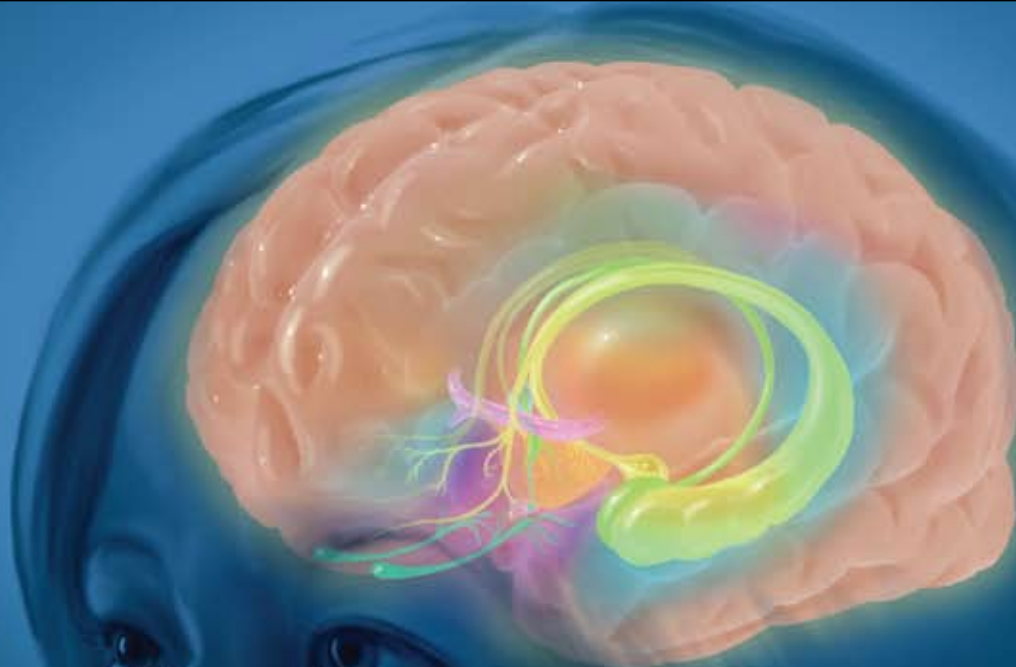


Neuroscience Core Concepts

THE ESSENTIAL PRINCIPLES OF NEUROSCIENCE



For more neuroscience education resources, please visit

www.sfn.org/nerve

What Are Neuroscience Core Concepts?

Neuroscience Core Concepts offer fundamental principles that one should know about the brain and nervous system, the most complex living structure known in the universe. They are a practical resource about:

- How your brain works and how it is formed.
- How it guides you through the changes in life.
- Why it is important to increase understanding of the brain.

The Neuroscience Core Concepts have broad application for K-12 teachers and the general public, offering the most important insights gained through decades of brain research. They also spotlight promising research paths ahead.

Eight concepts are organized within four “mega-concepts” and contain fundamental principles that serve to stimulate further thinking and exploration. The Core Concepts have been correlated to the U.S. National Science Education Standards and are a tool and resource for inclusion in K-12 teaching curricula.

The concepts were developed with leadership from the Public Education and Communication Committee of the Society for Neuroscience. In January 2007, more than a year of development began, including extensive consultation, review, and refinement by hundreds of neuroscientists and educators nationwide. This constitutes a living document that will be updated as new information becomes available.

Right now, your **BRAIN AND NERVOUS SYSTEM** are busy making sense of this sentence — just one example of how basic the brain is to every function of your waking and sleeping life. If you are sighted, nerve cells in your eyes are sensing the letters’ boundaries and transmitting the news from your eyes to the brain. (For Braille readers, nerves in the fingers send similar information from the skin up through the spinal cord to the brain.) About one fourth of the brain is involved in visual processing, more than any other sense. The precise process of reading, like many brain functions, is a topic of intense research by neuroscientists.

At its most basic level, reading, like other actions of the brain and nervous system, involves a series of electrical impulses moving through your body along a network of linked nerve cells called neurons.

The major goal of neuroscience is to understand how groups of neurons interact to generate behavior. Neuroscientists study the actions of molecules, genes, and cells, and also explore the complex interactions involved in bodily function, decision making, emotion, learning, and more. They also seek to understand diseases and disorders that occur when interactions don’t happen or go wrong.

The basic building block of the nervous system is the individual nerve cell or neuron. Neurons “talk” to each other at connections called synapses, which send and receive small “packets” of chemicals or electrical signals.

Knowledge of the human nervous system is based in part on ongoing fundamental discoveries in animals (e.g., worms, flies, fish, frogs, mice, and primates), aided by computer simulations.

There is much that we know but more that remains to be discovered. Research and discovery are funded by national science agencies around the globe, universities, research entities and companies, and private philanthropy.

TEACHING ABOUT THE BRAIN FROM EVERYDAY LIFE

There are many fun and easy opportunities to teach about the brain. For example, optical illusions and how our brain plays tricks on us are interesting to everyone. Students, teachers, and adults in general are intrigued to learn about the brain and related research that impacts our everyday life. News headlines continually grab our attention with new research findings, as can hopes for improved health and treatments for disease.

The Neuroscience Core Concepts provide content for teaching essential scientific knowledge. For example, teaching about the intricate wiring of the brain or the brain’s ability to form new memories can serve as models of how living systems are structured and how they function.

This guide serves as a starting point for considering the brain and nervous system as content for activities and inquiry in educational settings. The Core Concepts have been correlated to the U.S. National Science Education Standards as a guide, and relevant curricular resources and education materials are available at www.sfn.org/nerve.

This is an exciting era for neuroscience, with advances and discoveries emerging at a rapid pace. The progress being made requires a population that understands the basic science underlying issues and debates.

There is keen interest in discoveries about the way we learn. Scientists are increasingly interested in how the brain functions in complex environments such as the classroom. Educators are eager to learn which strategies and approaches in the classroom are most effective. Research that bridges education and neuroscience is underway.

The Nervous System Controls and Responds to Body Functions and Directs Behavior



Fig. 1 An artistic rendering of emerging technologies in action. Blue and yellow lights can be used to evoke or inhibit electrical activity in neurons (represented by the intense glow). **Credit:** Targeting and Readout Strategies for Fast Optical Neural Control *In Vitro* and *In Vivo*. Illustration credit: Feng Zhang, Steve Dixon, Viviana Gradinaru, Karl Deisseroth, Stanford University; Courtesy with permission: 2007, *The Journal of Neuroscience* 27: 14231-14238.

1 | The brain is the body's most complex organ.

- a. There are a hundred billion neurons in the human brain, all of which are in use.
- b. Each neuron communicates with many other neurons to form circuits and share information.
- c. Proper nervous system function involves coordinated action of neurons in many brain regions.
- d. The nervous system influences and is influenced by all other body systems (e.g., cardiovascular, endocrine, gastrointestinal and immune systems).
- e. Humans have a complex nervous system that evolved from a simpler one.
- f. This complex organ can malfunction in many ways, leading to disorders that have an enormous social and economic impact.

2 | Neurons communicate using both electrical and chemical signals.

- a. Sensory stimuli are converted into electrical signals.
- b. Action potentials are electrical signals carried along neurons.
- c. Synapses are chemical or electrical junctions that allow electrical signals to pass from neurons to other cells.
- d. Electrical signals in muscles cause contraction and movement.
- e. Changes in the amount of activity at a synapse can enhance or reduce its function.
- f. Communication between neurons is strengthened or weakened by an individual's activities, such as exercise, stress, and drug use.
- g. All perceptions, thoughts, and behaviors result from combinations of signals among neurons.

Nervous System Structure and Function Are Determined by Both Genes and Environment Throughout Life

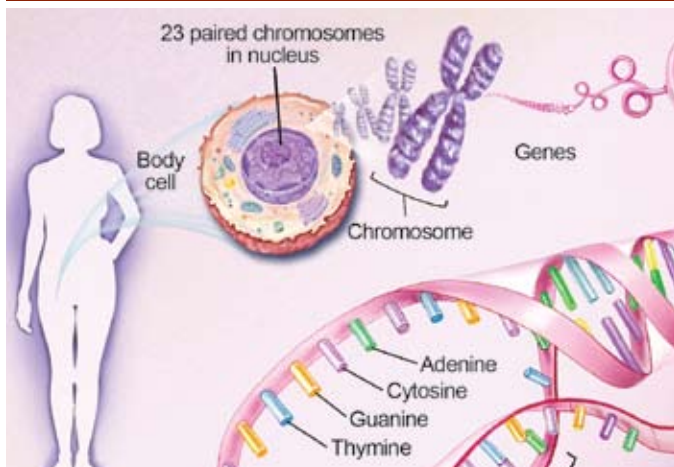


Fig. 2 Who we are is the product of our genes or blueprint, contained in every one of our cells (illustrated at the top), and our environment, much of which comes from the rich contributions of our family and culture. **Credit:** (Top) Copyright © 2005, Society for Neuroscience. All rights reserved. Illustrations by Lydia Kibiuk. (Bottom) Copyright © Tim Pannell/Corbis



Fig. 3 A dancer with the Mark Morris Dance Group leads a weekly dance class for people with Parkinson's disease allowing them to experience dance and movement. **Credit:** Photo by Katsuyoshi Tanaka

3 | Genetically determined circuits are the foundation of the nervous system.

- Neuronal circuits are formed by genetic programs during embryonic development and modified through interactions with the internal and external environment.
- Sensory* circuits (sight, touch, hearing, smell, taste) bring information to the nervous system, whereas *motor* circuits send information to muscles and glands.
- The simplest circuit is a reflex, in which a sensory stimulus directly triggers an immediate motor response.
- Complex responses occur when the brain integrates information from many brain circuits to generate a response.
- Simple and complex interactions among neurons take place on time scales ranging from milliseconds to months.
- The brain is organized to recognize sensations, initiate behaviors, and store and access memories that can last a lifetime.

4 | Life experiences change the nervous system.

- Differences in genes and environments make the brain of each animal unique.
- Most neurons are generated early in development and survive for life.
- Some injuries harm nerve cells, but the brain often recovers from stress, damage, or disease.
- Continuously challenging the brain with physical and mental activity helps maintain its structure and function — “use it or lose it.”
- Peripheral neurons have greater ability to regrow after injury than neurons in the brain and spinal cord.
- Neuronal death is a natural part of development and aging.
- Some neurons continue to be generated throughout life and their production is regulated by hormones and experience.

The Brain is the Foundation of the Mind



Fig. 4 Control of balance and coordinated movement arises at a specific stage of development and requires practice with a tutor. **Credit:** Copyright © Dynamic Graphics/Jupiterimages

5 | Intelligence arises as the brain reasons, plans, and solves problems.

- a. The brain makes sense of the world by using all available information, including senses, emotions, instincts and remembered experiences.
- b. Emotions are based on value judgments made by our brains and are manifested by feelings as basic as love and anger and as complex as empathy and hate.
- c. The brain learns from experiences and makes predictions about best actions in response to present and future challenges.
- d. Consciousness depends on normal activity of the brain.



Fig. 5 A student ponders the marvels of a model of the skull that contains the human brain. The top has been cut away to reveal the cranial nerves that leave the skull at its base. **Credit:** Copyright © 2008, Society for Neuroscience. All rights reserved. Photo by Joe Shymanski.

6 | The brain makes it possible to communicate knowledge through language.

- a. Languages are acquired early in development and facilitate information exchange and creative thought.
- b. Communication can create and solve many of the most pressing problems humankind faces.

Research Leads To Understanding that Is Essential for Development of Therapies for Nervous System Disorders

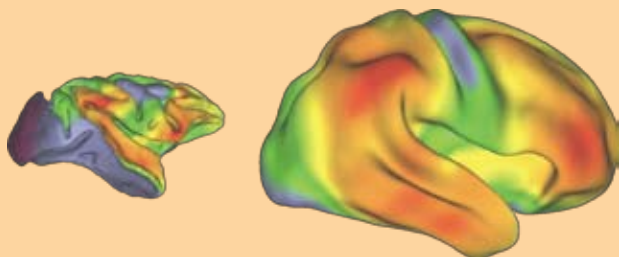


Fig. 6 A map of how the cerebral cortex has expanded in humans compared to the macaque monkey, displayed on side views of macaque (left panel) and human (right panel) cortical atlases. Red patches in the parietal, frontal, and temporal lobes indicate regions that are likely to have expanded most rapidly in humans compared to monkeys. **Credit:** Adapted, with permission, from Van Essen and Dierker (Neuron, 2007).

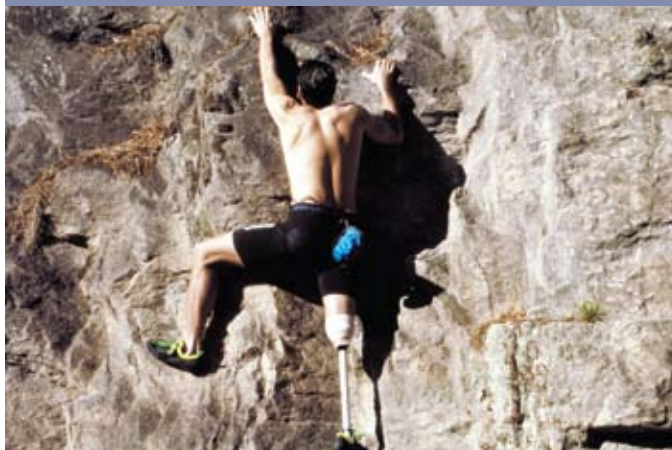


Fig. 7 Advanced therapeutics allow a climber to scale a cliff with an artificial leg. The development of brain-prosthesis interfaces give injured patients new hope. **Credit:** Copyright © Janis Christie/Corbis



Fig. 8 Young researchers become involved in laboratory work that will lead to future treatments for neurological disorders. **Credit:** Copyright © 2008, Society for Neuroscience. All rights reserved. Photo by Janis Weeks.

7 | The human brain endows us with a natural curiosity to understand how the world works.

- The nervous system can be studied at many levels, from complex behaviors such as speech or learning, to the interactions among individual molecules.
- Research can ultimately inform us about mind, intelligence, imagination, and consciousness.
- Curiosity leads us to unexpected and surprising discoveries that can benefit humanity.

8 | Fundamental discoveries promote healthy living and treatment of disease.

- Experiments on animals play a central role in providing insights about the human brain and in helping to make healthy lifestyle choices, prevent diseases, and find cures for disorders.
- Research on humans is an essential final step before new treatments are introduced to prevent or cure disorders.
- Neuroscience research has formed the basis for significant progress in treating a large number of disorders.
- Finding cures for disorders of the nervous system is a social imperative.

Glossary

ACTION POTENTIAL: An electrical charge that travels along the axon to the neuron's terminal, where it triggers the release of a neurotransmitter. This occurs when a neuron is activated and temporarily reverses the electrical state of its interior membrane from negative to positive.

ALZHEIMER'S DISEASE: A major cause of dementia in the elderly, this neurodegenerative disorder is characterized by the death of neurons in the hippocampus, cerebral cortex, and other brain regions.

CEREBRAL CORTEX: The outermost layer of the cerebral hemispheres of the brain. It is largely responsible for all forms of conscious experience, including perception, emotion, thought, and planning.

COGNITION: The process or processes by which an organism gains knowledge or becomes aware of events or objects in its environment and uses that knowledge for comprehension and problem-solving.

DEPRESSION: A mental disorder characterized by sadness, hopelessness, pessimism, loss of interest in life, reduced emotional well-being, and abnormalities in sleep, appetite, and energy level.

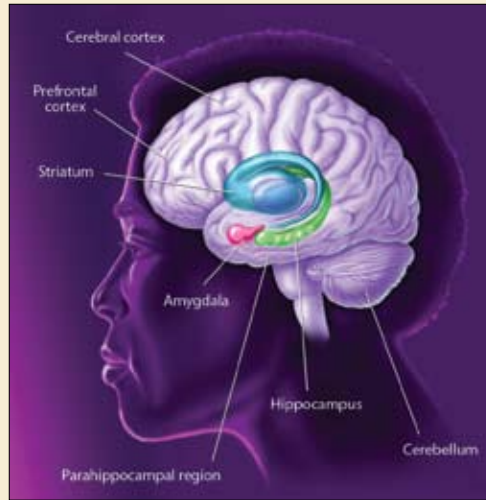
HIPPOCAMPUS: A seahorse-shaped structure located within the brain and considered an important part of the limbic system. One of the most studied areas of the brain, it functions in learning, memory, and emotion.

MEMORY CONSOLIDATION: The physical and psychological changes that take place as the brain organizes and restructures information to make it a permanent part of memory.

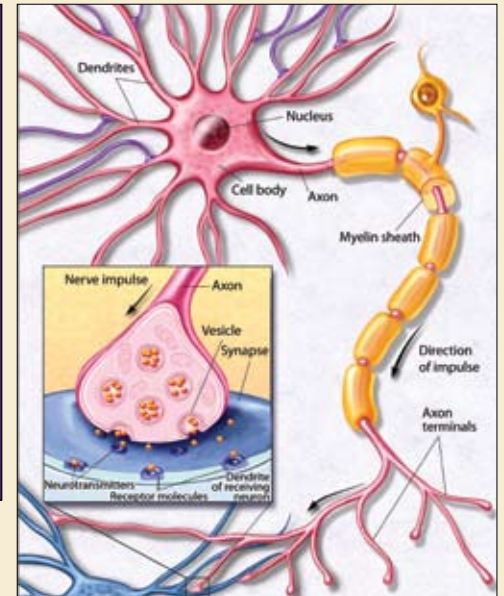
NEUROPLASTICITY: A general term used to describe the adaptive changes in the structure or function of nerve cells or groups of nerve cells in response to injuries to the nervous system or alterations in patterns of their use and disuse.

SCHIZOPHRENIA: A chronic mental disorder characterized by psychosis (e.g., hallucinations and delusions), flattened emotions, and impaired cognitive function.

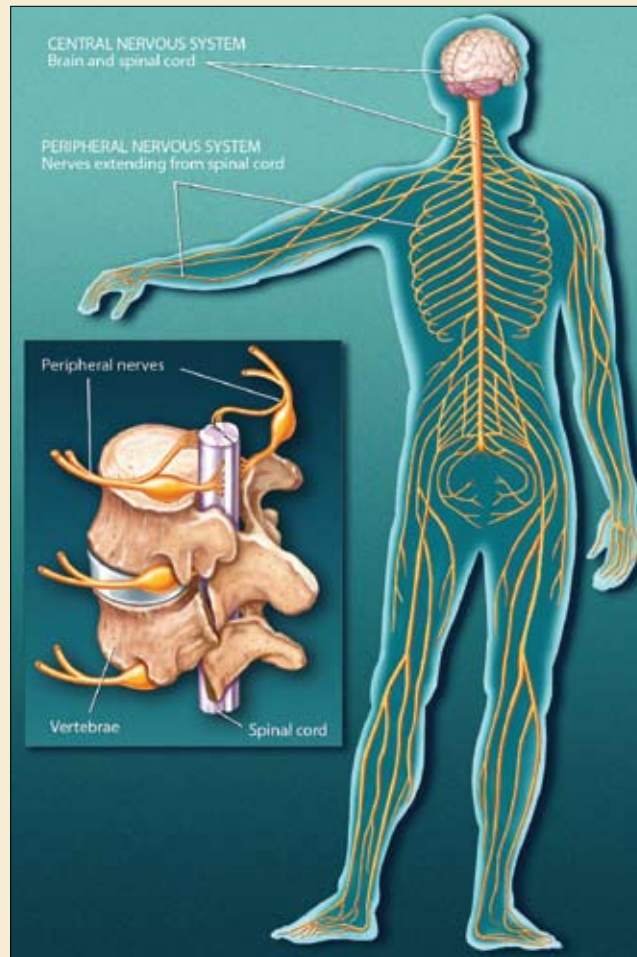
STROKE: A block in the brain's blood supply. A stroke can be caused by the rupture of a blood vessel, a clot, or pressure on a blood vessel (as by a tumor). Without oxygen, neurons in the affected area die and the part of the body controlled by those cells cannot function. A stroke can result in loss of consciousness and death.



▲ **LEARNING AND MEMORY.** Different brain areas and systems mediate distinct forms of memory. The hippocampus, parahippocampal region, and areas of the cerebral cortex (including prefrontal cortex) compose a system that supports declarative, or cognitive, memory. Different forms of nondeclarative, or behavioral, memory are supported by the amygdala, striatum, and cerebellum.



▲ **NEURON.** A neuron transmits electrical signals along its axon. When signals reach the end of the axon, they trigger the release of neurotransmitters that are stored in pockets called vesicles. Neurotransmitters bind to receptor molecules on the surfaces of adjacent neurons. The point of contact is known as the synapse.








◀ **SPINAL CORD AND NERVES.** The mature central nervous system (CNS) consists of the brain and spinal cord. The brain sends nerve signals to specific parts of the body through peripheral nerves, known as the peripheral nervous system (PNS). Peripheral nerves in the cervical region serve the neck and arms; those in the thoracic region serve the trunk; those in the lumbar region serve the legs; and those in the sacral region serve the bowels and bladder. The PNS consists of the somatic nervous system that connects voluntary skeletal muscles with cells specialized to respond to sensations, such as touch and pain. The autonomic nervous system is made of neurons connecting the CNS with internal organs. It is divided into the sympathetic nervous system, which mobilizes energy and resources during times of stress and arousal, and the parasympathetic nervous system, which conserves energy and resources during relaxed states.

For Educators: How To Use the Neuroscience Core Concepts Overview Matrix

The **Overview Matrix** (right) and the corresponding **Core Concepts and Essential Principles** chart (pages 3 - 6) show how the content of Neuroscience Core Concepts address the U.S. National Science Education Standards (NSES)[^]. The eight Core Concepts are numbered and run across the top of the matrix; the “Megaconcepts” are above the Core Concepts while the letters below correspond to the Essential Principles. Refer to the Concepts and Principles chart to find descriptions of each concept. Seven NSES^o content standards and sub-categories run vertically along the far left column. Grade spans are identified by color (see below).

We suggest that you view the matrix online at www.sfn.org/coreconcepts.

-  Elementary
-  Middle
-  High
-  All

 Dotted box = alignment of Neuroscience Core Concepts principle to NSES content standard.

[^]Note: National Academy of Sciences, 1996

^oNote: The Earth and Space standards category has been omitted from the matrix in this pamphlet as the Neuroscience Core Concepts do not correlate with the content.

NEUROSCIENCE CORE CONCEPTS: OVERVIEW MATRIX FOR K-12			Nervous System Controls & Responds to Body Functions & Directs Behavior													
			1. Brain is the body's most complex organ						2. Neurons communicate using electrical & chemical signals							
CORE CONCEPTS →			ESSENTIAL OR GUIDING PRINCIPLES →													
NSES	Standard Sub-Category	Level	a	b	c	d	e	f	a	b	c	d	e	f	g	
Unifying Concepts & Processes	Systems, Order, Organization	A	•	•	•	•	•	•	•	•	•	•	•	•	•	
	Evidence, Models, Investigation	A	•	•	•	•	•	•	•	•	•	•	•	•	•	
	Change, Constancy, Measurement	A	•	•	•	•	•	•	•	•	•	•	•	•	•	
	Evolution and Equilibrium	A					•									
	Form and Function	A	•	•	•	•	•	•	•	•	•	•	•	•	•	
Life Science	Characteristics of Organisms	E	•	•	•	•	•	•	•	•	•	•	•	•	•	
	Life Cycles of Organisms	E	•	•	•	•	•	•	•	•	•	•	•	•	•	
	Organisms and Environments	E			•	•		•	•			•	•	•		
	Structure and Function in Living Systems	M	•	•	•	•	•	•	•	•	•	•	•	•	•	
	Reproduction and Heredity	M					•									
	Regulation and Behavior	M	•	•	•	•	•	•	•	•	•	•	•	•	•	
	Populations and Ecosystems	M														
	Diversity and Adaptations of Organisms	M					•							•	•	
	Interdependence of Organisms	H						•								
	Behavior of Organisms	H	•	•	•	•	•	•	•	•	•	•	•	•	•	
	Matter, Energy, Organization in Living Systems	H	•		•	•	•			•	•	•	•	•	•	
	Biological Evolution	H					•									
	Molecular Basis of Heredity	H														
	The Cell	H	•	•	•	•	•	•	•	•	•	•	•	•	•	
Physical Science	Properties of Objects and Materials	E														
	Position and Motion of Objects	E														
	Light, Heat, Electricity, Magnetism	E														
	Properties and Changes of Properties in Matter	M									•					
	Motions and Forces	M														
	Transfer of Energy	M							•	•	•	•	•	•	•	
	Structure of Atoms	H														
	Structure and Properties of Matter	H									•					
	Chemical Reactions	H		•	•	•		•		•	•	•	•	•	•	
	Motions and Forces	H														
	Conservation of Energy and Increases in Disorder	H														
Interactions of Energy and Matter	H								•	•	•	•	•	•		
History of Nature & Science	Science As Human Endeavor K-12	E	•	•	•	•	•	•	•	•	•	•	•	•	•	
	Nature of Scientific Knowledge 5-12	E	•	•	•	•	•	•	•	•	•	•	•	•	•	
	History of Science	M	•	•	•	•	•	•	•	•	•	•	•	•	•	
	Historical Perspectives	H	•	•	•	•	•	•	•	•	•	•	•	•	•	
Personal and Social Perspectives	Personal Health K-8	A						•						•		
	Characteristics and Changes In Populations	E														
	Types of Resources	E														
	Changes in Environments	E														
	Science and Technology in Local Challenges	E						•						•		
	Populations, Resources and Environments	M														
	Natural Hazards	M														
	Risks and Benefits	M				•		•						•	•	
	Science and Technology in Society	M						•							•	
	Personal and Community Health	H				•		•					•	•		
	Population Growth	H														
	Natural Resources	H														
	Environmental Quality	H														
Nature and Human-Induced Hazards	H						•						•			
Science and Technology in Local, National, Global Challenges	H															
Science and Technology	Made by Humans	E														
	Abilities of Technological Design K-12	A	•	•	•	•	•	•	•	•	•	•	•	•	•	
	Understanding About Science and Technology K-12	A	•	•	•	•	•	•	•	•	•	•	•	•	•	
Science As Inquiry	Abilities Necessary to Do Scientific Inquiry K-12	A	•	•	•	•	•	•	•	•	•	•	•	•	•	
	Understanding About Scientific Inquiry K-12	A	•	•	•	•	•	•	•	•	•	•	•	•	•	



*Advancing the Understanding
of the Brain and Nervous System*

Neuroscience Core Concepts:

The Essential Principles of Neuroscience

Each essential principle is supported by fundamental concepts comparable to those underlying the U.S. National Science Education Standards (NSES). Consult the Overview Matrix (see page 8) to integrate Neuroscience Core Concepts into your curriculum.

www.sfn.org/coreconcepts

For more neuroscience education resources, please visit www.sfn.org/nerve

SfN gratefully acknowledges the Ocean Literacy Network, and its partners and supporters, for their groundbreaking work upon which this pamphlet is modeled. For more information visit www.oceanliteracy.net.