, experiences stress, or lacks the support of family and friends.

Despite the preconceptions and value judgments many people place on addiction, it is, in many ways, similar to other chronic diseases such as diabetes and coronary artery disease. Genetic, environmental, and behavioral components contribute to each of these diseases. Some people may argue that drug addiction is different because it is "self-inflicted." As presented in Lesson 4, the initial choice to use drugs is voluntary, but, once addiction develops, drug use is compulsive—not voluntary. Moreover, voluntary choices do contribute to the onset or severity of other chronic diseases as well. For example, a person who chooses to eat an unhealthy diet and not exercise increases his or her risk for coronary heart disease.

Successful treatment for any chronic disease necessitates patient compliance with the prescribed treatment regimen. Adhering to a treatment plan is difficult for those with any chronic disease. Less than 50 percent of people with diabetes follow their routine medication plan, and only 30 percent follow their dietary guidelines.[2] Problems adhering to a treatment plan lead to about 50 percent of diabetic people needing additional medical care within one year of diagnosis and initial treatment. Similar statistics hold true for other chronic diseases: approximately 40 percent of patients with hypertension need emergency room treatment for episodes of extreme high blood pressure, and only about 30 percent of adult asthma sufferers take their medication as prescribed. People treated for drug addiction also commonly relapse during treatment and recovery, resuming drug use. The difficulties in following a treatment plan and coping with the stresses of a chronic disease illustrate how difficult changing human behavior is. The challenge of adherence is particularly severe in the case of addiction because this disease implicates and coopts the very same brain substrates that underlie what we call free will.[8] Activities 2 and 3 of this lesson provide more insight into this topic.

Scientific research is likely to change how drug addiction is treated. Research to understand how the brain works and how drugs cause changes in the chemistry and function of the brain may lead to new medications to treat disease. Scientists continue to work on developing medications that relieve the cravings experienced when drugs are withdrawn. Also, scientific advances may reveal ways to reverse the long-term functional changes to the brain that drugs inflict.

In Advance

Web-Based Activities

Activity	Web Component?
1	No
2	Yes
3	No
4	No

Photocopies

For each group of 3 students	For each student
1 copy of Master 5.1, *Ruth's Story** 1 copy of Master 5.2, *Mike's Story** 1 copy of Master 5.3, *Carol's Story** 1 copy of Master 5.4, *Disease Reference Information**	1 copy of Master 5.5, *Evaluating the Cases*

* The Web version of Activity 2 is the preferred approach. Copies of Masters 5.1, 5.2, 5.3, and 5.4 are needed only if the Internet is unavailable for classroom use.

Materials

Activity	Materials
Activity 1	overhead projector
Activity 2	computers (optional)
Activity 3	overhead projector
Activity 4	none

Preparation

Arrange for students to have access to computers for viewing the case studies in Activity 2.

Activity 1: Is Addiction Treatable?

Procedure

This activity is intended to be a quick method to assess students' prior conceptions about treating drug addiction as a disease.

1. **Begin the activity by holding a classroom discussion about illness and disease. Ask, "What is a disease?" Ask students to name some diseases. Write responses on the board.**

   Students are likely to say a disease is some problem with the body that makes a person feel bad. They may also respond that a disease is something you see a doctor about or take medicine for. Students will list a variety of diseases and conditions. If they don't include both short-term minor diseases (such as a cold or flu) and long-term complex diseases (such as diabetes or heart disease), prompt them with questions such as, Is a cold a disease? Is diabetes?

2. **Introduce the terms chronic and acute and give examples of chronic and acute conditions. Categorize the diseases from Step 1 as either chronic or acute.**

   Chronic diseases are those that persist over a long period of time, whereas acute diseases last only a short time but may have a rapid onset and marked intensity. Diabetes, heart disease, asthma, and cancer are examples of chronic diseases. Colds, flu, and a broken bone are acute conditions.

3. **Ask students to consider whether addiction is chronic or acute. Have them explain their answer based on what they have learned in the unit so far. After students recognize that addiction is a chronic disease, add it to the list of chronic diseases.**

   Students' explanations should include something about the changes that occur in the brain as a result of drug use (Lessons 2, 3, and 4) and something about the compulsive, nonvoluntary nature of addiction.

4. **Ask, "Do all diseases or illnesses affect people the same way?"**

   No. Some are longer lasting and require more intervention from healthcare providers than others. Some require medicines, others require psychological treatment, and some require both. Students may give a cold as an example of a short-term illness that doesn't require a great deal of treatment and diabetes or heart disease as a longer-lasting illness that does require a lot of treatment. Students should realize that there are similarities as well as differences in disease treatment.

5. **Hold a class discussion to find out what students know about treatments for addiction. Probe student understanding of what a person experiences in treatment, what types of treatments are available, how long treatment lasts, and whether it is successful. Have students justify their ideas. Accept all reasonable answers, and record ideas on the board or a blank transparency.**

   At this stage, students are likely to have many ideas about treatment for addiction. Some of their ideas will likely be drawn from stories they have seen on the Internet or from media coverage of celebrities. Their ideas may also reflect societal perceptions of addiction and may not include explanations based on the biology of addiction.

   Note to Teachers: Save the list that students generate. They will revisit it in Activity 3.

6. **Explain that in the next activity, students will learn about treatment for addiction and how it compares with treatment for other chronic diseases.**

Activity 2: Evaluating the Case Studies

Content Standard F: An individual's mood and behavior may be modified by substances.
Content Standard F: Personal choice concerning fitness and health involves multiple factors.
Content Standard F: Families serve basic health needs, especially for young children.

The following procedures describe how to conduct the Web version of this activity, which is the preferred method of instruction. Instructions for conducting the alternative print version follow (on page 136).

1. **Divide the class into groups of three students. Give each student a copy of Master 5.5, *Evaluating the Cases*. Have the students complete the Web activity *Dealing with a Chronic Disease*. Each member of the group should answer questions 1–6 for a different case study. After they watch the three cases, the group should answer questions 7–11.**

   From the activities menu on the Web site, select Lesson 5—*Drug Addiction Is a Disease, So What Do We Do about It?* Then click to watch the video interviews.

2. **As a class, discuss the case studies and the answers to Master 5.5.**

Sample Answers to Questions on Master 5.5

Case Study: Ruth

Question 1. What disease does the individual have? Is it chronic or acute?

Ruth is addicted to heroin. Addiction is a chronic disease.

Question 2. How did the disease change the individual's life?

Ruth, like other drug-addicted people, was spending most of her energy focusing on how and where she was going to get her next drugs. She became isolated from her friends, lost her job, and got into trouble with the law.

Question 3. What is the recommended treatment?

The prescribed treatment for Ruth is a combination of medication (methadone or buprenorphine) and behavioral treatment.

Question 4. What did the individual do to improve his or her recovery?

Ruth followed her doctor's advice and got medicine and psychological treatment to help her deal with the problems of addiction. She also worked to change her life by enrolling in college, making new friends, and getting involved in running. After a recurrence of her drug problem, she again started her medical and psychological treatment.

Question 5. What did the individual do that impaired his or her recovery?

Ruth thought she had conquered her disease and didn't need to continue her treatment. Her life became very stressful, and she went back to the friends who started her on drugs in the first place.

Question 6. Are there other things the individual could do to help with the disease?

As long as Ruth continues her treatment plan, she should be able to manage her disease. If she ignores her treatment, her chance of having a recurrence increases.

Case Study: Mike

Question 1. What disease does the individual have? Is it chronic or acute?

Mike has diabetes, a chronic disease.

Question 2. How did the disease change the individual's life?

After being diagnosed with diabetes, Mike had to check his blood glucose levels regularly, give himself insulin injections, and watch his diet.

Question 3. What is the recommended treatment?

Mike's doctors placed him on insulin therapy. The doctors also prescribed behavioral treatments.

Question 4. What did the individual do to improve his or her recovery?

To help learn about diabetes, Mike attended a camp where he received information about coping with the disease. After some problems, Mike learned to control his blood sugar levels.

Question 5. What did the individual do that impaired his or her recovery?

Mike had trouble in social situations because he couldn't do the same things his friends did. When he ignored his treatment, Mike had trouble in school and ended up in the hospital.

Question 6. Are there other things the individual could do to help with the disease?

Mike needs to continue to follow his treatment plan and monitor his blood glucose level.

Case Study: Carol

Question 1. What disease does the individual have? Is it chronic or acute?

Carol has hypertension. Hypertension is a chronic disease.

Question 2. How did the disease change the individual's life?

Because of the disease, Carol had problems at work as well as with her family interactions. Her health problems became more severe, and she had a mild stroke.

Question 3. What is the recommended treatment?

Initially, the doctor prescribed medication as well as a change in Carol's diet to reduce her salt intake. The doctor also told Carol that exercise would be beneficial.

After Carol had problems following the plan, the doctor recommended that Carol get additional help from other health professionals.

Question 4. What did the individual do to improve his or her recovery?

Carol followed the treatment plan for a while.

Question 5. What did the individual do that impaired his or her recovery?

Carol didn't follow her doctor's advice after the initial period and then ignored her doctor's suggestion that she get additional help from other specialists.

Question 6. Are there other things the individual could do to help with the disease?

Carol needs to fit her treatment into her life.

Comparing the Cases

Question 7. Which individuals were successful in their treatment? Which individuals were not?

Ruth and Mike were both successful in their treatment. Although they had problems, both of them decided to again comply with their treatment. Carol was not successful; she did not follow the recommended treatment.

Question 8. Who was cured of their disease? What is the difference between treatment and cure?

None of the individuals was cured of his or her disease. Treatment eliminates or reduces the effects of the disease, but does not eliminate the disease. If a disease is cured, the problem is fixed and requires no additional treatment.

Question 9. How are the treatments for the different diseases similar?

In each case, the prescribed treatment included both medication and behavioral treatments. In each case, treatment is a long-term process.

Question 10. How are the treatments different?

Different medications are used to treat different diseases.

Question 11. Can you identify similarities and differences in the actions or strategies that individuals took to help them deal with their disease?

All three individuals initially complied with the prescribed treatment. All three individuals experienced a time when they ignored the treatment plan and had reoccurring problems with the disease. Ruth and Mike chose to get additional treatment and learned to cope with their disease. Carol, on the other hand, made the choice to continue to ignore the treatment plan and her doctor's advice.

The following procedure is for classes using the print version of this activity.

1. Break the class into groups of three students. Give one copy of each of the following masters to each group: Master 5.1, *Ruth's Story*; Master 5.2, *Mike's Story*; Master 5.3, *Carol's Story*; and Master 5.4, *Disease Reference Information*. Each student in the group should read a different case. Give each student a copy of Master 5.5, *Evaluating the Cases*. Each student should answer questions 1–6 about the case study that he or she read. The students should answer questions 7–11 as a group. Give students time to discuss and write answers to the questions. They may refer to the case studies for help.

2. After all the groups have finished the questions, discuss the cases with the class.

Sample answers for the questions on Master 5.5 are given in the procedures for the Web-based version of this activity (pages 133–135).

Activity 3: Is Treatment for Addiction Effective?

Content Standard A: Formulate and revise scientific explanations and models using logic and evidence.

1. Display students' ideas on addiction treatment from Activity 1, Step 5. Ask whether they now see these ideas as correct or incorrect based on what they learned from the case studies. Have students revise any incorrect statements and explain their changes.

   Students should be able to use pieces of information to correct some common misconceptions that are probably on their list. For example, one misconception is that treatment for addiction doesn't work and that once a person is addicted to drugs, there isn't anything that can be done for them. From the case studies, students should recognize that treatment can be successful, and people can improve their lives if they follow the treatment plan, which could include behavioral therapies and medications. (Medications are available to treat addiction to some drugs (for example, opiates, nicotine, alcohol), but not others.)

   If appropriate for the specific drug addiction, treatment that includes both behavioral therapy and medication is often more successful than treatment that uses only one approach. Students should recognize that the combination of behavioral therapy and medication helped the individual portrayed in the case study.

   Treatment is most effective when adjusted for the individual's needs and circumstances. The ultimate goal of drug addiction treatment is to enable an individual to achieve long-lasting abstinence, but the immediate goals are to reduce drug abuse, improve the patient's ability to function, and minimize the medical and social complications of drug abuse and addiction.

Now that students have evaluated the case studies, they should understand that addiction is a disease that is treated as effectively as, or more effectively than, other chronic diseases.

Some initial ideas about drug addiction treatment may reflect the idea that simply stopping drug use means that treatment is effective. Students should realize after reading the case studies that drug addiction and other chronic diseases can have wide-ranging effects on a person, both physically and emotionally. Thus, addressing the person's complex needs is imperative. For addiction, this may include helping with family problems, employment, legal concerns, and other co-occuring medical conditions. Reinforce to students that behavioral therapy, along with other services, can help individuals cope with the problems that can trigger a relapse. Just as treatment for diabetes or heart disease requires that people change their behaviors to adopt a healthier lifestyle, so does successful treatment for drug addiction.

2. **Point out that the individual in the case study experienced relapse at one point. She started using drugs again after stopping for a while. Ask students if relapse means that treatment is not effective.**

   Relapse is common during recovery from drug addiction, as it is for other chronic diseases depicted in the case studies. If someone relapses, that does not mean that treatment failed. Rather, relapse signals that the person needs to go back to treatment or that the person's treatment plan needs to be modified to better fit the individual's needs.

   Some students will suggest that relapse occurs because patients don't always comply with their treatment. This is correct. Treatment is more effective when the patient participates actively in the process. It's important for students to understand this. After all, therapies will not be effective if the patient chooses not to take the medicine or attend the counseling sessions.

3. **Have students consider the problems of following a treatment plan. Ask them if they have ever made New Year's resolutions. How long did they keep the resolution and why did they break it?**

   Each individual in the case studies experienced a relapse. The difficulties in making significant changes in lifestyle and behavior may be somewhat difficult for students to understand because they haven't had to experience this personally during their young lives. One of the hardest things humans do is change their behaviors. This is as true for adhering to a treatment plan for a disease as it is for adhering to a plan for other types of behavior changes.

Activity 4: Addiction Is a Brain Disease

This activity asks students to integrate the information they have learned in all of the lessons. Review their papers to evaluate their understanding.

1. **Read the following scenario to the class:**

   Robert has been arrested several times for drug possession. After the first arrest, he was given probation. After the second and third arrests, he was sentenced to jail for one year each time. The police arrested him a fourth time, but instead of having Robert serve more time in jail, the judge ordered him to enter a drug treatment program.

2. **Ask students to write a paper that provides scientific information that would support the judge's decision to have Robert undergo drug treatment instead of going to jail. Instruct the students to incorporate information they have learned from Lessons 1–5 to support their position.**

   Students may benefit from reviewing their work from all of the lessons. The crux of the paper should be that drug addiction is a brain disease and drugs cause long-term changes in the function of the brain.

Lesson 5 Organizer: WEB VERSION

What the Teacher Does	Procedure Reference
Activity 1: *Is Addiction Treatable?*	
Begin with a discussion on illness and disease. Ask, "What is a disease?" Have students name some diseases. Write responses on the board.	Page 131 Step 1
Introduce the terms *chronic* and *acute*, and give examples of chronic and acute conditions. Categorize the diseases from Step 1 as either chronic or acute.	Page 131 Step 2
Ask students to consider and explain whether addiction is chronic or acute. Add addiction to the list of chronic diseases.	Page 131 Step 3
Ask, "Do all diseases or illnesses affect people in the same way?"	Page 132 Step 4
Hold a class discussion to uncover student knowledge about addiction treatment. Probe understanding of what treatment involves, what a person experiences, how long treatment lasts, and whether it is successful. Have students justify their ideas. Record responses and save for use in Activity 3.	Page 132 Step 5
Explain that the next activity will detail treatment for addiction and examine how it compares with treatment for other chronic diseases.	Page 132 Step 6
Activity 2: *Evaluating the Case Studies*	
Divide the class into groups of three students. Give each student a copy of **Master 5.5**. Have students complete the activity *Dealing with a Chronic Disease* on the Internet. To access the Internet segment, click on Lesson 5—*Drug Addiction Is a Disease, So What Do We Do about It?* on the activities menu. Each team member should answer questions 1–6 for a different case study. Team members should work together to answer questions 7–11.	Page 132 Step 1
As a class, discuss the case studies and answers to the questions on **Master 5.5**.	Pages 132–135 Step 2

What the Teacher Does	Procedure Reference
Activity 3: *Is Treatment for Drug Addiction Effective?*	
Display students' ideas on addiction treatment from Activity 1, Step 5. Do they now see these ideas as correct or incorrect? Have students revise any incorrect statements and explain their changes.	Pages 136–137 Step 1
The individual in the case study experienced relapse at one point. She started using drugs again after stopping for a while. Ask students if relapse means that treatment is not effective.	Page 137 Step 2
Have students consider the problems of following a treatment plan. Have they ever made New Year's resolutions? How long did they keep the resolution and why did they break it?	Page 137 Step 3
Activity 4: *Addiction Is a Brain Disease*	
Read the following scenario to the class: Robert has been arrested several times for drug possession. After the first arrest, he was given probation. After the second and third arrests, he was sentenced to jail for one year each time. The police arrested him a fourth time, but instead of having Robert serve more time in jail, the judge ordered him to enter a drug treatment program.	Page 138 Step 1
Ask students to write a paper that provides scientific information that would support the judge's decision to have Robert undergo drug treatment. Instruct students to incorporate information they have learned from Lessons 1–5 to support their position.	Page 138 Step 2

= Involves using the Internet.

= Involves copying a master.

Lesson 5 Organizer: PRINT VERSION

What the Teacher Does	Procedure Reference
Activity 1: *How Effective Is Treatment?*	
Begin with a discussion on illness and disease. Ask, "What is a disease?" Have students name some diseases. Write responses on the board.	Page 131 Step 1
Introduce the terms *chronic* and *acute*, and give examples of chronic and acute conditions. Categorize the diseases from Step 1 as either chronic or acute.	Page 131 Step 2
Ask students to consider and explain whether addiction is chronic or acute. Add addiction to the list of chronic diseases.	Page 131 Step 3
Ask, "Do all diseases or illnesses affect people in the same way?"	Page 132 Step 4
Hold a class discussion to uncover student knowledge about addiction treatment. Probe understanding of what treatment involves, what a person experiences, how long treatment lasts, and whether it is successful. Have students justify their ideas. Record responses and save for use in Activity 3.	Page 132 Step 5
Explain that the next activity will detail treatment for addiction and examine how it compares with treatment for other chronic diseases.	Page 132 Step 6
Activity 2: *Evaluating the Case Studies*	
Divide the class into groups of three students. Give one copy of each of the following masters to each group: **Masters 5.1**, **5.2**, **5.3**, and **5.4**. Each student in the group should read a different case. Give each student a copy of **Master 5.5**, *Evaluating the Cases*. Each team member should answer questions 1–6 for a different case study. Team members should work together to answer questions 7–11.	Page 136 Step 1
As a class, discuss the case studies and answers to the questions on **Master 5.5**.	Page 136 Step 2

What the Teacher Does	Procedure Reference
Activity 3: *Is Treatment for Drug Addiction Effective?*	
Display students' ideas on addiction treatment from Activity 1, Step 5. Do students now see these ideas as correct or incorrect? Have students revise any incorrect statements and explain their changes.	Pages 136–137 Step 1
The individual in the case study experienced relapse at one point. She started using drugs again after stopping for a while. Ask students if relapse means that treatment is not effective.	Page 137 Step 2
Have students consider the problems of following a treatment plan. Have they ever made New Year's resolutions? How long did they keep the resolution and why did they break it?	Page 137 Step 3
Activity 4: *Addiction Is a Brain Disease*	
Read the following scenario to the class: Robert has been arrested several times for drug possession. After the first arrest, he was given probation. After the second and third arrests, he was sentenced to jail for one year each time. The police arrested him a fourth time, but instead of having Robert serve more time in jail, the judge ordered him to enter a drug treatment program.	Page 138 Step 1
Ask students to write a paper that provides scientific information that would support the judge's decision to have Robert undergo drug treatment. Instruct students to incorporate information they have learned from Lessons 1–5 to support their position.	Page 138 Step 2

M = Involves copying a master.

Additional Resources for Teachers

The following resources may provide additional background information for you or your students about neurobiology or drugs of abuse.

RESOURCES ON THE INTERNET

National Institute on Drug Abuse (NIDA)

NIDA is the world's leading supporter of research on the health aspects of drug abuse and addiction. This site provides current and authoritative information about the latest research on drugs and addiction.

NIDA DRUG*PUBS* Research Dissemination Center

NIDA publications are available through NIDA DRUG*PUBS*. Included are the latest available student and teacher materials, prevention packets, booklets, posters, research reports, clinical reports, clinical reports, survey reports, and brochures. Most of these can be downloaded or ordered for free, by phone (1-877-NIDA-NIH, or 1-877-643-2644; TTY/TDD: 240-645-0228), fax (240-645-0227), or e-mail (*drugpubs@nida.nih.gov*).

National Clearinghouse for Alcohol and Drug Information (NCADI)

NCADI is part of the U.S. Department of Health and Human Services and functions as the information service for the Center for Substance Abuse Prevention.

Office of National Drug Control Policy

The purpose of the Office of National Drug Control Policy (ONDCP) is to establish policies, priorities, and objectives for the nation's drug control program. The National Drug Control Policy is available on this Web site. This site also provides information about specific drugs (including statistics on their use), treatment, research, and enforcement.

Society for Neuroscience

The Society for Neuroscience is the world's largest organization of scientists and physicians dedicated to understanding the brain, spinal cord, and peripheral nervous system. This site provides a wide variety of information on topics related to the function of the brain and nervous system. The site also provides an opportunity to submit a specific question that may be answered online.

Partnership for a Drug-free America

Information posted at this address includes information about specific drugs and their effects.

The Dana Foundation

The Charles A. Dana Foundation is a private philanthropic foundation with principal interests in health and education. Their Web site provides information for the general public on the latest research findings about the brain and brain disorders. The Web site also provides access to their publications.

The Reconstructors
This Web game enables students to learn more about the history of opioids, club drugs, and inhalants. The activities incorporate aspects of chemistry, neuroscience, medicine, public policy, and history.

Office of Science Education
This address takes you directly to the home page of the National Institutes of Health's Office of Science Education. This site provides access to a variety of resources for teachers and students, including NIH publications on drug abuse and brain function.

U.S. National Library of Medicine
The U.S. National Library of Medicine is the world's largest medical library. This site provides extensive online information about health issues and includes access to Medline and MedlinePlus for searching for information about specific health topics.

BOOKS AND VIDEOTAPE

Friedman, D.P., and Rusche, S. 1999. *False Messengers: How Addictive Drugs Change the Brain*. Amsterdam: Harwood Academic Publishers.

Kuhn, C., Swarzwelder, S., and Wilson, W. 1998. *Buzzed: The Straight Facts about the Most Used and Abused Drugs from Alcohol to Ecstasy*. New York: W.H. Norton & Company.

Gross de Núñez, G., and Schwartz-Bloom, R.D. 1998. *Animated Neuroscience and the Action of Nicotine, Cocaine, and Marijuana in the Brain*. Princeton, NJ: Films for the Humanities and Sciences.

Glossary

Definitions for the following terms were adapted from a variety of sources. Specific sources are listed in the References section.

absorption: The process by which elements move from outside of the body into the blood and other tissues. Breakdown products of food are absorbed through the stomach and intestines. When tobacco is smoked, nicotine is absorbed through the lungs.

acetylcholine: A neurotransmitter that functions in the brain to regulate memory and that controls the actions of skeletal and smooth muscle in the peripheral nervous system.

action potential: The electrical part of a neuron's two-part, electrical-chemical message. An action potential consists of a brief pulse of electrical current that travels along the axon. When the action potential reaches the axon terminal, it triggers neurotransmitter release.

acute: Refers to an effect, disease, or condition that has a relatively rapid onset, marked intensity, and short duration.

addiction: A chronic, relapsing brain disease characterized by compulsive drug-taking despite adverse health, social, or legal consequences.

adenosine: A neurotransmitter that binds to the adenosine receptor. Adenosine is a by-product of adenosine triphosphate (ATP) metabolism and is an important regulator of sleep. Caffeine is an adenosine antagonist.

agonist: A drug that binds to a receptor of a cell and triggers a response by the cell. An agonist often mimics the action of a naturally occurring substance. Opioids, THC, and nicotine are examples.

alcohol: A psychoactively complex drug in beverages such as beer, wine, and whiskey. Alcohol is a depressant drug with potential for abuse and addiction.

all-or-none phenomenon: Used to describe an action potential and the principle that a nerve fiber will respond maximally or not at all to a stimulus.

amphetamines: Stimulant drugs with effects very similar to cocaine's.

amygdala: A component of the limbic system involved in the expression and perception of emotion.

anandamide: A neurotransmitter produced in the body that binds to the cannabinoid receptor.

antagonist: A chemical that, when it binds to a receptor, blocks the cell from responding. Antagonists prevent agonists from binding, or attaching, to the receptor. Antagonists include caffeine (for adenosine) and naloxone (for opioids).

astrocyte: A type of glial cell that provides nutrients, support, and insulation for neurons of the central nervous system.

axon: The fiber-like extension of a neuron through which the cell carries information to target cells.

axon terminal: The structure at the end of an axon that produces and releases chemicals (neurotransmitters) to transmit the neuron's message across the synapse.

barbiturates: Depressant drugs that produce relaxation and sleep. Sleeping pills such as pentobarbital and secobarbital are barbiturates.

bind: The attaching of a neurotransmitter or other chemical to a receptor. The neurotransmitter "binds" to the receptor.

blood-brain barrier: A network of tightly packed cells in the walls of capillaries in the brain that prevents many molecules, including poisons, from entering the brain.

brainstem: The structure at the base of the brain through which the forebrain sends information to, and receives information from, the spinal cord and peripheral nerves.

buprenorphine: A long-lasting opioid medication that has both agonist and antagonist properties. Buprenorphine is useful for treating heroin and other opioid addictions.

caffeine: A mild stimulant found in coffee and kola nuts. Caffeine is the most widely used drug in the world.

cannabinoid receptor: The receptor in the brain that recognizes anandamide and THC, the active ingredient in marijuana.

cannabis: The botanical name for the plant from which marijuana comes.

cannula: A tube that is inserted into a cavity or duct.

cell body (or soma): The central structure of a neuron, which contains the cell nucleus. The cell body contains the molecular machinery that regulates the activity of the neuron.

central nervous system (CNS): The brain and spinal cord.

cerebellum: A portion of the brain that helps regulate posture, balance, and coordination.

cerebral cortex: The outer layer of the cerebral hemispheres that controls conscious experience, including perception, emotion, thought, and planning. It also controls movement.

cerebral hemispheres: The two specialized halves of the brain. The left hemisphere is specialized for speech, writing, language, and calculation; the right hemisphere is specialized for spatial abilities, facial recognition, and some aspects of music perception and production.

cerebrum: The upper part of the brain consisting of the left and right hemispheres.

chronic: Being long-lasting and of constant or regular frequency. Can refer to a disease or condition that persists or to repeated drug use.

cocaine: A highly addictive stimulant drug derived from the coca plant that produces profound feelings of pleasure.

craving: Compulsive and uncontrollable hunger for drugs or other rewards such as food. Drug craving is caused by drug-induced changes in the brain.

dendrite: The specialized branches that extend from a neuron's cell body and function to receive messages from other neurons.

depressants: Drugs that depress the CNS. Include sleep and anxiety medications and alcohol.

dopamine: A neurotransmitter that relays messages within the reward circuitry of the brain.

dopamine transporter: Located on the cell membrane of the axon terminal of a dopamine-releasing neuron. Terminates the neuron signal by removing dopamine from the synapse for recycling or breakdown.

drug: A chemical compound or substance that can alter the structure and function of a cellular component. Psychoactive drugs affect the function of the brain, and some of these may be illegal to use and possess.

drug abuse: The use of illegal drugs or the inappropriate use of legal drugs. The repeated use of drugs to produce pleasure, to alleviate stress, or to alter or avoid reality (or all three).

drug addiction: A chronic, relapsing brain disease characterized by compulsive drug-taking despite adverse health, social, or legal consequences.

ecstasy (methylenedioxymethamphetamine, or MDMA): A chemically modified amphetamine that has hallucinogenic as well as stimulant properties.

electroencephalogram (EEG): A graphic record of the electrical activity of the brain made by attaching electrodes to the scalp.

endogenous: Something produced by the brain or body.

endorphins: Peptides with opioid-like effects that bind to opioid receptors. Endorphins are made by neurons and used as neurotransmitters.

enkephalins: One of the endogenous opioids that binds to opioid receptors and functions as a neurotransmitter.

enzyme: A molecule that living organisms use to catalyze (speed up) chemical reactions. Enzymes are used to build, modify, or break down different molecules without themselves being permanently altered or destroyed.

excitatory neurotransmitter: A neurotransmitter that elicits an action potential or makes it more likely that one will be elicited.

exocytosis: A process by which secretory products are released from a cell via transport within vesicles to the cell surface and subsequent fusion with the plasma membrane, resulting in the extrusion of the vesicle contents from the cell.

forebrain: The largest division of the brain, which includes the cerebral cortex and basal ganglia. It is credited with the highest intellectual functions.

frontal lobe: One of the four divisions of each cerebral hemisphere. The frontal lobe is important for controlling movement, thinking, and judgment. It associates the functions of other cortical areas.

GABA (gamma-amino-butyric acid): The major inhibitory neurotransmitter in the brain.

glial cells (glia): Brain cells that support neurons by performing a variety of "housekeeping" functions in the brain.

glutamate: The most common excitatory neurotransmitter in the brain.

hallucinogens: A diverse group of drugs that alter perceptions, thoughts, and feelings. Hallucinogenic drugs include LSD, mescaline, MDMA (ecstasy), PCP, and psilocybin (magic mushrooms).

heroin: The potent, widely abused opioid that produces addiction. It consists of morphine with two acetyl groups attached to it.

hippocampus: A brain structure that is involved in learning and memory.

homeostasis: The process of keeping the internal environment of the body stable by making adjustments to changes in the external environment.

hypothalamus: The part of the brain that controls many bodily functions, including feeding, drinking, and the release of many hormones.

ingestion: The act of taking in food or other material into the body through the mouth.

inhalant: Any drug that is typically administered only by breathing in its vapors and by no other route. Inhalants commonly are organic solvents, such as glue and paint thinner, or anesthetic gases, such as ether and nitrous oxide.

inhalation: The act of administering a drug or combination of drugs by nasal or oral respiration. Also, the act of drawing air or other substances into the lungs. Nicotine in tobacco smoke enters the body by inhalation.

inhibitory neurotransmitter: A neurotransmitter that acts to prevent a neuron from firing an action potential.

injection: A method of administering a substance such as a drug into the skin, subcutaneous tissue, muscle, blood vessels, or body cavities, usually by means of a needle.

limbic system: A set of brain structures that regulates our feelings, emotions, and motivations. It is also important in learning and memory.

LSD (lysergic acid diethylamide): A hallucinogenic drug that binds to and activates the serotonin receptor.

magnetic resonance imaging (MRI): An imaging technique that uses magnetic fields to generate images of the structure of the brain.

marijuana: A drug, usually smoked but it can be eaten, that is made from the leaves of the cannabis plant. The main psychoactive ingredient is THC.

medication: A drug that is used to treat an illness or disease according to established medical guidelines.

metabolism: The processes by which the body breaks things down or alters them so they can be eliminated.

methadone: A synthetic opioid used to treat pain and heroin addiction.

methamphetamine: A commonly abused, potent stimulant drug that is highly addictive and part of a larger family of amphetamines.

morphine: The most potent natural opiate compound produced by the opium poppy. Morphine is a very effective medicine for treating pain.

myelin: Fatty material that surrounds and insulates axons of some neurons.

naloxone: A short-acting opioid antagonist that binds to opioid receptors and blocks them, preventing opioids from binding to these receptors.

naltrexone: Structurally similar to naloxone, an opioid antagonist used to treat heroin addiction and, more recently, alcohol addiction.

neuron (nerve cell): A unique type of cell found in the brain and body that is specialized to process and transmit information.

neurotransmission: The process that occurs when a neuron releases neurotransmitters to communicate with another neuron across the synapse.

neurotransmitter: A chemical produced by neurons to carry messages to other neurons.

nicotine: The addictive drug in tobacco. Nicotine activates a specific type of acetylcholine receptor.

NMDA (N-methyl-D-aspartate): A synthetic amino acid that is the defining agonist for the NMDA receptor, one of the glutamate receptors on neurons.

norepinephrine: A neurotransmitter and a hormone. It is released by the sympathetic nervous system onto the heart, blood vessels, and other organs and by the adrenal gland into the bloodstream as part of the fight-or-flight response. Norepinephrine in the brain is used as a neurotransmitter in normal brain processes.

nucleus: A cluster or group of nerve cells that is dedicated to performing its own special function(s). Nuclei are found in all parts of the brain but are called cortical fields in the cerebral cortex.

nucleus accumbens: A part of the brain reward system that processes information related to motivation and reward. Virtually all drugs of abuse act on the nucleus accumbens to reinforce drug taking.

occipital lobe: The lobe of the cerebral cortex at the back of the head that includes the visual cortex.

opiate: Any of the psychoactive drugs that originate from the opium poppy or that have a chemical structure like the drugs derived from opium. Some opiates (such as opium, codeine, and morphine) are derived from the plant, while others were first synthesized by chemists.

opioid: Any chemical that has opiate-like effects; commonly used to refer to endogenous neurochemicals that activate opioid receptors but also includes natural, synthetic, and semisynthetic drugs.

opioid receptors: Receptors that recognize natural, synthetic, and endogenous opioids. When activated, they slow down or inhibit the activity of neurons on which they reside.

parallel processing: The division of an information-processing job into smaller parts that are each handled simultaneously by various cortical fields and brain nuclei.

parietal lobe: One of the four subdivisions of the cerebral cortex; it is involved in sensory processes, attention, and language.

phencyclidine (PCP): Originally developed as an anesthetic, PCP may act as a hallucinogen, stimulant, or sedative.

pituitary gland: An endocrine organ closely linked with the hypothalamus. The pituitary secretes a number of hormones that regulate the activity of other endocrine organs in the human body.

plasticity: The capacity of the brain to change its structure and function within certain limits. Plasticity underlies brain functions such as learning and allows the brain to generate normal, healthy responses to long-lasting environmental changes.

positron: A positively charged particle having the same mass and spin as, but opposite charge of, an electron.

positron emission tomography (PET): An imaging technique for measuring brain function in living subjects by detecting the location and concentration of small amounts of radioactive chemicals.

postsynaptic neuron: The neuron that receives a given message from other neurons.

presynaptic neuron: The neuron that releases neurotransmitters into the synaptic space to send messages to another neuron.

psychedelic drug: A drug that distorts perception, thought, and feeling. This term is typically used to refer to drugs with actions like those of LSD.

psychoactive drug: A drug that changes the way the brain works.

psychosocial therapy: Therapy that uses a combination of individual psychotherapy and group (social) therapy approaches to rehabilitate or provide the interpersonal and intrapersonal skills to help someone recover from drug addiction.

receptor: A protein that recognizes specific chemicals (normally neurotransmitters, hormones, and similar endogenous substances) and transmits the message carried by the chemical into the cell on which the receptor resides.

relapse: In drug abuse, relapse is the resumption of drug use after stopping. Relapse is a common occurrence in many chronic disorders, including addiction.

resting membrane potential: The difference in electrical charge between the inside and the outside of a nerve cell when the cell is not firing. The inside of a resting neuron has a greater negative charge than the outside of the neuron.

reuptake: The process by which neurotransmitters are removed from the synapse by being "pumped" through transporters back into the axon terminals that first released them.

reuptake pump (transporter): The protein that actually transports neurotransmitter molecules back into the axon terminals that released them.

reward: The process that reinforces behavior, making it more likely to recur. It is mediated at least in part by the release of dopamine into the nucleus accumbens.

reward pathway (or brain reward system): A brain circuit that, when activated, reinforces behaviors. The circuit includes the dopamine-containing neurons of the ventral tegmental area, the nucleus accumbens, and part of the prefrontal cortex. The activation of this circuit causes feelings of pleasure.

route of administration: The way a drug is introduced into the body. Drugs can enter the body by eating, drinking, inhaling, injecting, snorting, smoking, or absorption through mucous membranes.

rush: Intense feelings of euphoria a drug produces when it is first injected or smoked.

second messenger: A molecule produced inside neurons as a step in the process of communication between cells. The second messenger lets other parts of the cell know that a specific receptor has been activated, thereby completing the message carried by the neurotransmitter that bound to the receptor. Some receptors (dopamine and opiate receptors, for example) use second messengers. Others (nicotine and GABA receptors, for example) do not.

sensitization: An increased response to a drug caused by repeated administration. It is most commonly seen in some responses to stimulants.

serotonin: A neurotransmitter that regulates many functions, including mood, appetite, and sensory perception.

single photon emission computed tomography (SPECT): An imaging process that measures the emission of single photons of a given energy from radioactive tracers in the human body.

stimulants: A class of drugs that elevates mood, increases feelings of well-being, and increases energy and alertness. Stimulants include nicotine, cocaine, methamphetamine, and methylphenidate (Ritalin).

synapse: The site where presynaptic and postsynaptic neurons communicate with each other.

synaptic space (or synaptic cleft): The intercellular space between the presynaptic and postsynaptic neurons.

temporal lobe: One of the four major subdivisions of each hemisphere of the cerebral cortex. It functions in auditory perception, speech, and visual perceptions.

tetrahydrocannabinol (THC): The active ingredient in marijuana that is primarily responsible for producing the drug's psychoactive effects.

thalamus: Located deep within the brain, the thalamus is the key relay station for sensory information flowing into the brain from the periphery. It also serves as a relay station for motor information leaving the brain to regulate function of the muscles.

tolerance: A physiological change resulting from repeated drug use that requires the user to take larger amounts of the drug to get the same effect initially felt from a smaller dose.

transporter: A large protein on the cell membrane of the axon terminals. It removes neurotransmitter molecules from the synapse by carrying them back into the axon terminal that released them.

ventral tegmental area (VTA): The group of dopamine-containing cell bodies that make up a key part of the brain reward system. These neurons extend axons to the nucleus accumbens and the prefrontal cortex.

vesicle: A membranous sac within an axon terminal that stores and releases neurotransmitter.

withdrawal: Symptoms that occur when a person who is dependent on a drug abruptly stops using the drug.

References

Introduction to the Module

1. Loucks-Horsley, S., Love, N., Hewson, P.W., and Stiles, K.E. 1998. *Designing Professional Development for Teachers of Science and Mathematics*. Thousand Oaks, CA: Corwin Press.

Implementing the Module

1. National Research Council. 1996. *National Science Education Standards*. Washington, DC: National Academy Press.

Lesson 1—*The Brain: What's Going On in There?*

1. Friedman, D.P., and Rusche, S. 1999. *False Messengers: How Addictive Drugs Change the Brain*. Amsterdam: Harwood Academic Publishers.

2. National Institute on Drug Abuse. 1997. *Mind Over Matter: The Brain's Response to Drugs*. NIH Publication No. 98-3592.

3. Kandel, E.R. 1991. Brain and behavior. In E.R. Kandel, J.H. Schwartz, and T.M. Jessell (Eds.), *Principles of Neural Science*, 3rd edition (pp. 5-17). Norwalk, CT: Appleton & Lange.

4. Martin, J.H., Brust, J.C.M., and Hilal, S. 1991. In E.R. Kandel, J.H. Schwartz, and T.M. Jessell (Eds.), *Principles of Neural Science*, 3rd edition (pp. 309-324). Norwalk, CT: Appleton & Lange.

5. Gatley, S.J., and Volkow, N.D. 1998. Addiction and imaging of the living human brain. *Drug and Alcohol Dependence*, 51, 97-108.

6. National Institute on Drug Abuse. 1996. The basics of brain imaging. NIDA Notes.

7. Lincoln, A. *The Gettysburg Address*.

8. Damasio, H., Grabowski, T., Frank, R., Galaburda, A.M., and Damasio, A.R. 1994. The return of Phineas Gage: Clues about the brain from the skull of a famous patient. *Science*, 264, 1102-1105.

9. Macmillan, M. *The Phineas Gage information page*.

Lesson 2—*Neurons, Brain Chemistry, and Neurotransmission*

1. Friedman, D.P., and Rusche, S. 1999. *False messengers: How addictive drugs change the brain*. Amsterdam: Harwood Academic Publishers.

2. National Institute on Drug Abuse. 1997. *Mind Over Matter: The Brain's Response to Drugs*. NIH Publication No. 98-3592.

3. Kandel, E.R. 1991. Nerve cells and behavior. In E.R. Kandel, J.H. Schwartz, and T.M. Jessell (Eds.), *Principles of Neural Science, 3rd edition* (pp. 18-32). Norwalk, CT: Appleton & Lange.

4. Rowland, L.P., Fink, M.E. and Rubin, L. 1991. Cerebrospinal fluid: Blood-brain barrier, brain edema, and hydrocephalus. In E.R. Kandel, J.H. Schwartz, and T.M. Jessell (Eds.), *Principles of Neural Science, 3rd edition* (pp. 1050-1060). Norwalk, CT: Appleton & Lange.

5. Society for Neuroscience. 1999. Blood-brain barrier.

6. Darnell, J., Lodish, H., and Baltimore, D. 1990. Nerve cells and the electric properties of cell membranes. In *Molecular Cell Biology, 2nd edition* (pp. 763-814). New York: Scientific American Books, W.H. Freeman and Company.

7. Guyton, A.C., and Hall, J.E. 1996. Organization of the nervous system; basic functions of synapses and transmitter substances. In *Textbook of Medical Physiology, 9th edition* (pp. 565-582). Philadelphia: W.B. Saunders Company.

8. Society for Neuroscience. 1999. *The short answer: Definitions for common neuroscience terms.*

Lesson 3—*Drugs Change the Way Neurons Communicate*

1. Friedman, D.P., and Rusche, S. 1999. *False Messengers: How Addictive Drugs Change the Brain*. Amsterdam: Harwood Academic Publishers.

2. National Institute on Drug Abuse. 2005. *Mind Over Matter: The Brain's Response to Drugs.* NIH Publication No. 05-3592.

3. Kuhn, C., Swarzwelder, S., and Wilson, W. 1998. *Buzzed: The Straight Facts about the Most Used and Abused Drugs from Alcohol to Ecstasy*. New York: W.H. Norton & Company.

4. Gross de Núñez, G., and Schwartz-Bloom, R.D. 1998. *Animated neuroscience and the action of nicotine, cocaine, and marijuana in the brain*. Princeton, NJ: Films for the Humanities and Sciences.

5. National Institute on Drug Abuse. 2006. *Methamphetamine abuse and addiction*. NIDA Research Report. NIH Publication No. 06-4210.

Lesson 4—*Drug Abuse and Addiction*

1. Steindler, E.M. 1998. ASAM addiction terminology. In *Principles of Addiction Medicine, 2nd edition* (pp. 1301-1304). Chevy Chase, MD: American Society of Addiction Medicine.

2. Kuhn, C., Swarzwelder, S., and Wilson, W. 1998. *Buzzed: The Straight Facts about the Most Used and Abused Drugs from Alcohol to Ecstasy*. New York: W.H. Norton & Company.

3. Friedman, D.P., and Rusche, S. 1999. *False Messengers: How Addictive Drugs Change the Brain*. Amsterdam: Harwood Academic Publishers.

4. Childress, A.R., Mozley, P.D., Elgin, W., Fitzgerald, J., Reivich, M., and O'Brien, C.P. 1999. Limbic activation during cue-induced cocaine craving. *American Journal of Psychiatry*, 156, 11-18.

5. Eriksson, P.S., Perfilieva, E., Bjork-Eriksson, T., Alborn, A.M., Nordborg, C., Peterson, D.A., and Gage, F.H. 1998. Neurogenesis in the adult human hippocampus. *Nature Medicine*, 4, 1313-1317.

6. Villemagne, V., Yuan, J., Wong, D.F., Dannals, R.F., Hatzidimitriou, G., Matthews, W.B., Ravert, H.T., Musachio, J., McCann, U.D., and Ricaurte, G.A. 1998. Brain dopamine neurotoxicity in baboons treated with doses of methamphetamine comparable to those recreationally abused by humans: Evidence from [^{11}C]WIN-35,428 positron emission tomography studies and direct in vitro determinations. *Journal of Neuroscience*, 18, 418-427.

7. Fischer, C., Hatzidimitriou, G., Wlos, J., Katz, J., and Ricaurte, G. 1995. Reorganization of ascending 5-HT axon projections in animals previously exposed to the recreational drug (+)3,4-methylenedioxymethamphetamine (MDMA, "Ecstasy"). *Journal of Neuroscience*, 15, 5476-5485.

8. Volkow, N.D., Hitzemann, R., Wany, G.-J., Fowler, J.S., Wolf, A.P., and Dewey, S.L. 1992. Long-term frontal brain metabolic changes in cocaine abusers. *Synapse*, 11, 184-190.

9. National Institute on Drug Abuse. 1999. *Drug abuse and addiction research: 25 years of discovery to advance the health of the public.*

10. Gogtay, N., Giedd, J.N., Lusk, L., et al. 2004. Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National Academy of Sciences USA*, 101(21), 8174-9.

11. Joy, J.E., Watson, S.J., Jr., and Benson, J.A., Jr. (Eds.). 1999. *Marijuana and medicine: Assessing the science base.*

12. Stanton, M.D. 1976. Drugs, Vietnam, and the Vietnam veteran: An overview. *American Journal of Drug and Alcohol Abuse*, 3, 557-570.

13. National Institutes of Health. 1996. *Public health service policy on humane care and use of laboratory animals.*

Lesson 5—*Drug Addiction Is a Disease, So What Do We Do about It?*

1. Leshner, A.I. 1997. Addiction is a brain disease, and it matters. *Science*, 278, 45-47.

2. Tobler, N.S., Roona, M.R., Ochshan, P., Marchall, D.G., Streke, A.V., Stackpole, K.M. 2000. School-based adolescent drug abuse prevention programs: 1998 Meta-analysis. *Journal of Primary Prevention*, 20, 275-335.

3. O'Brien, C.P., and McLellan, A.T. 1998. Myths about the treatment of addiction. In *Principles of Addiction Medicine*, 2nd edition (pp. 309-313). Chevy Chase, MD: American Society of Addiction Medicine.

4. National Institute on Drug Abuse. 2008. *Treatment medications.* NIDA Infofacts.

5. Friedman, D.P., and Rusche, S. 1999. *False Messengers: How Addictive Drugs Change the Brain.* Amsterdam: Harwood Academic Publishers.

6. National Institute on Drug Abuse. 2009. *Principles of Drug Addiction Treatment: A Research-Based Guide, 2nd edition.* NIH Publication No. 09-4180.

7. National Institute on Drug Abuse. 2008. *Treatment approaches for drug addiction.* NIDA Infofacts.

8. Baler, R.D., and Volkow, N.D. 2006. Drug addiction: the neurobiology of disrupted self-control. *Trends in Molecular Medicine*, 12, 559-66.

Glossary

1. Friedman, D.P., and Rusche, S. 1999. *False Messengers: How Addictive Drugs Change the Brain*. Amsterdam: Harwood Academic Publishers.

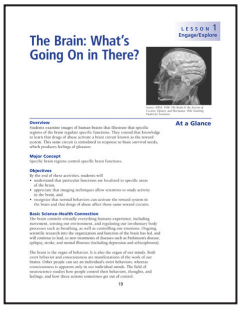
2. Society for Neuroscience. 1999. *The short answer: Definitions for common neuroscience terms*.

3. Morris, C. (editor). 1999. *Academic Press Dictionary of Science and Technology*. San Diego: Academic Press.

4. Brynie, F.H. 1998. *101 Questions Your Brain Has Asked about Itself but Couldn't Answer Until Now*. Brookfield, CT: Millbrook Press.

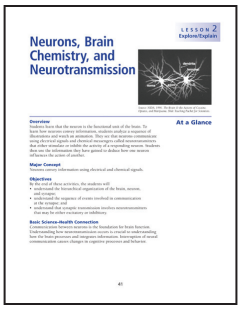
Masters

Refer to the *In Advance* section in each lesson for more information about the number of copies required for each master. Masters marked with an asterisk (*) are not needed if you use the Web-based version of the activity.



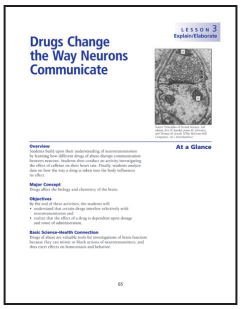
Lesson 1—The Brain: What's Going On in There?

Master 1.1: *Positron Emission Tomography (PET) Images**
Master 1.2: *Interpreting PET Images*
Master 1.3: *PET Image Tasks*
Master 1.4: *Major Regions of the Brain*
Master 1.5: *Areas of the Cerebral Cortex and Their Functions*
Master 1.6: *What Happened to Phineas Gage?*
Master 1.7: *The Reward System*



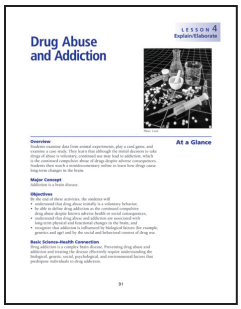
Lesson 2—Neurons, Brain Chemistry, and Neurotransmission

Master 1.7: *The Reward System (from Lesson 1)*
Master 2.1: *Anatomy of a Neuron*
Master 2.2: *Neurons Interact with Other Neurons through Synapses*
Master 2.3: *How Do Neurons Communicate?*
Master 2.4: *Neurons Communicate by Neurotransmission**
Master 2.5: *Neurotransmission*
Master 2.6: *Recording the Activity of a Neuron*
Master 2.7: *Neurotransmitter Actions*
Master 2.8: *Neurons in Series*



Lesson 3—Drugs Change the Way Neurons Communicate

Master 3.1: *Cocaine Alters Neurotransmission*
Master 3.2: *Methamphetamine and Nicotine Disrupt Neurotransmission*
Master 3.3: *How Does Alcohol Affect Neurotransmission?*
Master 3.4: *Parent Letter*
Master 3.5: *Caffeine: How Does Your Heart Respond?*
Master 3.6: *How Do Drugs Get Into the Brain?*
Master 3.7: *What Should the Doctor Do?*


LESSON 4
Explain/Elaborate

Drug Abuse and Addiction

Overview

At a Glance

Major Concept

Objectives

Basic Science–Health Connection

31

Lesson 4—Drug Abuse and Addiction

Master 4.1: *Data for Rat Self-administration Experiment*
Master 4.2: *Worksheet for Rat Experiment Data*
Master 4.3: *Evaluating the Experiment*
Master 4.4: *Playing the Game*
Master 4.5: *Who Is Addicted?*
Master 4.6: *Long-term Effects of Drugs on the Brain**


LESSON 5
Elaborate/Evaluate

Drug Addiction Is a Disease—So What Do We Do about It?

Overview

At a Glance

Major Concept

Objectives

Basic Science–Health Connection

125

Lesson 5—Drug Addiction Is a Disease, So What Do We Do about It?

Master 5.1: *Ruth's Story**
Master 5.2, *Mike's Story**
Master 5.3: *Carol's Story**
Master 5.4: *Disease Reference Information**
Master 5.5: *Evaluating the Cases*

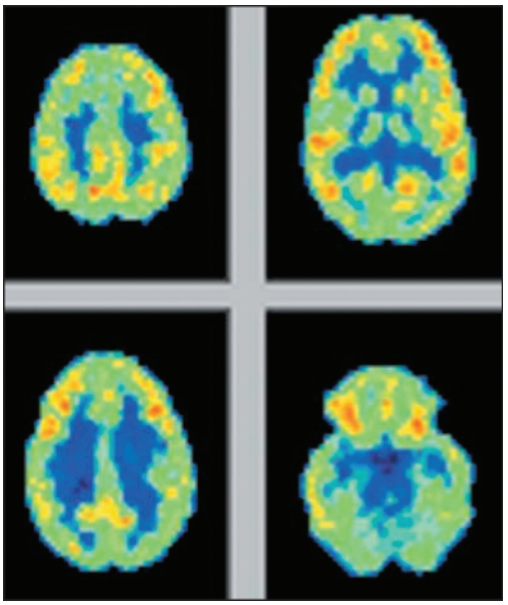
* Not needed if you use the Web-based version of the activity.

Positron Emission Tomography (PET) Images

Each set of PET images below contains four images of a human brain. The four images show cross-sections taken at different levels of the brain.

Set 1

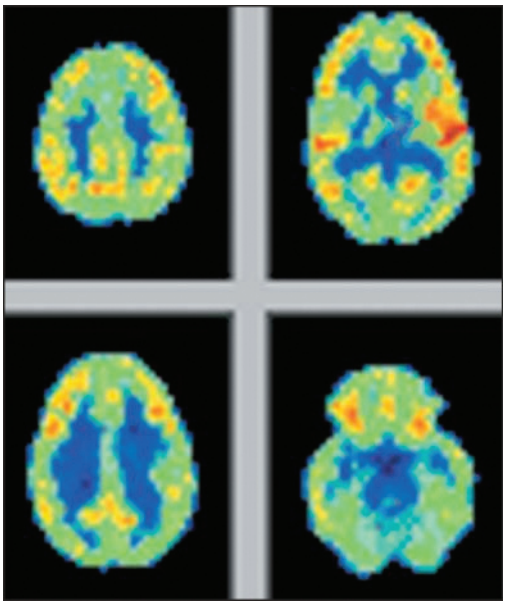
a b



c d

Set 2

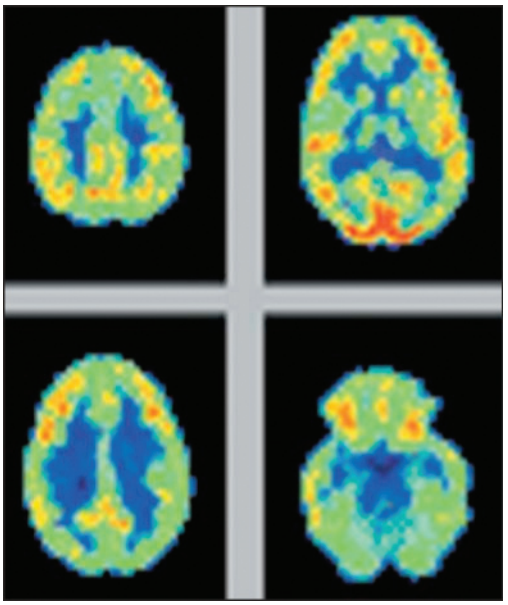
a b



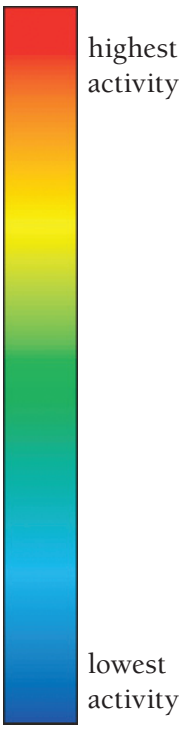
c d

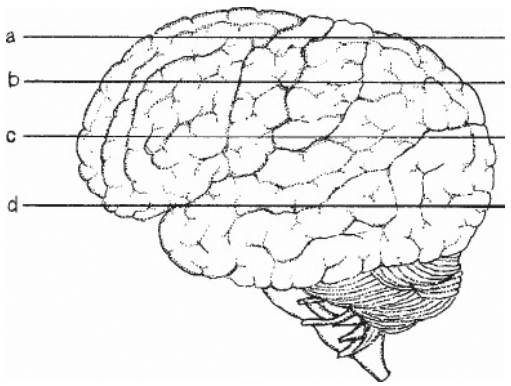
Set 3

a b



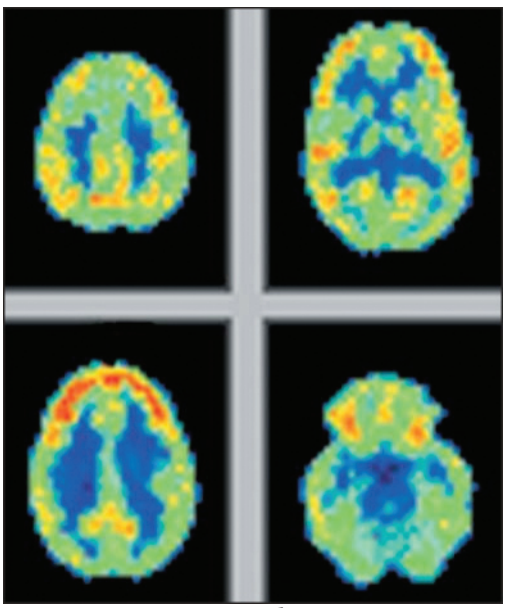
c d





Set 4

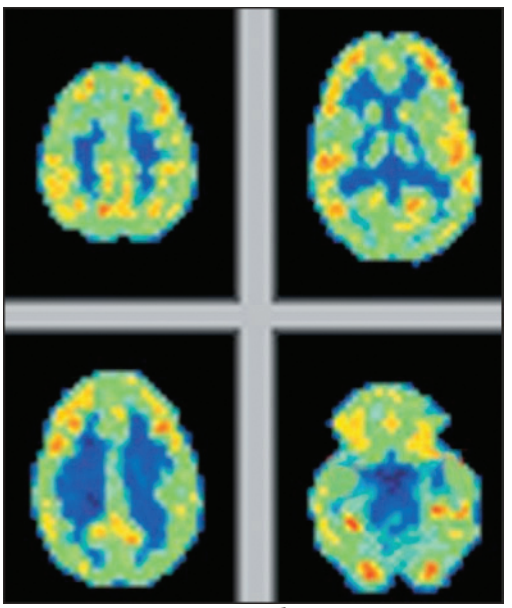
a b



c d

Set 5

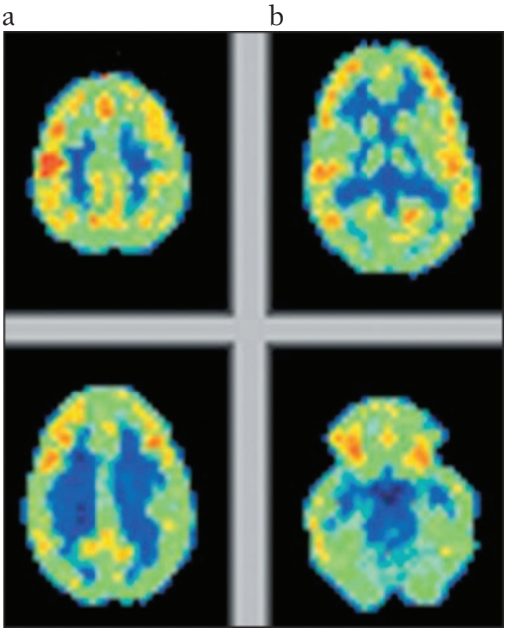
a b



c d

Set 6

a b



c d

PET images provided by:

Sanjiv S. Gambhir, M.D., Ph.D.
UCLA School of Medicine
Crump Institute for Biological Imaging
Copyright 1998
Regents of the University of California

Interpreting PET Images

Name(s)_____ Date_____

1. When you look at the images that make up Set #1 (Master 1.1), how do the four images differ from each other?

2. Why are four images shown in each set of PET images? Why would scientists need to examine more than one PET image taken of a subject's brain?

3. When comparing the images in Set #1 with the images in Sets #2, 3, 4, 5, and 6, how is the activity of the brain in each of these sets different from Set #1's?

Set Number	Identify the image that shows the greatest change (a, b, c, or d)	Describe the change in brain activity
2		
3		
4		
5		
6		

4. The PET images shown in Set #1 show brain activity in a resting brain. The images in Sets #2 through 6 show activity in the brains of humans who are doing different tasks. When you look at the PET scans and the chart in question #3, what generalizations can you make about the activity of the brain when different tasks are performed?

5. Compare the tasks that the subject performed during each of the PET scans (as shown on the overhead transparency of Master 1.3) with the individual's brain activity. Use the information from the overhead and from the PET images to complete the following chart.

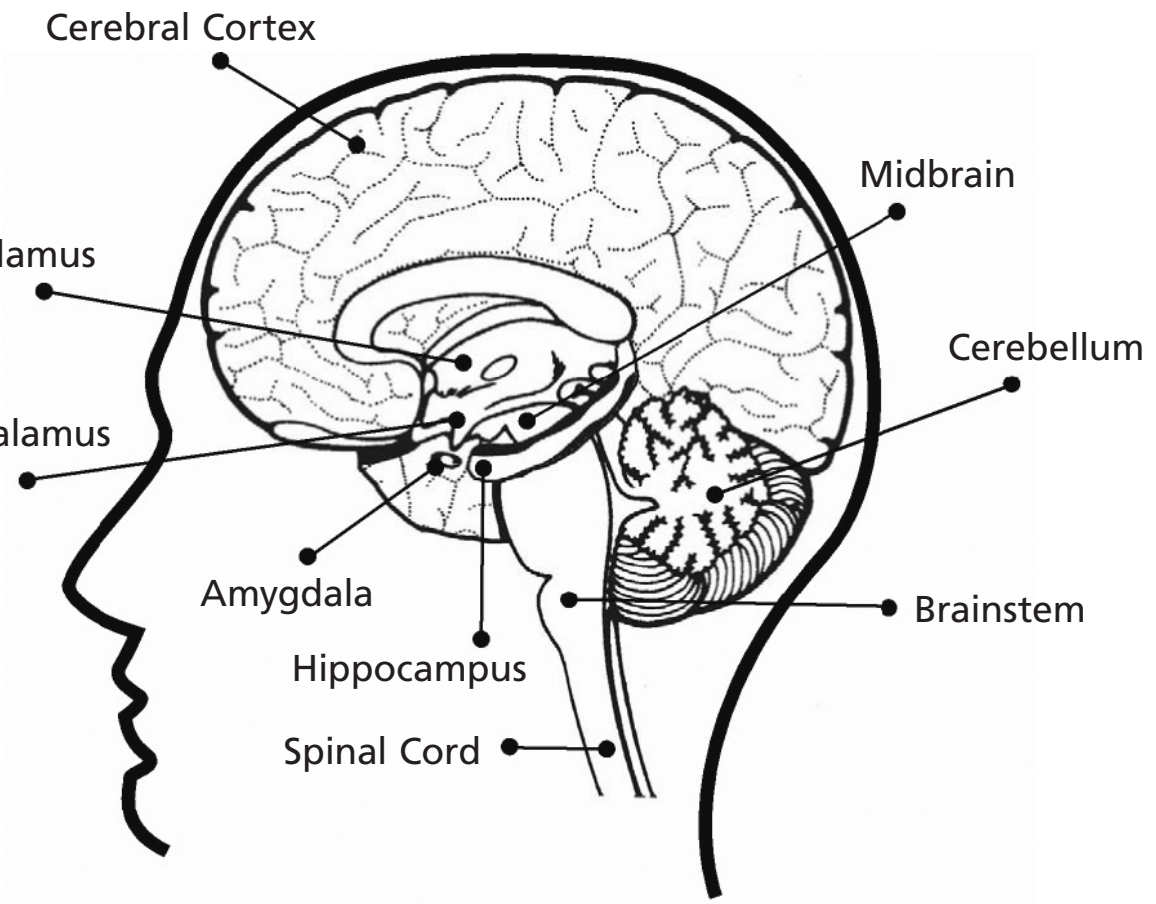
Set Number	Brain region that is more active in the PET image	This region is involved in processing information related to
2	auditory cortex	
3	primary visual cortex	
4	frontal cortex	
5	hippocampus	
6	motor cortex	

PET Image Tasks

The tasks that the subject performed during each of the PET scans are as follows:

- Set #1 Subject is resting.
- Set #2 Subject is listening to music.
- Set #3 Subject is looking at a picture showing both pattern and color.
- Set #4 Subject is performing a thinking task.
- Set #5 Subject must remember an image for later recall.
- Set #6 Subject is hopping up and down on the right foot.

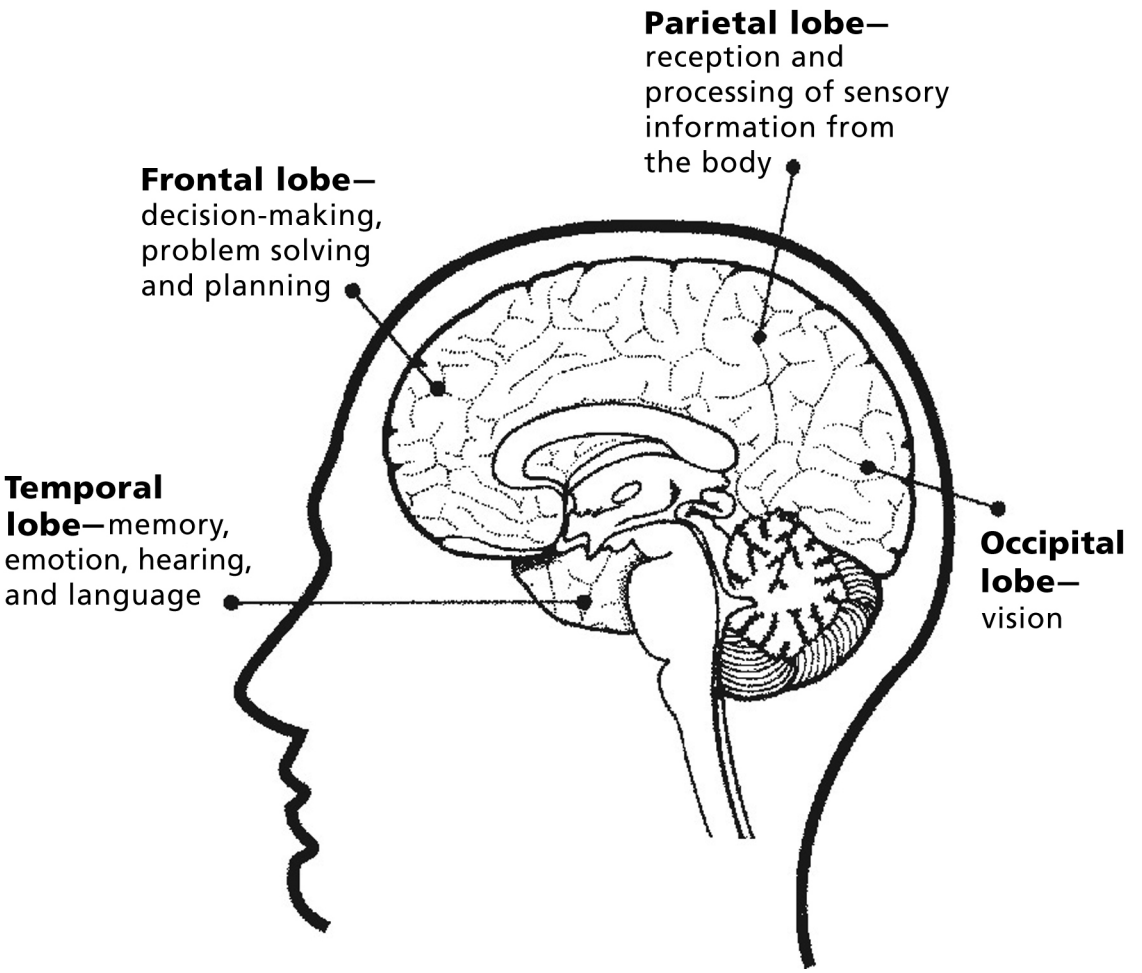
Major Regions of the Brain



Drawing of a brain cut in half, showing the major regions.

Source: National Institute on Drug Abuse (1997). *Mind Over Matter: The Brain's Response to Drugs*, Teacher's Guide.

Areas of the Cerebral Cortex and Their Functions



Drawing of a brain cut in half, showing areas of the cerebral cortex and their functions.

Source: National Institute on Drug Abuse (1997). *Mind Over Matter: The Brain's Response to Drugs*, Teacher's Guide.

What Happened to Phineas Gage?

Name(s)_____ Date_____

Due to an accident while he was working, Phineas Gage made a contribution to the understanding of how the brain works. In 1848, 25-year-old Phineas Gage worked for the Rutland and Burlington Railroad Company laying railroad tracks across Vermont. Before railroad track could be laid, however, the uneven ground needed to be leveled. Gage and coworkers had to drill holes in the stone, put explosive in the holes, cover the explosive with sand, and then use a fuse and tamping iron to trigger an explosion. One day, an accident occurred that changed Gage's life forever. The explosive went off early, sending the tamping iron, which was 1.25 inches in diameter and 43 inches long, shooting into Gage's face, through his skull and brain, and out the top of his head. The tamping iron landed about 25 yards away. Gage regained consciousness within a few minutes. Amazingly, he not only survived the blast, but he was able to talk and to walk! His coworkers took him to the doctor, who cleaned and bandaged the wounds, the standard medical treatment at the time.

Although Gage survived the physical injuries from the blast, he was a changed man. He appeared to be just as intelligent as before the accident, and he did not have any impairment in movement, speech, or memory. But, something was different. Before the accident, he was a responsible, intelligent, and likeable person. After the accident, he was irresponsible, used profanity extensively, and demonstrated no respect for social customs. His friends commented that "Gage was no longer Gage." He could not hold the responsible jobs that he had before the accident and apparently wandered for the next several years. Phineas Gage ended up in San Francisco in the custody of his family, where he died approximately 12 years after the accident.

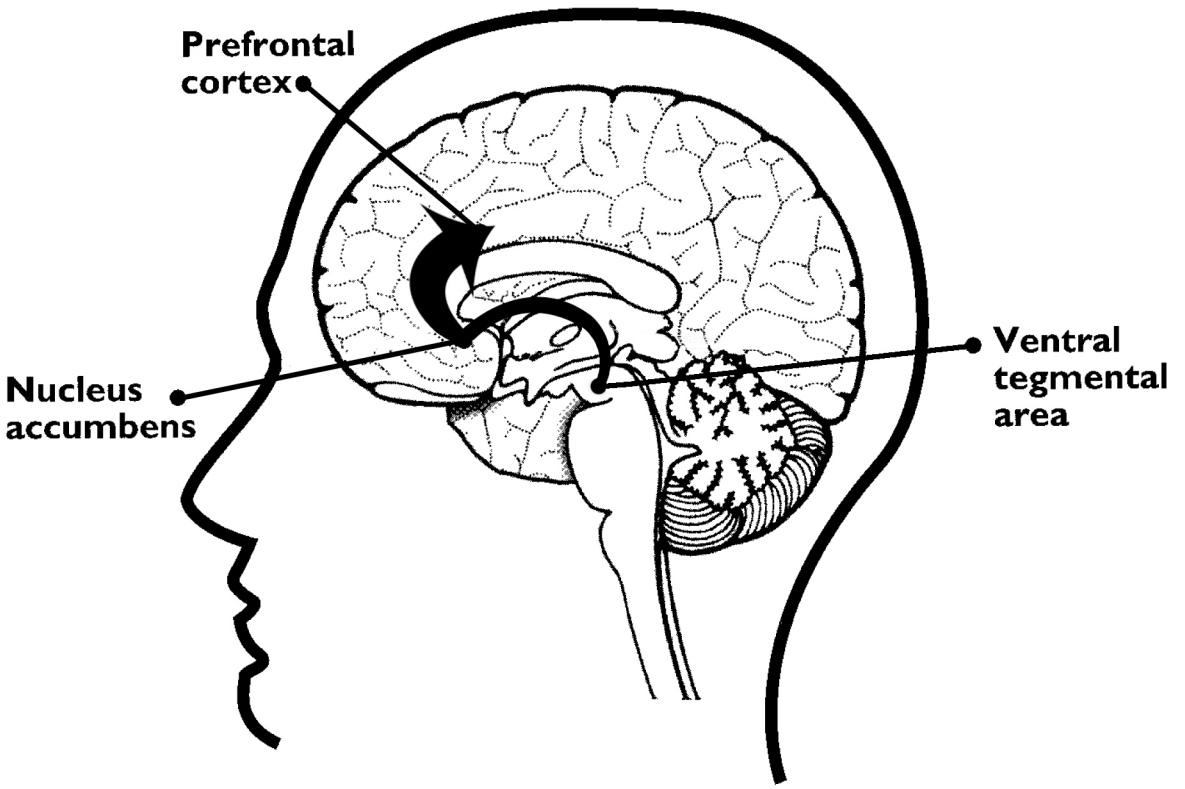
Twenty years after the accident, the physician who treated Gage correlated the behavioral changes with damage to the frontal region of the brain. At the time, the brain was thought to control language and movement, but the suggestion that the brain functioned to process emotions and social behavior was new. In addition, scientists at the time believed the brain lacked localized functions. Unknowingly, Phineas Gage contributed to our understanding of how the brain processes information.

In the 1990s, scientists used their improved understanding of brain function, computer modeling techniques, and new data from Gage's skull. On the basis of this information, they found that the accident damaged both hemispheres of the frontal lobe, which is the part of the brain that influences social behavior. Today, physicians see patients with damage to the frontal lobe that has occurred through motor vehicle accidents, gun accidents, or major falls. These individuals, like Phineas Gage, often have dramatic changes in their emotional and decision-making abilities.

1. How did Phineas Gage change after the accident?

2. How did Phineas Gage's accident change scientists' understanding of the brain?

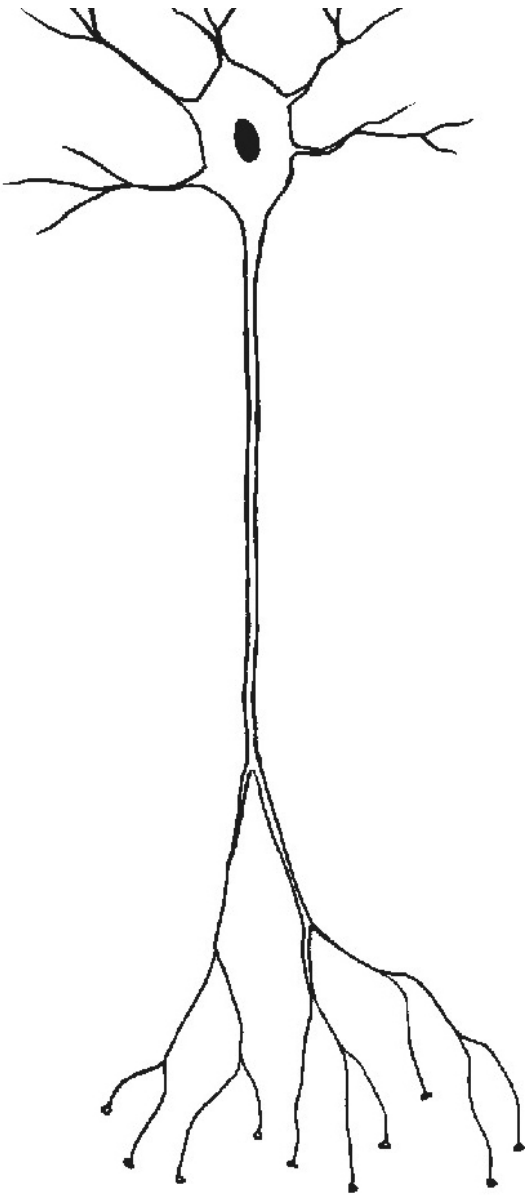
The Reward System



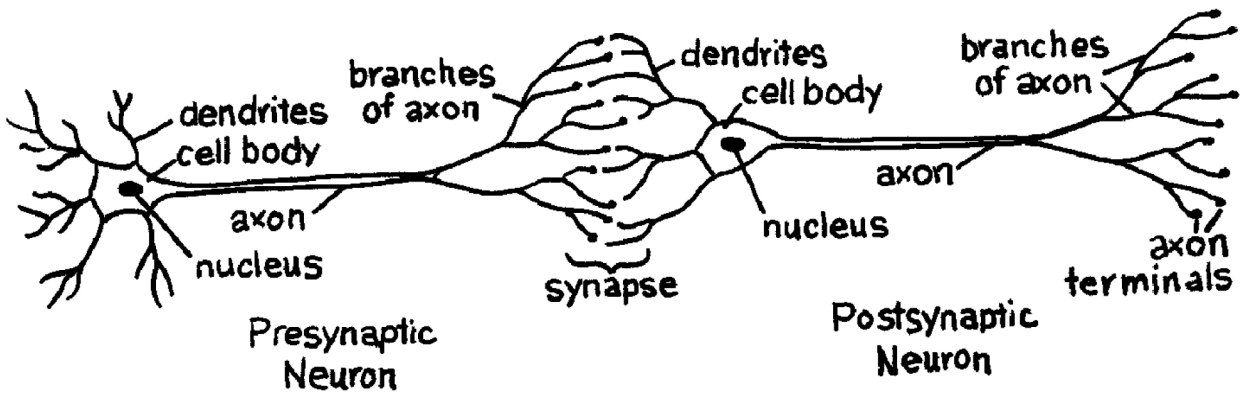
Drawing of a brain cut in half, showing the reward system.

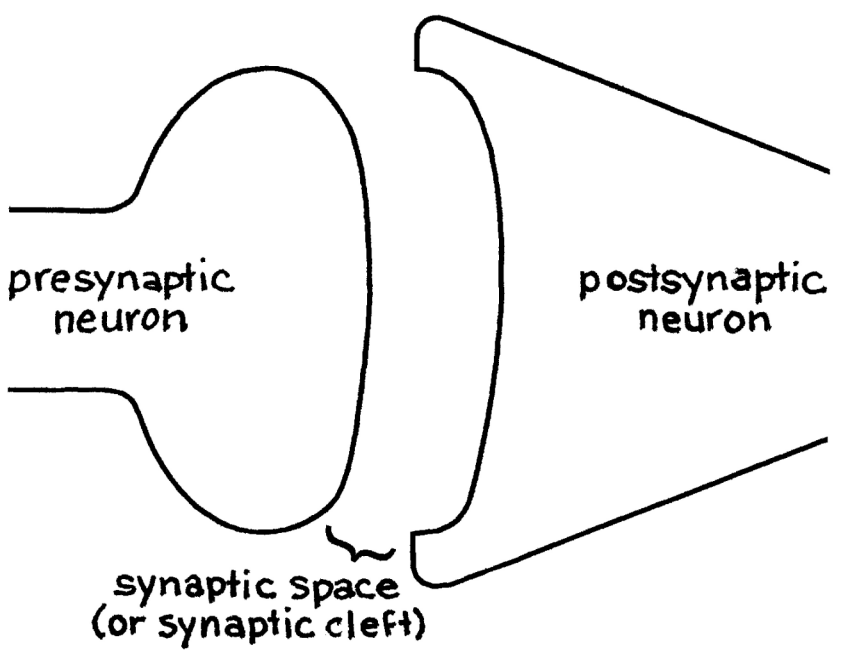
Source: National Institute on Drug Abuse (1997). *Mind Over Matter: The Brain's Response to Drugs*, Teacher's Guide.

Anatomy of a Neuron



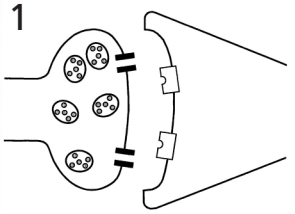
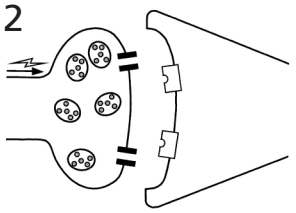
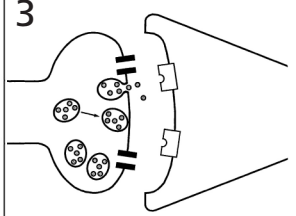
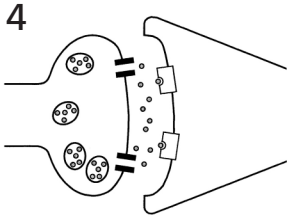
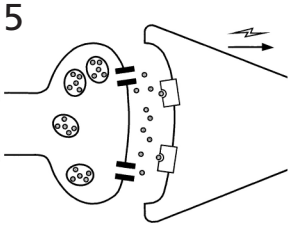
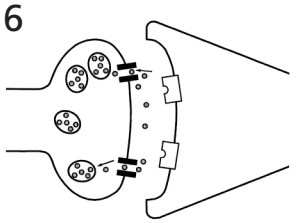
Neurons Interact with Other Neurons through Synapses





How Do Neurons Communicate?

Name(s)_____ Date _____

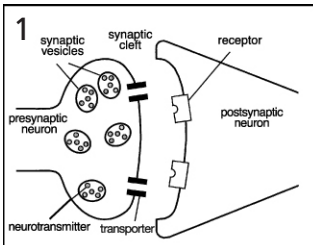
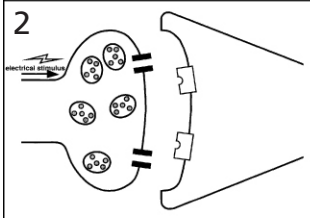
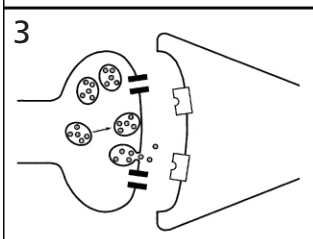
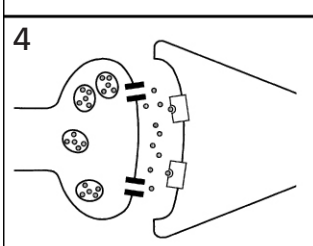
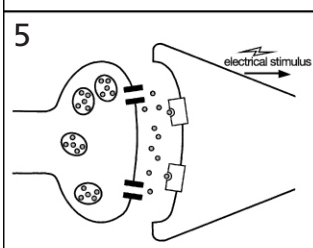
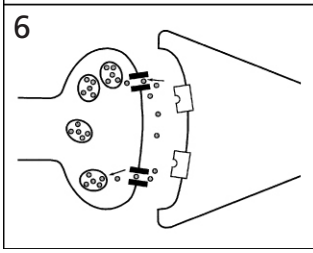
1 	
2 	
3 	
4 	
5 	
6 	

Neurons Communicate by Neurotransmission

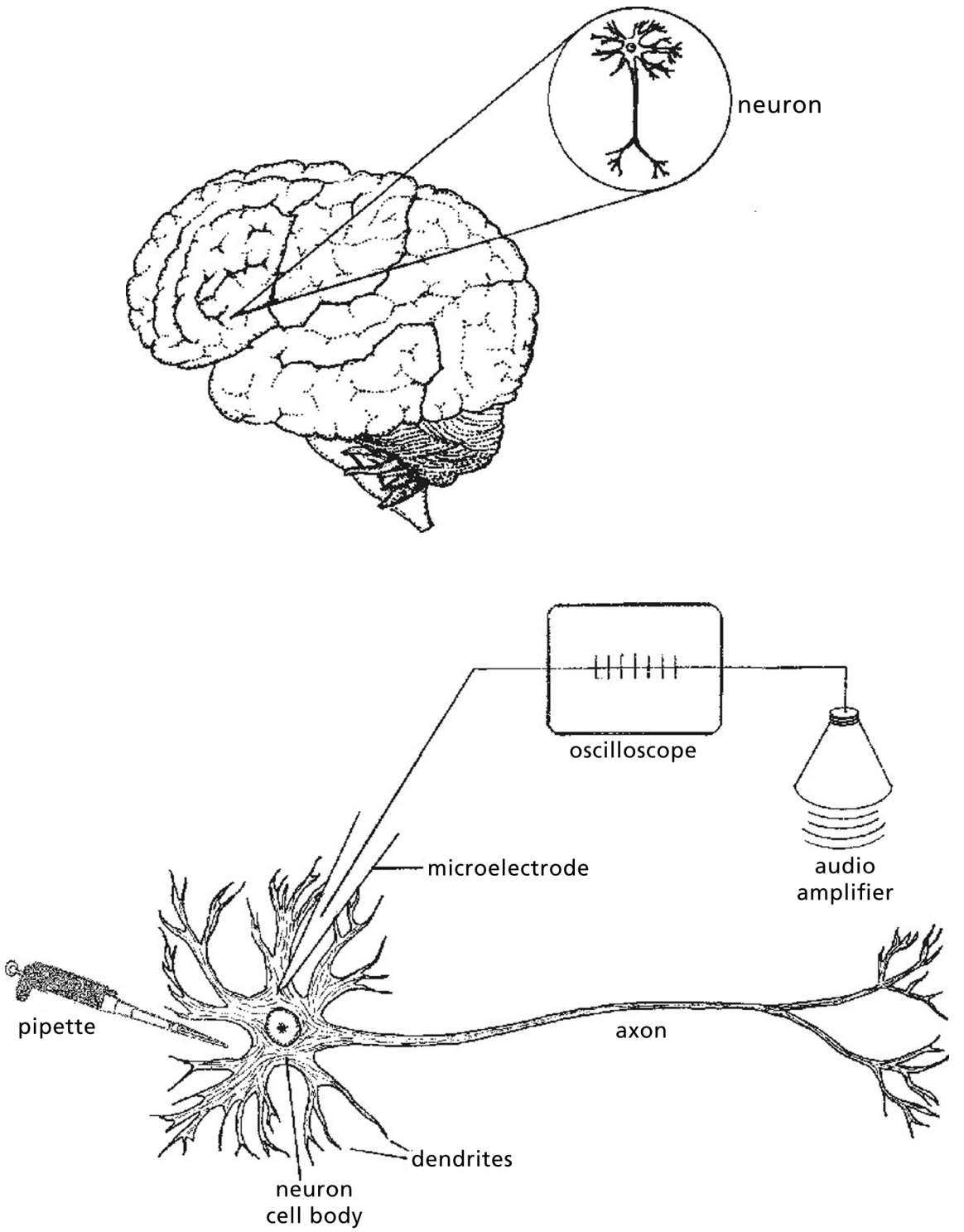
Neurons communicate using both electrical signals and chemical messages. Information in the form of an electrical impulse is carried away from the neuron's cell body along the axon of a presynaptic neuron toward the axon terminals. When the electrical signal reaches the terminal, it cannot cross the synaptic space, or synaptic cleft, to reach the postsynaptic neuron. Instead, that electrical signal triggers chemical changes that can cross the synapse and affect the postsynaptic cell. When the electrical impulse reaches the presynaptic axon terminal, it causes membranous sacs, called vesicles, to move toward the membrane of the axon terminal. When the vesicles reach the membrane, they fuse with the membrane and release their contents into the synaptic space. The molecules contained in the vesicles are chemical compounds called neurotransmitters. Each vesicle contains many molecules of a neurotransmitter. The released neurotransmitter molecules drift across the synaptic cleft and then bind to special proteins, called receptors, on the postsynaptic neuron. A neurotransmitter molecule will bind only to a specific kind of receptor. The binding of neurotransmitter to its receptor causes a change in the postsynaptic neuron that in turn causes that neuron to generate an electrical impulse. The electrical impulse then moves away from the neuron ending toward the cell body of the receiving neuron. After the neurotransmitter binds to the receptor and transmits the signal to the postsynaptic neuron, it comes off, or releases from, the receptor into the synaptic space. Specific proteins called transporters or reuptake pumps carry the neurotransmitter back into the presynaptic neuron. When the neurotransmitter molecules are back in the presynaptic axon terminal, they can be repackaged into vesicles for release the next time an electrical impulse reaches the axon terminal. Enzymes present in the synaptic space degrade neurotransmitter molecules that are not taken back up into the presynaptic neuron.

Neurotransmission

Name(s)_____ Date _____

1 	
2 	
3 	
4 	
5 	
6 	

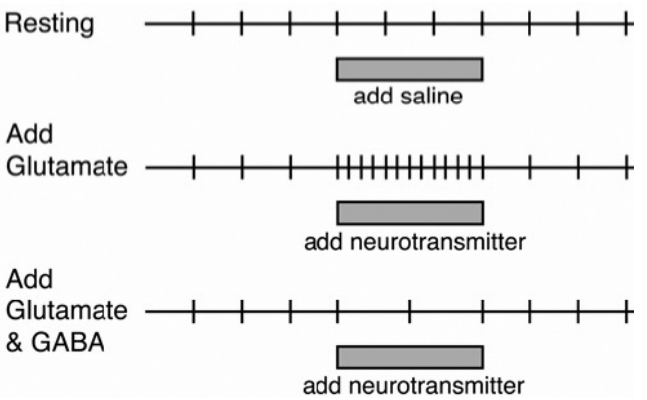
Recording the Activity of a Neuron



Neurotransmitter Actions

Name(s)_____ Date_____

The following diagrams represent recordings of the electrical activity of a neuron over a period of time. Each vertical line on the diagram represents an electrical impulse, or action potential, occurring in the neuron. The first diagram represents a neuron at rest. For the other recordings, a solution containing neurotransmitter was applied to the neuron.



1. **Why is saline applied to the resting neuron?**

2. **When the neurotransmitter glutamate is applied to the neuron, how does its activity change?**

3. **How does the application of the two neurotransmitters, glutamate and GABA, change the activity of the neuron?**

4. **Predict how the activity of the neuron would change if only GABA was applied to the neuron.**

5. **Do all neurotransmitters affect a neuron in the same way?**

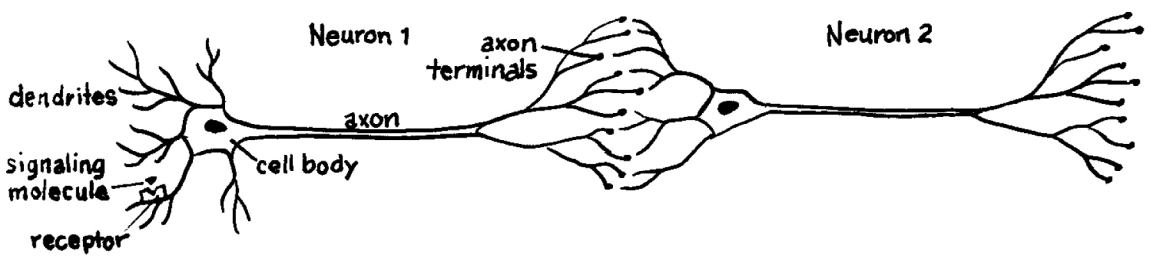
6. **How would the application of glutamate to a neuron change the amount of neurotransmitter released from that neuron? How would the application of GABA to a neuron change the amount of neurotransmitter released from that neuron?**

Neurons in Series

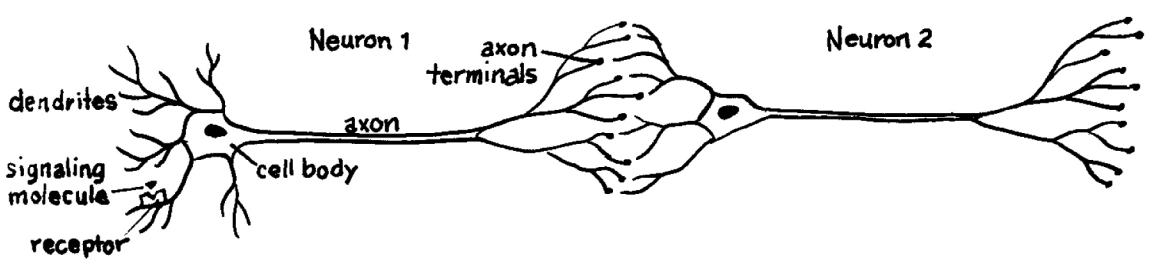
Name(s)_____ Date_____

Using what you have learned about the effects of the neurotransmitters glutamate and GABA, determine how the different signals that affect Neuron #1 can change the release of the neurotransmitter dopamine from Neuron #2. Use the chart to help you work through the cases. You can use a down arrow to indicate a decrease or an up arrow to indicate an increase.

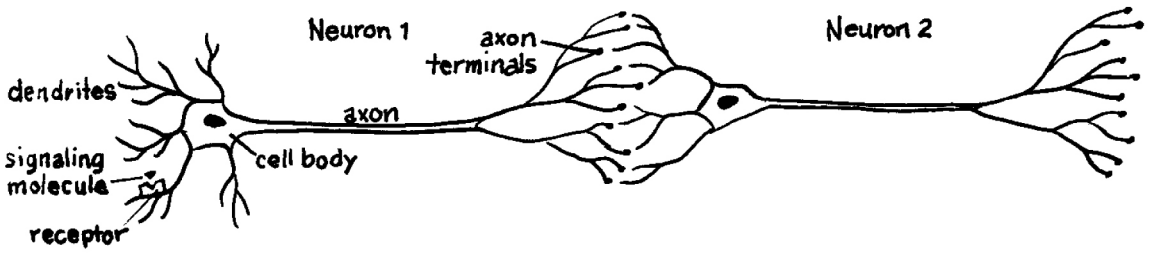
A. The signaling molecule is inhibitory. Neuron #1 releases glutamate as its neurotransmitter. Neuron #2 releases dopamine as its neurotransmitter.



B. The signaling molecule is excitatory. Neuron #1 releases glutamate as its neurotransmitter. Neuron #2 releases dopamine as its neurotransmitter.



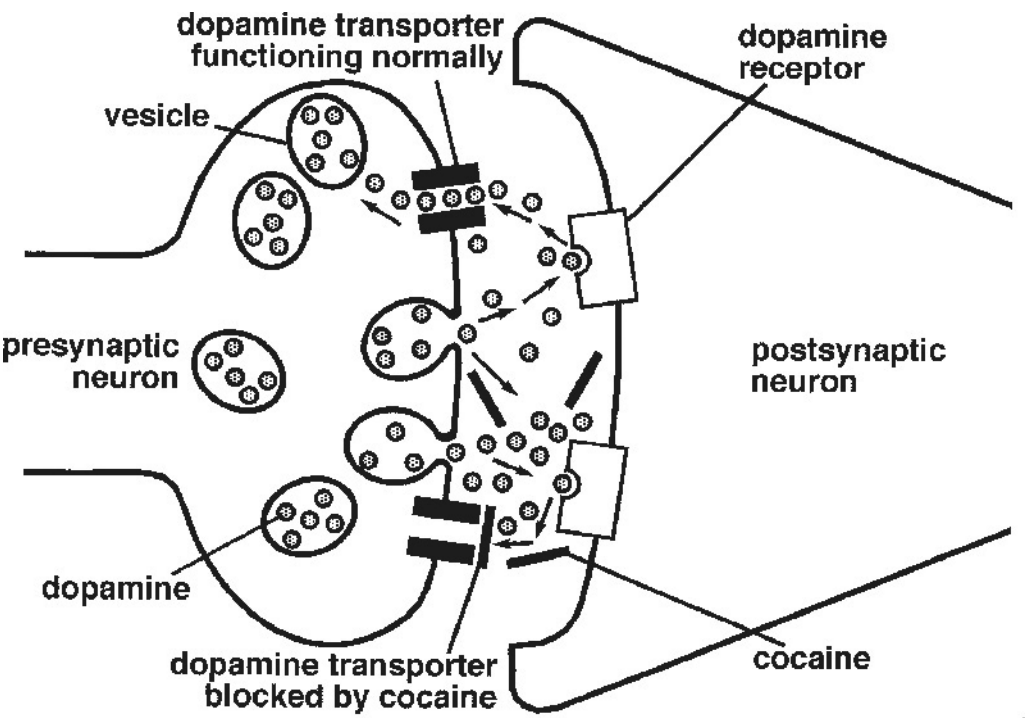
C. The signaling molecule is inhibitory. Neuron #1 releases GABA as its neurotransmitter. Neuron #2 releases dopamine as its neurotransmitter.



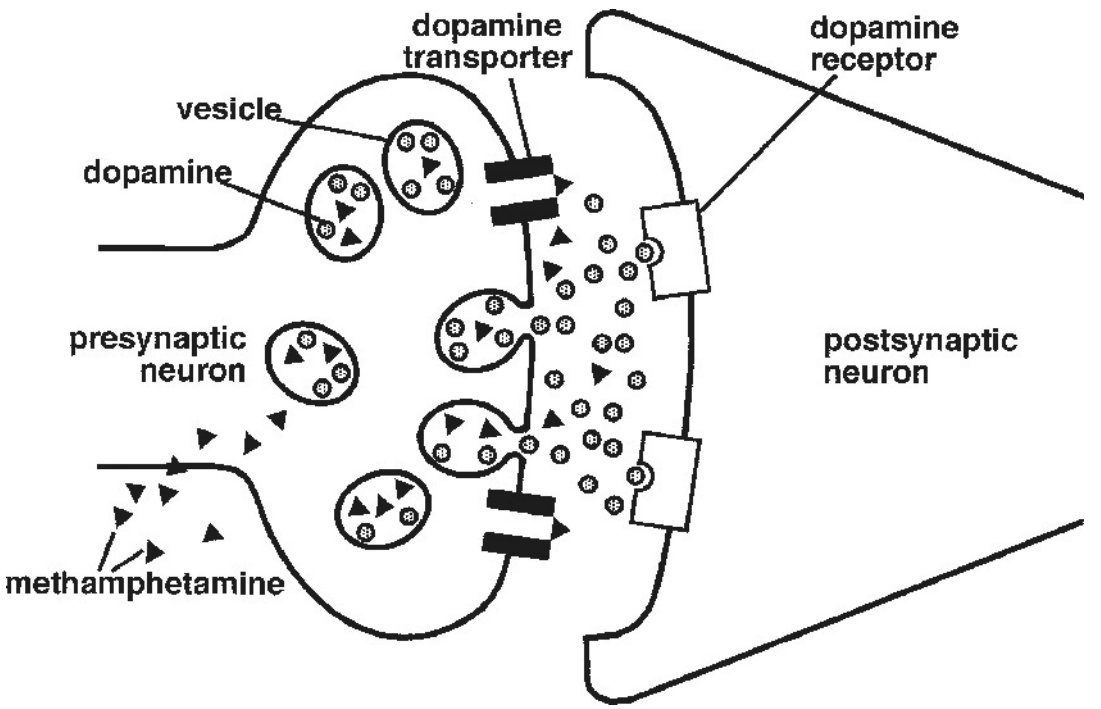
D. The signaling molecule is excitatory. Neuron #1 releases GABA as its neurotransmitter. Neuron #2 releases dopamine as its neurotransmitter.

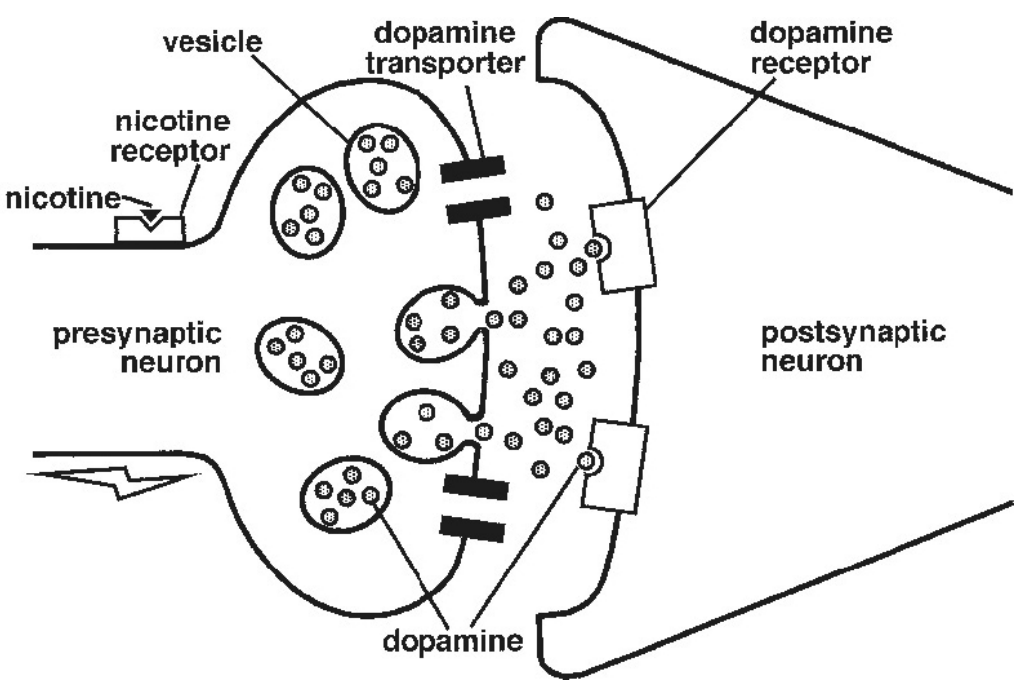
Case	Does the signal molecule excite or inhibit Neuron #1?	Does the activity of Neuron #1 increase or decrease?	Does the amount of neuro-transmitter released from Neuron #1 increase or decrease?	What is the name of the neuro-transmitter released from Neuron #1?	Is the neuro-transmitter released from Neuron #1 excitatory or inhibitory?	Does the activity of Neuron #2 increase or decrease?	Does the amount of dopamine released from Neuron #2 increase or decrease?
A							
B							
C							
D							

Cocaine Alters Neurotransmission

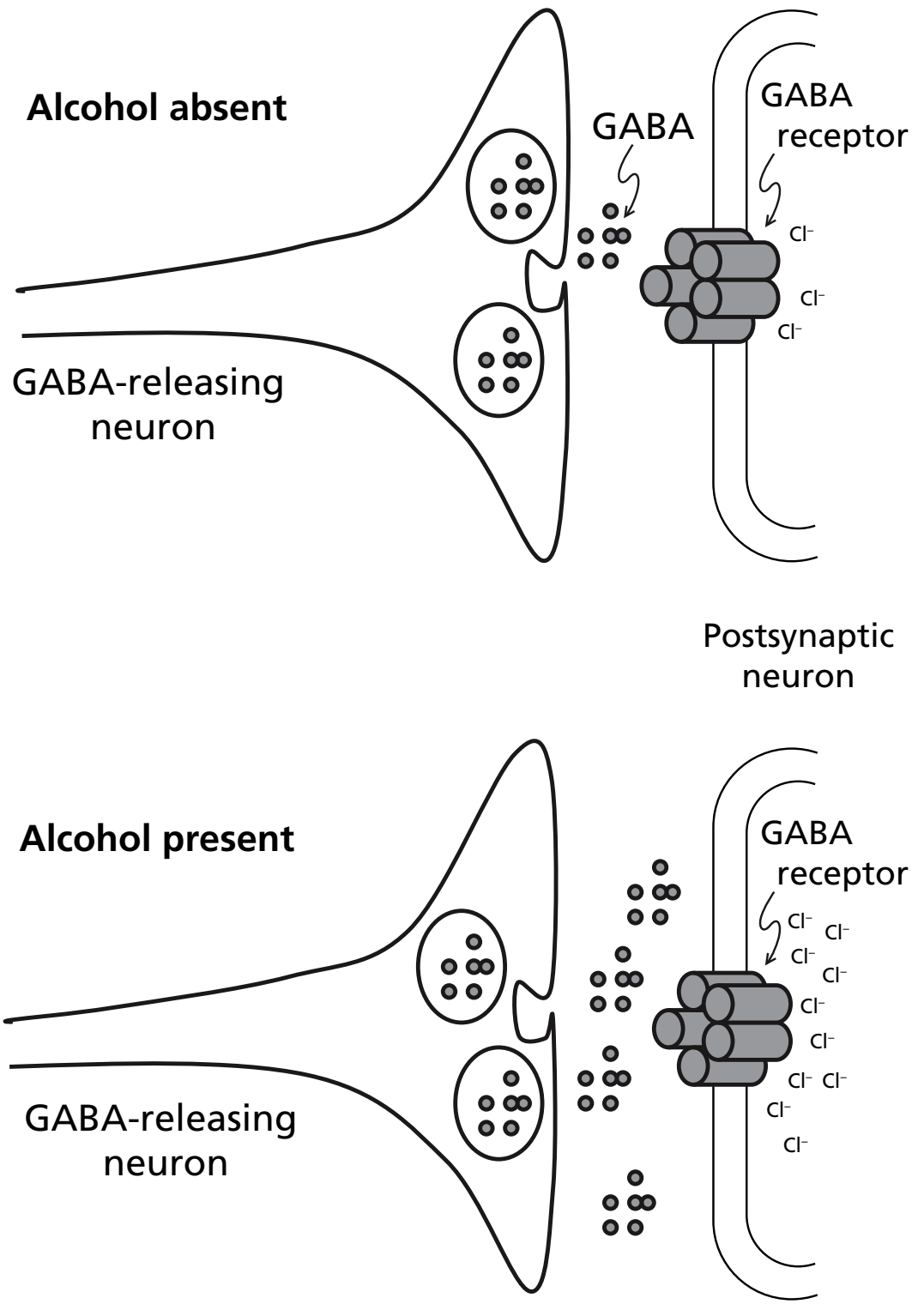


Methamphetamine and Nicotine Disrupt Neurotransmission





How Does Alcohol Affect Neurotransmission?



Parent Letter

Dear Parents,

Next week in biology class, we will investigate the effect of caffeine on the body. Each student will need to bring in a 12-ounce can of _____. Please provide one can labeled with your child's name and class period.

During the activity, students will consume 12 ounces of the above-specified soft drink and measure what effect it has, if any, on their heart rates.

Students are not to bring in any soft drink other than the one specified. Because the different brands and flavors vary in their caffeine content, it is important that all students consume the same brand.

Students who choose not to bring in a soft drink, or those without signed permission forms, can participate in the activity by drinking 12 ounces of water. They will be an important part of the activity by serving as "controls."

Thank you for your continued support.

Teacher's Signature

My child, _____, has permission to participate in the caffeine activity in class and will bring in a 12-ounce can of _____ to consume as part of the activity.

My child, _____, has permission to participate in the activity in class and will bring in a 12-ounce can of caffeine-free _____ to consume as part of the activity.

My child, _____, will not drink a 12-ounce soft drink during the activity, but will participate by drinking 12 ounces of water.

Parent's or Guardian's Signature: _____

Date: _____

Caffeine: How Does Your Heart Respond?

Name(s)_____ Date_____

MATERIALS FOR EACH TEAM

2 cans of soft drink (caffeinated or caffeine-free)
1 watch or classroom clock with a second hand

PROCEDURE

Do Steps 1 to 3 with your teacher.

1. When your teacher directs you to do so, find your pulse. You can find it most easily by pressing two fingers against the artery in your neck or on the inside of your wrist. Practice counting the beats.

2. When your teacher directs you to start, count the number of beats you feel in 15 seconds. Your teacher will tell you when to stop. Record the number in the data table on the next page.

3. Multiply the number of beats you counted in 15 seconds by four to calculate your resting heart rate in beats per minute.

Complete the rest of the activity with your partner.

4. Predict what you think might happen to your heart rate after you drink a caffeinated soft drink. What might happen after drinking a caffeine-free soft drink? Write your predictions here:

5. At the same time as your partner, drink your can of soft drink. Write down the time when you started drinking it. For best results, try to drink it quickly, taking less than 10 minutes to finish the can. Write the type of soft drink at the top of the data table on the next page.

6. Watch the time. Sit quietly for 5 minutes. You can talk softly with your partner or read, but keep your body still so that you will not change your heart rate due to activity.

7. After 5 minutes, have one partner measure his or her pulse rate for 15 seconds. Record the number of beats in the data table. The other partner should be the timer, saying "Start" and then "Stop" when the 15-second period is over. Now the partners should switch roles.

8. Continue to take pulse rates every 2 minutes until you have measured your heart rate at least 10 times. Record each measurement in the data table.

9. Use the data that you collected to calculate your heart rate in beats per minute.

Name of Drink: _____		Type (circle one): Caffeinated or Caffeine-Free	
Time (minutes after drinking soft drink)	**Heartbeats counted in 15 seconds**	**Multiply by 4**	**Heart rate (beats per minute)**
0 (resting heart rate)		x 4	
5		x 4	
7		x 4	
9		x 4	
11		x 4	
13		x 4	
15		x 4	
17		x 4	
19		x 4	
21		x 4	
23		x 4	
25		x 4	
27		x 4	
29		x 4	
31		x 4	
33		x 4	
35		x 4	

Difference between resting heart rate and the highest heart rate after drinking the soft drink: _____

Number of minutes after finishing the drink when the heart rate reached its peak: _____

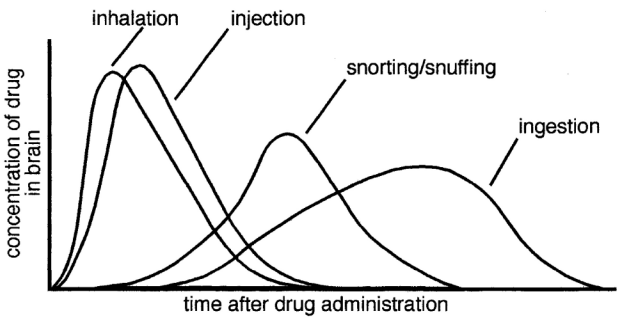
Number of minutes after finishing the drink when the heart rate returned to resting rate: _____

Could you drink some amount of caffeinated soft drink without any effect on your heart rate? What would happen if you drank a large amount of caffeinated soft drink? Design an investigation to determine how the amount, or dose, of caffeine affects your heart rate.

How Do Drugs Get Into the Brain?

Name(s)_____ Date_____

Use the information in the graph below to help you answer the questions.



1. Four people who abuse drugs each take a drug. One person injects 100 milligrams (mg) of it into a vein, one person smokes 100 mg, one person snorts 100 mg, and one person swallows or ingests 100 mg. Who will experience the greatest effect of the drug? The individual with the greatest concentration of drug in the brain will have the greatest effect.

2. Who will experience the quickest effect from the drug?

3. Who will experience the least behavioral effect from the drug?

4. Who will experience the slowest effect from the drug?

5. Tobacco smokers can use nicotine patches to help them quit smoking. The nicotine patches help the smoker slowly lower the amount of nicotine that enters the body. How does the nicotine in the patch enter the body?

6. Explain why the different ways of taking drugs cause different behavioral responses.

What Should the Doctor Do?

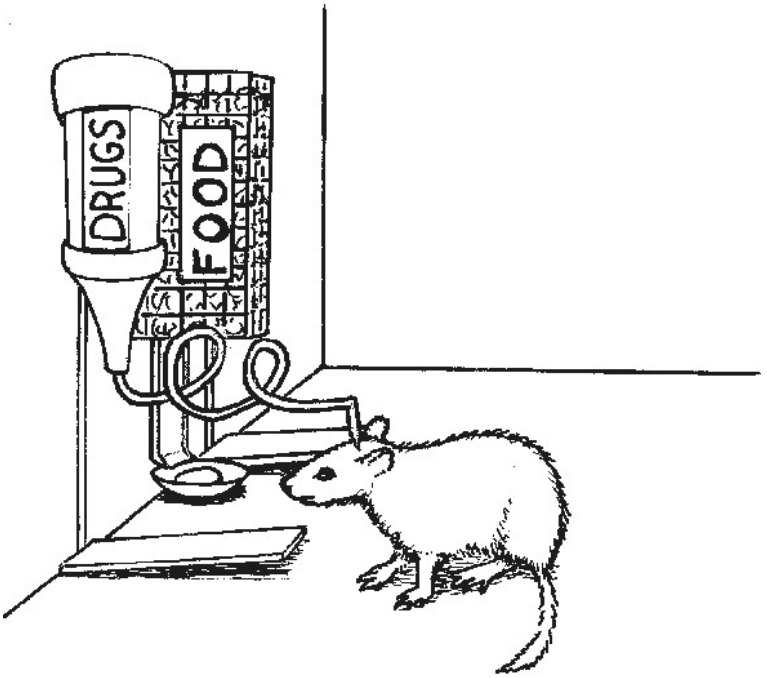
A teenage boy is brought into the hospital emergency room after a skateboarding accident. He complains of pain in his left leg. The doctor orders an X-ray of his leg, which reveals a fracture in the tibia. Before the doctor can set the fracture and put a cast on the boy's leg, he needs to relieve the patient's pain. The doctor prescribes morphine.

On the basis of what you have learned about how drugs act in the body, how should the morphine be given to the patient? Should the morphine be given as a(n):

- pill
- shot
- inhalant

Consider each alternative and explain why the doctor should choose one method over another.

Data for Rat Self-administration Experiment



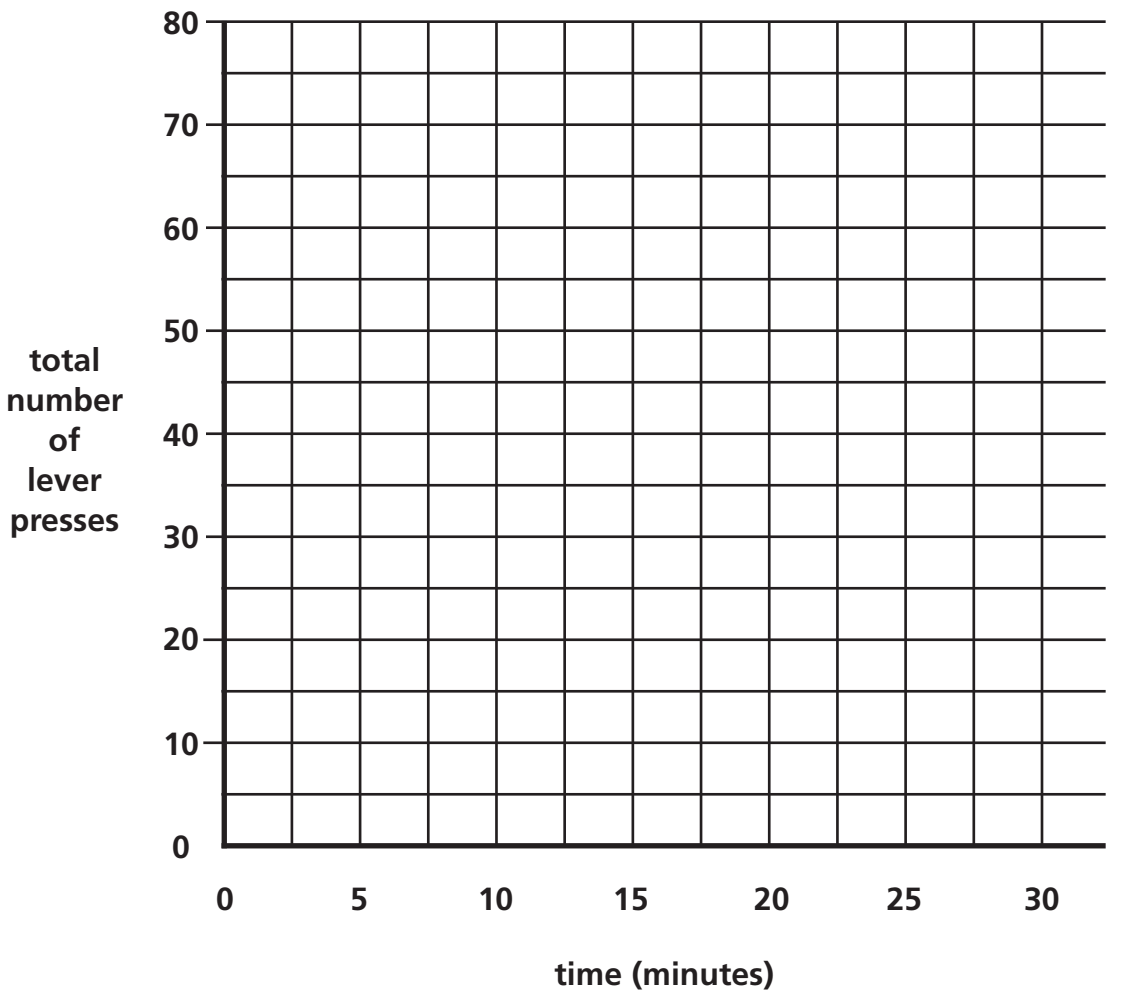
Total number of lever presses							
Rat	**Lever**	**5 minutes**	**10 minutes**	**15 minutes**	**20 minutes**	**25 minutes**	**30 minutes**
A	**Stimulus**	2	7	12	29	52	73
	Food	1	3	4	6	6	6
B	**Stimulus**	1	3	3	4	6	7
	Food	2	4	5	8	9	12
C	**Stimulus**	1	6	13	26	49	70
	Food	1	1	2	4	4	4
D	**Stimulus**	1	2	2	4	4	4
	Food	2	3	5	6	8	11

Worksheet for Rat Experiment Data

Name(s)_____ Date_____

Plot the data for one of the rats in the experiment in the graph below. Plot the data for the stimulus lever using a colored pencil and the data for the food lever with another color.

Rat: _____



Evaluating the Experiment

Name(s)_____ Date_____

1. Why do the rats press a lever the first time?

2. Compare the lever-pressing behaviors of the four different rats. Which rat pressed the stimulus lever the most? Which one pressed the stimulus lever the least? Which rat pressed the food lever the most? Which one pressed the food lever the least?

3. Rat A was injected with cocaine each time it pressed the stimulus lever. Can you use this fact to explain why Rat A behaved the way it did?

4. On the basis of the data you analyzed, do you think Rat B was injected with cocaine when it pressed the stimulus lever? From what you have learned so far in this unit, do you think Rat B was injected with a different addictive drug when it pressed the stimulus lever? Why?

5. Do you think Rat C received cocaine when it pressed the stimulus lever? Why?

6. Rat C did not receive an injection of cocaine when it pressed the stimulus lever. When Rat C pressed the stimulus lever, it received a mild electrical stimulation in the brain. From what you have learned, can you predict what part of the brain was stimulated?

7. Rat D also received a mild electrical stimulation in the brain when it pressed the stimulus lever. Do you think the same part of the brain was stimulated in Rat D as was stimulated in Rat C? Why?

8. Why did Rats A and C press the stimulus lever more than the food lever?

9. Why did Rats B and D press the food lever more than the stimulus lever?

10. Why did the scientists who conducted this experiment include Rats B, C, and D in this experiment? How did the data from those rats help scientists understand more about how cocaine acts in the brain?

11. Do you think that Rats A and C will stop pressing the stimulus lever if they continue to receive the same stimulation each time they press it? Why?

12. On the basis of what you learned from these data, what might this investigation tell you about drug use by humans? Explain your view.

Playing the Game

1. Each person draws one card from the small pile of cards. Place it face up in front of you. This is your switch card. Set the rest of the cards in the short deck aside. You won't need them again.

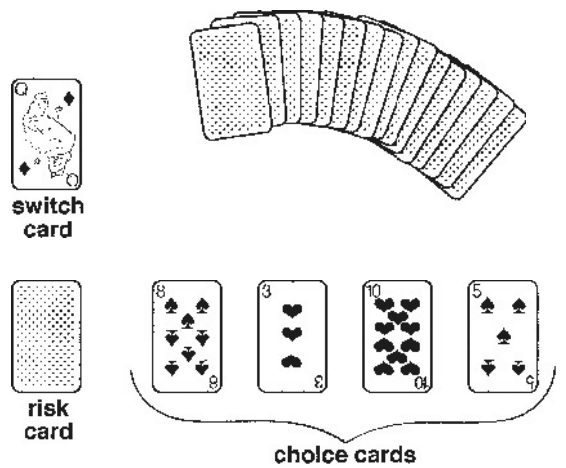
    - If you drew a jack, your switch value is 25.
    - If you drew a queen, your switch value is 35.
    - If you drew a king, your switch value is 45.

2. Draw a card face down from the larger pile that contains aces and the number cards. **Don't look at this card**. Place it face down below your switch card. This is your risk card.

3. Draw cards from the large pile and place them face up next to the risk card. These are your choice cards. Draw as many choice cards as you wish, but keep in mind that you do not want the total of these cards plus the risk card to equal or go over your switch value.

    - An ace = 1 point
    - Other cards = the number on the card

4. When you have finished drawing cards, turn over the risk card. Did you match or go over your switch value?



Who Is Addicted?

Two people have been using morphine. Chris has been taking between 50 milligrams (mg) and 500 mg each day for a year. Pat has been taking 100 mg each day for six months. Only one of these individuals is addicted to morphine.

- Who do you think is addicted to morphine? Explain your answer.

Pat is addicted to morphine.

- Can you think of any reasons to explain why Pat is addicted even though Chris has been taking a much higher dose for a longer period of time?

Pat has been living on the streets for a year after losing a job. When the savings ran out, Pat couldn't afford the rent for an apartment any longer and couldn't afford to keep a car. Pat became really depressed. When another homeless person offered some morphine, Pat thought the drug might help make the problems of life go away. For the past six months, Pat and friends have been shooting up with morphine once each day.

Twelve months ago, Chris was in an accident and received third-degree burns over 30 percent of the body. While in the hospital undergoing treatment, the pain was very intense. The doctors prescribed morphine that Chris could self-administer to control the pain. After all, morphine is one of the most effective pain-relief medicines available. At first, 50 mg of morphine each day would ease the pain. Later, however, Chris needed as much as 500 mg a day to ease the pain. Chris may need a dose of morphine 12 times each day.

Long-Term Effects of Drugs on the Brain

So, why are drugs so bad? After all, the high or rush only lasts a little while, right? What else could be happening in the brain of a person who abuses drugs? Consider that the brain is continuously changing. After all, learning occurs because neurons are forming new synapses. Scientists say that the brain is plastic and call this "neuroplasticity." That doesn't mean the brain is made of a chemical plastic like a credit card, but it refers to the brain's ability to modify connections in response to experience. When a person learns something or has new experiences, some new synapses may form or existing synapses may get stronger. Other synapses may disappear.

When a person takes drugs repeatedly, the brain changes in response to this experience. If a person takes drugs and then stops, he or she will crave the drug. In other words, the individual will have a strong desire to take more of the drug. Scientists can actually see evidence of cravings in the brain. If someone addicted to cocaine sees pictures of drug paraphernalia, PET scans show that a part of the brain that is important for emotional memory (called the amygdala) is activated, and the person reports feelings of drug craving. If he or she sees a video with mountains, trees, and animals, the amygdala is not stimulated. Thus, just seeing pictures of drugs or things associated with drugs can trigger an uncontrollable urge for drugs.

After taking drugs for a period of time, a person may need to take a higher dose of the drug to have the same experience that he or she did when first taking the drug. This is called tolerance. The brain has adapted to having a certain amount of drug present and does not respond the same way it did initially. That is why people who abuse and who are addicted to drugs take increasingly higher amounts of an abused drug. Tolerance may develop because the body may become more efficient at eliminating the chemical from the body, or because the cells of the body and brain become less responsive to the effect of the drug.

Scientific studies have shown clearly that certain drugs can cause dramatic changes in the brain, but not all questions have been answered. Drugs can change the structure of the brain. Perhaps one of the most dramatic long-term effects of a drug is to kill neurons. Many people have heard that drinking alcohol will kill brain cells. It's true. If alcohol is abused over a period of time, neurons in the brain can die. Some neurons in the brain are more sensitive to alcohol than others. Neurons that make up the mammillary bodies (small round structures on the brain's undersurface) and hippocampus, areas in the brain that are important for memory, are more vulnerable to the effects of alcohol than are some other neurons in the brain. The neurons in the cerebral cortex, the part of the brain that controls most of our mental functions and endows us with consciousness, may also die if a person frequently abuses alcohol in high doses.

Another drug that can be toxic to neurons is an amphetamine derivative called MDMA, or ecstasy. In rats and nonhuman primates, MDMA damages the axon terminals of neurons that release serotonin, a neurotransmitter that is involved in regulating appetite, sleep, emotions, and so on. In some parts of the brain, the axons of some of these neurons may regenerate (or re-grow) after drug use is stopped, but the new growth of the neurons is not normal. Some areas are not reinnervated (nerve fibers do not grow back into the area), and some areas have abnormally high regrowth of the neurons. Either way, the neurons do not look normal. Studies have not yet been able to determine whether MDMA has this same effect on humans.

Cocaine also changes the brain in ways that may last for a long time. PET scans of human brains have shown that glucose metabolism is reduced even three months after the last use of cocaine. Remember that glucose metabolism is an indicator of how active the brain cells are. If the neurons are using less glucose in certain areas, they are not as active. The changes that cocaine causes in the brain last much longer than the pleasurable feelings it produces. Other drugs cause similar decreases in brain activity. Even two years after the last use of amphetamines, PET images show that the brain of a person who has abused drugs is less active than the person's who never used drugs.

Scientists, for many reasons, don't know all of the effects that a drug has. First, the brain is such a complicated organ that, despite great scientific advances, understanding all that it does will take many more years. Second, individuals may respond differently to drugs due to genetic and other differences among people. Third, many people who abuse drugs abuse more than one drug. Many individuals who take cocaine, for example, also drink alcohol. The combination of the drugs makes it difficult to determine what the effect of one drug alone may be. Another complication is that people addicted to drugs may have other health problems in addition to their drug problem. People addicted to heroin, for example, spend most of their energy and activity trying to get their next "fix." Consequently, they do not eat well and may have impaired immune systems. Also, drug-addicted people often suffer from mental illnesses, such as depression. The changes that occur in the brain because of mental illness make it difficult to determine what changes the drugs have caused.

The brain is an incredibly complex organ. This complexity will keep scientists working for many years to understand how the brain works. Someday, scientists will answer questions about what happens in the brain to cause addiction, which will then help scientists understand how to prevent addiction.
On a separate sheet of paper, answer the following questions:

1. What are some of the ways that drugs cause long-term changes in the brain?

2. How does the brain adapt to the presence of drugs?

3. How may the abuse of drugs relate to the plasticity of the brain?

4. What are some problems that scientists have when they investigate the effects of drugs on the brain?

Ruth's Story

Ruth is 24 years old and has a good job and a boyfriend. Everything seems to be going well in her life. But it hasn't always been that way. When she was 14 years old, her friends began smoking cigarettes and drinking alcohol. Because she wanted to be part of the group, she also began smoking and drinking when she went to parties with her friends. One night when Ruth was 16, her friends had some marijuana and they all tried smoking it. After using marijuana for about a year, she began experimenting with other drugs and, by the time she was 18, Ruth was using heroin every day. Her drug habit was costing her $75 a day. After a while, her boyfriend left her, and the rest of her friends were tired of her asking for money to buy drugs. She was fired from her part-time job because she had missed work so many times. She was arrested several times for shoplifting items from local department and discount stores. She tried to quit using heroin several times, but she had strong cravings for the drug. Each time she began having symptoms of withdrawal, Ruth went back to abusing drugs.

When Ruth was 20, her brother convinced her to go to a drug rehabilitation center. The doctors at the center began treating her with methadone, and she participated in group behavioral treatments. She followed her treatment exactly as the doctors prescribed and, after six months, Ruth thought she had beaten her addiction. She enrolled in college and made new friends. Her friends got her involved in sports, and Ruth found that she enjoyed running. She even competed in a 10K run. She continued her methadone treatment and saw her therapist every two months.

When she was 22, Ruth was under a great deal of stress when she took on a new part-time job in addition to her school work. She ran into her old high school friends at a party and did some heroin with them. She thought she could handle it. Over the next couple of months, however, she quit her methadone treatment and began doing heroin more frequently, every couple of days. She was beginning to isolate herself from her friends and was having trouble at work. Ruth was scared. She called her doctors, and they started her treatments again. With her doctors' help, Ruth realized that she needed to continue her medication and her counseling.

Mike's Story

Mike grew up an active boy who loved participating in sports. When he was 14, he was diagnosed with Type I diabetes. Mike learned how to measure his blood glucose levels before meals and give himself insulin injections based on his blood glucose level. He also learned how he should change his diet. Mike learned what types and amounts of foods he could eat and how he should schedule the time interval between meals. But, actually making these changes was very difficult for him. After discussions with the family doctor, Mike and his family decided he would spend six weeks at a summer camp for teenagers who have diabetes. While at camp, Mike ate the correct diet and learned how other kids cope with their diabetes. He even made several friends there.

After he got home, Mike often e-mailed his friends from camp and they would talk about school, sports, and how diabetes changed their lives. Mike's life was pretty normal for a teenager—school, sports, friends. He found that as long as he regulated his blood glucose levels, he could do most of what he wanted. When he was 16, he got his driver's license. On weekends, he would sometimes forget his diet and eat hamburgers, french fries, and sodas with his friends. Because he only had a minor problem the first time he did this, he continued to ignore his diet when he was with his friends.

One Saturday night, Mike's parents had to take him to the emergency room because his blood sugar level was over 600. Although this scared him, he recovered. After a few weeks, though, he went back to eating whatever he wanted instead of the proper diet, especially if he was with his friends. Mike only checked his blood glucose level if he thought he might have a problem. He ended up back in the hospital several more times that year. His grades fell from As to Cs because he could not keep up with the work. He had trouble concentrating and was tired a lot. He and his parents argued all the time about Mike's failure to eat a healthy diet.

The last time Mike went into the hospital, the doctor warned him that he was at risk for permanent health problems if he didn't control his blood glucose level: he could have kidney failure or could go blind. Mike's doctor recommended a specialist who could help Mike learn to cope with diabetes and still maintain an active social life. Mike's family also talked to the specialist to learn how they could help him. For the past four years, Mike has been able to control his blood sugar levels and has only had two minor episodes.

Carol's Story

Carol is the mother of two high school students. Although she is only 42 years old, her doctor has told her that she has high blood pressure, or essential hypertension. On one visit to her doctor, her blood pressure was 160/105. When her doctor checked her blood pressure again on another day, her blood pressure was 150/95. Her doctor prescribed medicine to lower her blood pressure and told her to watch her diet and to begin exercising. The doctor also told Carol that she needed to be very careful in controlling the amount of salt that she ate in her diet.

Carol followed the doctor's plan for about six months. Gradually she started skipping her exercise sessions and gave up making healthy eating choices. Carol had a difficult time skipping the potato chips and peanuts that she liked to eat for an afternoon snack. Often she forgot to take her medication. At her next appointment, Carol and her doctor discussed the problems she was having, and the doctor informed her that her blood pressure had actually gone up. The doctor talked to her about getting advice from a nutritionist, working with a personal trainer to help her establish an exercise plan, and seeing a psychologist who could help her make the needed changes. Carol decided that she didn't need help from those people and tried again to diet and exercise on her own. But, with her long hours at work and her family to take care of, she found it difficult. Because she was missing work more often, Carol's boss gave a promotion to someone else instead of her. Carol's kids complained that she didn't come to their football games and band concerts anymore.

One night, Carol complained that she was having another headache and her vision was blurry. Her kids commented that she was slurring her words when she spoke. Her husband immediately called an ambulance to take her to the emergency room. Carol received medical help in time, but the doctors told her that she had a mild stroke.

Disease Reference Information

HEROIN ADDICTION

The following information is drawn from the NIDA Research Report Series, Heroin: Abuse and Addiction (*http://www.drugabuse.gov/ResearchReports/Heroin/Heroin.html*).

What is heroin?
Heroin is a member of the opioid family of drugs and is derived from morphine. In the brain, heroin is changed back into morphine. Because heroin enters the blood and reaches the brain more quickly than morphine, people who abuse or are addicted to heroin often abuse heroin instead of morphine. Heroin is a white powder that is most often dissolved in saline and injected into the bloodstream, but it can also be snorted (sniffed) or smoked.

What does heroin do in the body?
After taking heroin, the person who abuses drugs experiences a "rush," the intensity of which depends on the amount taken and how it was taken. The rush is accompanied by a warm flushing of the skin, dry mouth, and a heavy feeling in the extremities, which can be accompanied by nausea, vomiting, and severe itching. Heroin blocks pain messages transmitted from the body. After the initial effects, the person will be drowsy for several hours. Mental function is clouded by heroin's effect on the nervous system. Cardiac functions slow; breathing is also severely slowed, sometimes to the point of death. Overdose is a particular risk because the amount and purity of the drug cannot be accurately known.

Treatment for heroin abuse and addiction
The first step in treatment is detoxification to rid the body of the drug. During detoxification, patients can be managed with medications until their bodies adjust to a drug-free state. This stage is short-term and needs to lead to a long-term treatment plan.

Methadone is a synthetic opioid that blocks the effects of heroin and eliminates withdrawal symptoms. Methadone binds to the same opiate receptor that morphine does (remember that heroin breaks down into morphine in the brain). Methadone, however, binds to the receptor more tightly than heroin. People usually take methadone orally one time each day to suppress cravings and withdrawal symptoms for 24 to 36 hours (four to six times longer than heroin). Methadone is not intoxicating or sedating and does not produce the feelings of euphoria that heroin does, unless taken in very high doses. Some people take methadone continuously for many years without problems. Methadone maintenance treatment is provided in specialized opioid treatment programs that patients must attend regularly (daily) in order to get their required dosage. These clinics often provide comprehensive social and other rehabilitation services.

Buprenorphine is a more recent alternative for the treatment of opiate addiction that offers several advantages over methadone, including the ability of qualified physicians to prescribe it in an office setting. Buprenorphine is a long-acting *partial* agonist that also acts on the opiate-receptor targets of heroin and morphine, but it does not produce the same intense high or dangerous side effects. These properties also make it a good potential treatment for addiction to opiate analgesics.

Buprenorphine comes in two formulations, one of which includes a small amount of naloxone, an opioid antagonist. This limits abuse by causing severe withdrawal symptoms in those who inject buprenorphine to get high but no adverse effects when taken orally as prescribed. This exemplifies the feasibility of developing strategies that minimize the risk of abuse of opiate medications.

Although these medications represent major breakthroughs in the treatment of addiction, it is still believed that the most effective approaches combine medications with behavioral therapies and other services as needed by patients who have the complex, multifaceted problems that often accompany addiction.

Long-term consequences of uncontrolled or poorly controlled heroin abuse: If heroin abuse is untreated, it can lead to the following health problems:

- addiction
- scarred and/or collapsed veins
- bacterial infections of the blood vessels and heart valves
- abscesses and other soft-tissue infections
- liver disease
- kidney disease
- lung diseases such as pneumonia and tuberculosis

In addition, the additives in street heroin often include substances that clog blood vessels that lead to the lungs, liver, kidneys, or brain. Contaminated injection equipment can lead to blood-borne viral infections including hepatitis B, hepatitis C, and HIV, which can then be passed on to other individuals through shared needles or sexual activity.

DIABETES TYPE I

The following information is drawn from the American Diabetes Association Web site (*http://www.diabetes.org*).

What is diabetes?
Type I diabetes is a disease that affects the way the body uses food. In a person with Type I diabetes, the body destroys the cells in the pancreas that produce insulin. Insulin is a hormone that regulates the level of sugar in the blood. Type I diabetes is also called immune-mediated diabetes, and was formerly known as insulin-dependent diabetes.

In Type II diabetes, once known as non-insulin-dependent diabetes, the pancreas does not make enough insulin or the body cannot use it properly. We will not discuss Type II diabetes any further.

Cause
Scientists do not know what causes Type I diabetes, but there appears to be a genetic component to the cause. Other factors also are likely to increase the risk for getting diabetes. Diabetes is not contagious.

Symptoms and diagnosis

- high levels of sugar in the blood
- high levels of sugar in the urine
- frequent urination (and/or bed-wetting in children)
- extreme hunger
- extreme thirst
- extreme weight loss
- weakness and tiredness
- feeling edgy and having mood changes
- feeling sick to the stomach and vomiting

Treatment
Treatment for Type I diabetes involves keeping the level of sugar in the blood as close to normal (80–120 mg/dL) as possible. Treatment usually includes

- Insulin injections to lower blood sugar. The number of injections required depends on the individual and the type of insulin treatment used.
- A meal plan to control changes in blood sugar levels. Food raises blood-sugar levels. A dietician can help develop a plan that lets the diabetic person eat the food he or she enjoys.
- Exercise to lower the blood sugar.
- Blood and urine testing to determine if the blood-sugar level is low, normal, or high. The results enable a diabetic person to modify his or her food intake, exercise, or insulin injections.

Long-term consequences of uncontrolled or poorly controlled diabetes

- blindness
- kidney disease
- nerve damage leading to abnormal sensations, including pain in the hands, feet, and legs
- vascular (blood vessel) disease leading to heart disease and strokes

Long-term outlook for diabetes if treated and controlled
People with Type I diabetes can live happy, healthy lives if they follow their treatment plans.

HYPERTENSION

The following is drawn from materials from the American Heart Association (*http://www.americanheart.org*) and the National Heart, Lung, and Blood Institute (*http://www.nhlbi.nih.gov/health/public/heart/index.htm*).

What is hypertension?
Hypertension, or high blood pressure, is defined in an adult as a blood pressure greater than or equal to 140 mm Hg systolic pressure or greater than or equal to 90 mm Hg diastolic pressure. Hypertension does not refer to being tense, nervous, or hyperactive. Optimal blood pressure for an adult is 120 mm Hg systolic and 80 mm Hg diastolic. Blood pressures are normally written as systolic/diastolic, such as 120/80.

Cause
In most cases, the cause of high blood pressure is unknown. This type of high blood pressure is called essential hypertension.

In the remaining cases (5% to 10% of cases), high blood pressure, called secondary hypertension, is a result of another health problem such as a kidney abnormality, tumor of the adrenal gland, or congenital defect of the aorta. Blood pressure usually returns to normal when the underlying cause is corrected.

Symptoms and diagnosis:
Diagnosis of high blood pressure is based on the average of two or more readings taken at each of two or more visits after an initial screening.

Hypertension usually has no symptoms. Many people have high blood pressure and don't know it. If hypertension is severe, symptoms may include

- tiredness
- confusion
- headaches
- anxiety
- excessive perspiration
- pale skin
- muscle tremors
- chest pain

Treatment
The prescribed treatment depends on the severity of hypertension, but may involve the following components:

- taking medication
- modifying diet to reduce sodium intake
- increasing exercise
- maintaining proper weight
- limiting alcohol intake

Long-term consequences of uncontrolled hypertension
High blood pressure directly increases the risk of coronary heart disease (which leads to heart attack) and stroke, especially along with other risk factors. Uncontrolled hypertension can also lead to renal failure.

Long-term outlook for hypertension if treated and controlled
Hypertension is controllable with treatment, which may require periodic adjustment.

Evaluating the Cases

Name(s)_____ Date_____

As a team, decide which member of the group will watch or read each case study. When you finish with your case, answer questions 1 to 6. Then, discuss and answer questions 7 to 11 with your group members. If you wish, watch or read the case studies again to help with your answers.

Case Study: _____

1. What disease does the individual have? Is it chronic or acute?

2. How did the disease change the individual's life?

3. What is the recommended treatment?

4. What did the individual do to improve his or her recovery?

5. What did the individual do that impaired his or her recovery?

6. Are there other things the individual could do to help with the disease?

Comparing the Cases

7. Which individuals were successful in their treatment? Which individuals were not?

8. Who was cured of their disease? What is the difference between treatment and cure?

9. How are the treatments for the different diseases similar?

10. How are the treatments different?

11. Can you identify similarities and differences in the actions or strategies that individuals took to help them deal with their disease?