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The Brain, Our Silent Partner: Anatomy and Cognition

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by Laura Carroll-Koch

Introduction

Look up to the heavens on a crisp, clear, dark night and while gazing upon the stars, know that the awe and wonder felt can only be compared to the experience one might have as the brain reveals itself.

Thinking about the complex nature of our brain with its multifaceted functions, involving abstract outcomes and unfamiliar interactions stretches the limits of our imagination. Trillions of simultaneous neural actions are working together in unique harmony. These connections create a vast interwoven labyrinth of electrical and chemical pathways with orchestrated explosions and purposeful connections responding to a plethora of perpetual activity in an elaborate symphony that defines our very being. These interwoven, ever changing neural pathways sculpt the way one views, connects, and functions in the world. They shape our learning, but how we learn also shapes these pathways. Every brain is unique. It is the organ that gives us our individuality and our identity. It makes us, who we are, the fingerprint of our thinking. Although daunting, one cannot help but be drawn to this complex organ, the rememberer, controller, interpreter, organizer, assessor, and creator inside our very own head.

We live in an exciting age, a New Age Renaissance, the Age of Neuroscience, reshaping every facet of society. The forward thinking cultures of medicine, communication, science, and technology are exploding with new understandings, creating a highly active, dense network of shared ideas and insights. Cutting edge technology is revolutionizing neuroscience, providing tools that enable study of unchartered territories resulting in groundbreaking discoveries. Medical breakthroughs offer relief to brain related illness and injury involving the spinal cord, chronic pain, Parkinson's, ALS-Lou Gehrig's disease, Alzheimer's, Traumatic Brain Injury and finally, a glimpse of hope for the lost and forgotten victims, profoundly suffering with mental illness.

Furthermore, these findings are reshaping the culture of education, a profession devoted to fostering a love of learning and the acquisition of knowledge. Teachers can use advances in neuroscience to guide their instruction and classroom culture. Developments in neuroscience can be applied in the classroom to improve the ways students learn and provide insight into the way we teach and how we reach. Ultimately, we want our students to know how to think, and become independent, innovative problem solvers. In order to do this, students should to be aware of their own thinking and must understand the metacognitive skills necessary to develop it. Most students have very little knowledge about the brain's anatomy and its functions as they relate to the cognitive domains. These domains have varied levels of complexity involving many of the brain's anatomical functions. In addition, a student's cognitive flexibility, the ability to change ones mental states as needed, is a major component in one's ability to create and generate novel ideas, and develop them; a new measure of intelligence. As students learn how the functions of their brain work together, they will discover their personal power over how they learn and be encouraged to stretch their own accepted limits. In addition, when one is conscious of how one acquires knowledge, than one can improve it by employing metacognitive skills. As in learning to ride a bike, or drive a car, skills are learned best when taught directly and explicitly.

I designed this unit to teach students the anatomy and cognitive functions of the brain through engaging, hands on activities. An evolutionary journey of development will highlight the roots of our brain's anatomy, functions, and cognition, offering students a perspective and appreciation for the way this extraordinary organ has developed. As a result, students will understand the significance of our most recently acquired anatomical feature, the cerebral cortex. Distinguishing us as a species, the cortex brought consciousness and our ability to make decisions, plan, evaluate, and create; our higher level complex thinking. Students will construct a clay model of the brain as they learn its anatomy and major functions, discovering how these systems relate to learning. As students realize how these cognitive systems determine their own thinking both anatomically and functionally, they will be empowered to exercise their cognitive skills and engage in thinking that is more complex. A focus on the structure and function of the neuron will develop an understanding of its complex nature. Simulations of neural connections and electrical pathways will help students understand how messages move between neurons and will demonstrate how memories are made and recalled. As students explore memory processing, they will come to understand that these systems collectively produce our ability to think and learn. Creating, evaluating, analyzing require different mental states which can be controlled and changed. With this understanding, students will learn to exercise cognitive flexibility adapting as necessary to the needs of a particular situation, stretching their mental limits propelling them forward, as thinkers, innovators, and creators breaking through the once accepted limits of their own mind.

Rationale

"At 1:30 we get to do science!" Rosanna whispered with excitement as she glanced anxiously at the clock. The clock strikes 1:30 and science begins. Sparks begin to fly. The air is electrified with curiosity, thinking and wondering. The beautiful buzz of thinking fills the air as students are fully engaged in learning, through science. I can't think of a better way of teaching students to think than through the subject of science. Teaching through science is like feeding your child their vegetables by hiding them in spaghetti sauce. They get the nutrition needed while enjoying a favorite meal. As student learn and explore their amazing brain power in this unit, they will be expanding vocabulary, writing, questioning, hypothesizing, evaluating, comparing and drawing conclusions. Students will be actively applying their brainpower through engaging activities that exercise their cognitive skills and flexibility, stretching higher level thinking in the process of inquiry and discovery!

As a fourth grade teacher in the New Public Schools, my students are strapped with the demands of testing; the Connecticut Mastery Test, as well as district assessments. Subjects compete for center stage, often squeezing the science curriculum to its bare bones. Students are not prepared for the rigors and expectations of the science CMT in fifth grade. I would like to bring the subject of science back to center stage, making it the star; shining light across the curriculum through the relevant and enlightening subject matter of the human brain.

"The brain, a cold grey matter with the consistency between butter and jelly, was once discarded. The Egyptians, when mummifying their dead, actually scooped out the brains and threw them away. It did not beat like the heart or expand like the lungs, if you sliced off the top of someone's skull and peered inside, you wouldn't see much happening at all." [1] It is no wonder the brain was tossed and discarded as useless matter. The brain is only beginning to reveal its secrets in ways that we can now measure and understand. Recent advances in the past 50 years in magnetic resonance imaging (MRI) and now functional MRI (fMRI) have opened the doors to an explosion in neuroscience. Although new information is unraveling secrets of the mind, an infinite number of questions remain unanswered.

Our abilities to evaluate, synthesize, and create are rather newly acquired skills. We can thank evolution, and our predecessors, for the gift of our frontal lobes. Thankfully, the luxury of their expression is taken for granted, with our highly sophisticated neural network of the cortex. Clearly, these exceptional skills set us uniquely apart from the animal kingdom. Our thinking has a fascinating story of development, connecting us to our past and future; earned as a species it continues to evolution. How does our brain work? What is the story behind our evolving brain? How does the human brain compare to that of a fish, an amphibian, or a reptile? How does our brain process our memories and use what we know, to solve what we do not? How do we create innovative solutions to problems? With these questions in mind, this unit shines a light on the brain, its evolution, anatomy, and cognitive functions.

Evolution of the Brain

Rita Carter asserts that the anatomy and functions of our brain are linked to fish that lived 300 million years ago. Beginning as a bundle of nerve cells incased in a small tube in the fish, Carter describes the layers of the brain as they evolve to the complex systems of the human brain of today. Carter connects evolutionary steps of development linking the primitive functions of a tiny aquatic invertebrate, to an earthworm, and then to a fish, reptile, mammal, and finally to the extraordinary specialized functions of the human brain. The story starts with a tiny aquatic invertebrate called a hydra. The hydra showed evidence of brain function in its loose network of sensory cells that connected to groups of cells called ganglia. In the earthworm, this group of cells began to function as a crude brain with a nerve cord that extended the length of the earthworm's body. Just like our spinal cord, the earthworm's nerve cord extended from a centralized location in the head to the tail, functioning as a primitive nervous system that communicated information by sending and receiving messages to produce movement. [2]

The next notable step in evolution is the change from invertebrates to vertebrates. The nerves in the fish, the first vertebrate group, came together according to their sensitivity to smell, forming the smell brain. [3] Additional nerve cells organized according to their sensitivity to light, forming eyes. These groups of nerves connected to another group of nerves that controlled movement in a new unit at the top of the spine, the cerebellum. These three grouping of nerves and their specific sensitivity to smell, light and movement characterized the fish brain. The amphibian brain is similar to the fish brain except for the more fully developed olfactory bulb, marking a significant change in the improved ability to perceive smell. This change came along with the first recognizable limbs. As their environment changed, so did the criteria for survival. An improved, more developed olfactory bulb increases these chances for the amphibian.

These sensory groups took a giant leap in evolutionary terms represented in the development of the thalamus in the anatomy of the reptilian brain. The thalamus added a system for sensory control. This system enabled the sensory information collected through the senses of sight, smell, and hearing to become integrated. [4] Consequently, the reptilian's senses were able to work together causing a more complex interaction with its surrounds. This sensory integration gave rise to a more sophisticated response to the environment. The reptile could gather sensory information in the thalamus and use it to eat and avoid being eaten.

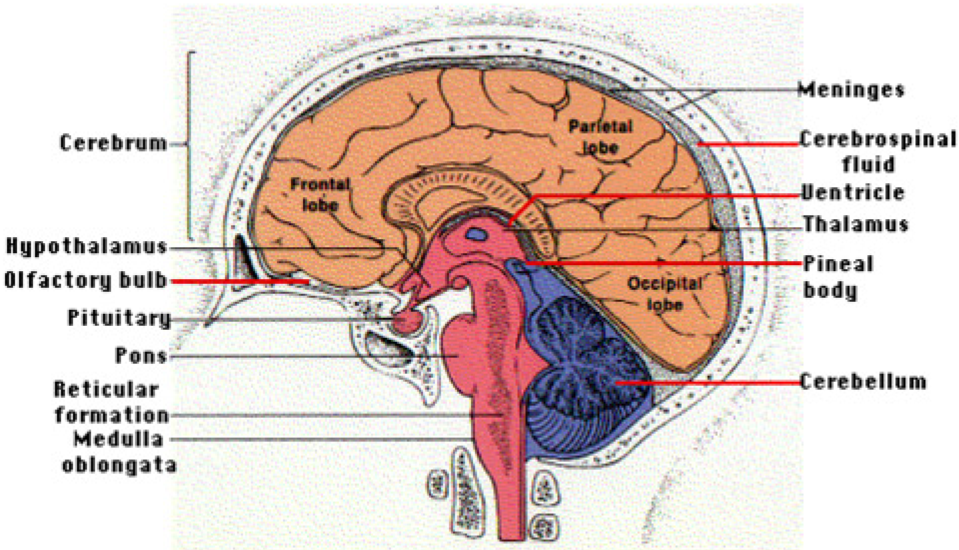
The limbic system and a wrinkled covering called a cortex distinguish the mammalian brain. Unlike the smooth cortex of the reptilian brain, the newly developed wrinkles on the cortex of the mammalian brain allowed the enlarged surface area of the cortex to fit within the skull. In addition, within the limbic system, the hippocampus and amygdala together formed a crude memory system for the first time, encoding experiences. This early limbic system enabled the production of emotions and behaviors that extended beyond primitive survival responses of fight or flight. This more complex group of systems involving memory, emotion, and sensory integration allowed for a more sophisticated response to the environment – for the first time, a step beyond pure instinct. [5] The mammalian brain continued to show improvement in response to the changing environment with the development of the cortex and its expressed ability to think and make planned responses to the environment.

Consciousness, as we understand it, came to life in the next evolutionary stage. Carter describes this as an explosive period of development marked by increased neural connections caused by the sensory units forming a thin sheet of cells that allowed intense connectivity. The integration of these systems involved new nerve cells within the cortex with heightened neural activity, interconnecting and forming an extensive matrix of neural connections. This thin layer of cells with intense connectivity is the cerebral cortex. Consciousness emerged from this connectivity. An explosive enlargement of the brain occurred with the development of our cerebrum. It created our flat forehead, the shape of our skull, and our complex thinking. [6] This was the first glimpse of today's mind and its ability to perceive, communicate, remember, understand and appreciate; distinguishing the *Homo sapiens* . [7] Man's brain is unique among other mammalian brains because of its size and the density of the cortex. The neural density increased the gray matter found in the frontal cortex and is responsible for our complex thought, judgment, and reflection; our fully conscious existence.

The comparative anatomist, Neil Shubin, in his discussion of anatomical evolution, begins with life's building blocks, DNA. Shubin describes specific examples of the DNA and the genetic recipes for organ building and traces them back 300 million years ago. He lays out evidence that connects the way organs develop, revealing a reoccurring theme that has continued for millions of years, suggesting that the genetic elements of our anatomy extend all the way back to the fish. Shubin says, "When you see these deep similarities among different organs and bodies, you begin to recognize that the diverse inhabitants of our world are just variations of the same theme." [8] As we compare species in an evolutionary context, we are able to see the relationship between the species and its environment change as the systems of the brain evolve. Primitive species were controlled by and reacted to their environment, through the process of evolution, species developed, interacting with their environment in more complex ways. We have grown and evolved to fully conscious beings interacting with our environment in a highly sophisticated way; a new global consciousness; connecting as a collective world-wide community, assessing, evaluating, creating, developing innovative approaches to problems with a broad scope and vision.

Anatomy of the Brain

The physical structure of the brain can be compared with its mental organization and evolutionary origins. [9] When examined from the outside in, it is as though one is tunneling back through time when burrowing vertically through the skull from the top of the head to where the spinal cord connects with the brainstem. Deep down in this region, functions are regulated by the unconscious, autonomic systems of the pons, medulla, and thalamus, whose origins are rooted in the primitive reptilian brain. Moving vertically outward through the limbic system and then just beneath the skull, we find the most highly complex fully conscious mental processing center of the brain, the cerebral cortex, a thin gray matter that covers the four lobes of the cerebrum, [10] the latest and greatest evolutionary feature of the brain.



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The brain can be divided into three main parts; the cerebrum, cerebellum, and brain stem. The cerebrum is the largest part of the brain made up of folds that wrap around the hemispheres of the brain. These folds are called "gyri" and increase the surface area of the cortex. The cerebrum is divided into four main lobes, the occipital, temporal, parietal, and frontal as well as the hippocampus, basal ganglia and amygdala. Each of these lobes has specific functions. Furthermore, the cerebrum is divided into two hemispheres, the right hemisphere, and the left hemisphere, connected by a huge complex of cables called the corpus callosum. The cerebellum sits in the back of the brain above the brainstem. The brainstem connects the cerebrum and the spinal cord, as well as having its own specialized functions.

Brainstem: Midbrain Pons Medulla

The three parts of the brainstem are the midbrain, pons and medulla. The functions at the brainstem are highly involved in the autonomic systems of our body. Carter compares the brainstem to the ancient reptilian brain because of their anotomical and functional similarities, particularly the regulation of autonomic unconscious movement. All the nerves that run between the spinal cord to the brain pass through the medulla. [11] Of the 12 cranial nerves that serve the head, 10 connect to the brain stem. The olfactory (1 st cranial) nerve goes directly to the limbic system. [12] The optic nerve (2 nd cranial) is actually a tract of the brain, connecting directly with the thalamus. The medulla monitors, controls and regulates respiration, heartbeat and blood pressure as well as vomiting, swallowing, coughing and sneezing. Circadian rhythm, our body clock, is passed to the brainstem, from the hypothalamus, so that body processes follow a 24 hour rhythm. [13] The pons looks like a bulge on the side of the medulla, like an aneurism. Pons means bridge in Latin, which describes the way the pons links the lower brainstem and the cerebellum in order to coordinate complex muscle movement. [14] The pons serves as a relay station made up of bundles of nueronal pathways that connect the cerebrum and sensory input coming up from the spinal cord and the cerebellum. The midbrain's main fuctions are arousal or alertness, eye movement, body movement and hearing. [15]

Cerebellum

The cerebellum, or little brain, is located in nape of our neck. The main function of the cerebellum is to regulate and integrate the actions of the muscles in order to produce balance, coordination, muscle control, and learning new motor skills. [16] The cerebellum is divided symmetrically; between each hemispheres of the brain. Its surface area consists of dense deep folds like the cerebrum. It is thought that the cerebellum stores memories of automated movements like walking and swimming. Recent studies suggest that the cerebellum serves as a support structure for cognitive processing by coordinating the processing of thoughts, emotion, memory, and senses. The cerebellum secures an elaborate number of motor tasks with automaticity, thus freeing up mental space for other activities. [17]

Thalamus

The thalamus is made up of two oval masses, shaped like two small eggs sitting side-by-side 1 ½ long by ½ inch wide. [18] The thalamus receives a plethora of nerve signals coming from all the senses, except smell, through the cranial nerves and spinal cord as they pass to the sensory cortexes in the cerebrum. When this information passes through the thalamus, it integrates, screens, and sorts incoming sensory information and then relays it to the cerebral cortex and appropriate parts of the brain for further processing. In this way, the thalamus is screening sensory input enabling more focused attention on matters of value and filtering out distractions. [19]

Hypothalamus

The hypothalamus is the "mother" of our autonomic system. It controls the autonomic nervous system maintaining homeostasis in the body. The hypothalamus monitors the internal systems keeping homeostasis through its neural connections, controlling the release of various hormones. It regulates sleep, hunger, thirst, body temperature, blood pressure, hormone secretion, and water balance. [20] Along with the pituitary gland, the hypothalamus keeps the body systems stable. The hypothalamus interacts mostly with two systems, the nervous system, and the endocrine system, stimulating organs to release hormones. Although the functions of the hypothalamus are extraordinary, it is only the size of a dime.

Hippocampus and Amygdala

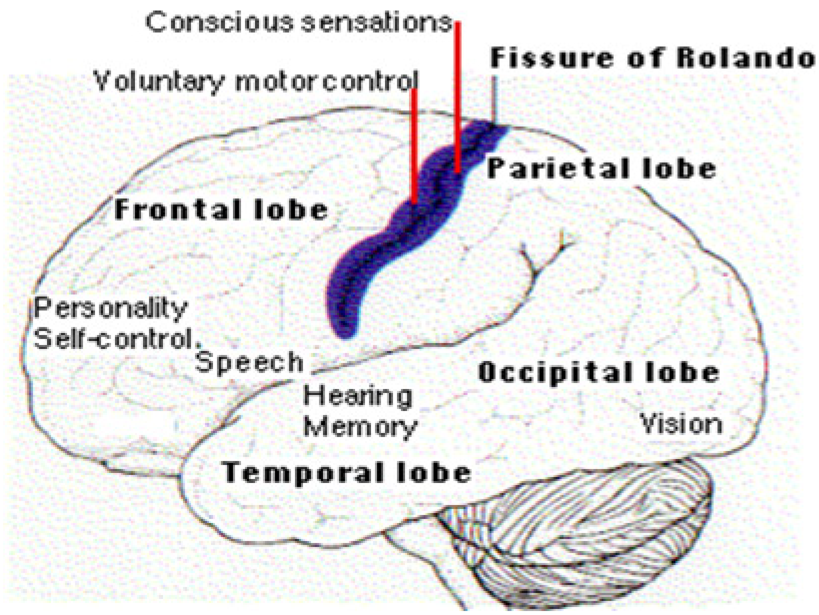
The hippocampus is one of the most important parts of the brain and the limbic system. The hippocampus is named after its shape; meaning seahorse in Greek and is one of the only parts of the brain that produces new neurons into adulthood. [21] The main function of the hippocampus is memory formation and consolidation. It sorts, files, and stores information. The hippocampus filters out insignificant information, keeps information that is important enough to store as memories, and then decides where those memories should be stored.

These memories are stored in areas with sensory associations. The hippocampus is able to retrieve memories and process them in conjunction with the frontal cortex. The hippocampus bridges these sensory associates where visual memories, auditory memories and other associated sensory memories are stored with the prefrontal cortex where these memories are processed. When the hippocampus is exercised and highly active, as in London Taxi drivers who must memorize a vast labyrinth of roads around London, its size increases. [22]

A significant discovery was made in 1953 that showed how vital the hippocampus is to memory when a large part of the hippocampus was surgically removed from a patient named, HM, in an effort to relieve his suffering from severe epileptic seizers. As a result, HM was unable to retain a new memory for more than seconds. This now famous case showed how significant the hippocampus is to integrating and laying down new memory. The hippocampus converts working memory into long-term storage areas and constantly checks information relayed to working memory. The functions of the amygdala are involved with emotion, memory, and learning. Like the hippocampus, the amygdala is also part of a larger system called the limbic system. [23] The main function of the amygdala is its involvement with emotion. The amygdala is attached to the end of the hippocampus and regulates the most basic emotional responses to the environment, fear fight, flight, or attack. In addition, it is believed that the amygdala encodes the emotional parts of memories. Emotions can make memories stronger. The interaction of the hippocampus and amygdala is thought to allow one to experience the emotions of a memory when recalled, insuring that we remember events that are emotionally charged. [24]

Cerebrum

The cerebrum is the largest part of the brain and divided into four lobes with specialized functions: the frontal lobe, temporal lobe, parietal lobe, and occipital lobe. Korbinian Broman a German neurologist, actually mapped the cortex based on its microscopic anatomy of cells on the arrangement of nerves. The occipital lobe is involved with processing visual information. The temporal lobe is the home for the auditory cortex where our unique ability to make sounds and speak is a function. The temporal lobe is involved with auditory processing of music, sound, comprehension of speech and some memory. Our unique ability to make sounds and speak is a function found in the temporal lobe in Wernicke's area, named after the neurologist who discovered it. This is where information associated with the printed word/language is processed. It is normally located only on the left temporal lobe of the left cerebral hemisphere, defining one of the many characteristics of this hemisphere. The parietal lobe is involved in movement, orientation, calculation and certain kinds of recognition. The frontal lobe is involved in movement and the most integrated processes of brain functions. This is where the brain conducts its highest order thinking, planning, conceptualizing, and is able to appreciate and interpret and regulate emotion according to Carter. [25]



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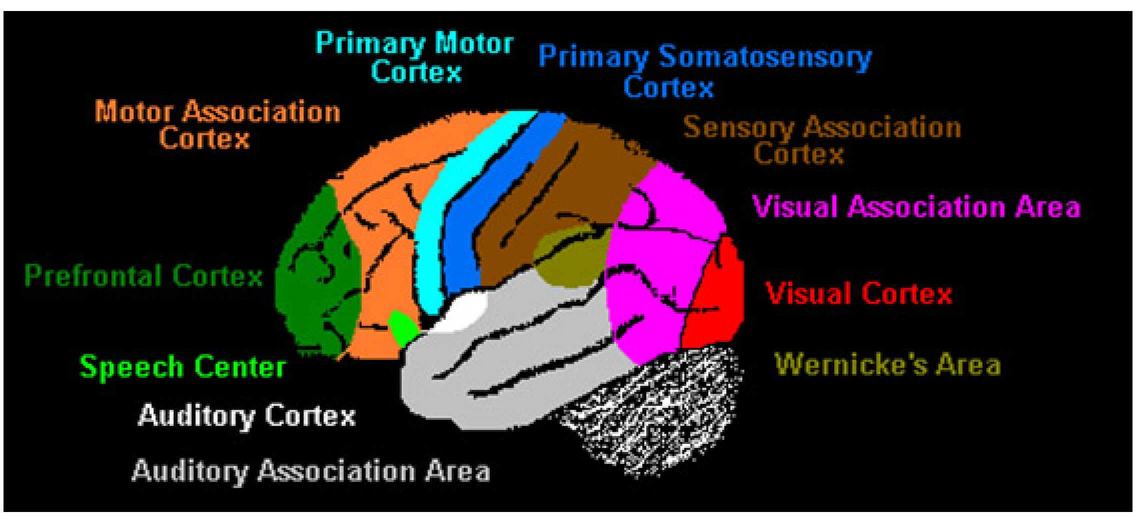
The frontal lobe maintains attention and intense concentration filtering out other objects of attention so that maximum cognitive resources are available for the task. [26] The prefrontal cortex is part of this frontal lobe located directly behind the forehead. The frontal lobes are where executive function is located. It is the most evolved of the lobes, able to retrieve and process vast amounts of information from various systems of the brain to evaluate, problem solving and create. [27]

Although the cerebrum is divided into four main lobes, specialized functions have been identified and marked by specific folds on the cerebrum called cortical areas. Below is a chart naming each cortical area and the major function associated with the area.

Cortical Areas of the Cerebrum



http://faculty.washington.edu/chudler/functional.html- www.Neuroscience for Kids

Cortical Area-	Function
Prefrontal Cortex	Problem Solving, Emotion, Complex Thought
Motor Association Cortex	Coordination of complex movement
Primary Motor Cortex	Initiation of voluntary movement
Primary Somatosensory Cortex	Receives tactile information from the body
Sensory Association Area	Processing of multisensory information
Visual Association Area	Complex processing of visual information
Visual Cortex	Detection of simple visual stimuli
Wernicke's Area	Language comprehension
Auditory Association Area	Complex processing of auditory information
Auditory Cortex	Detection of sound quality (loudness, tone)
Broca's Area	Speech production and articulation[28]

Cerebral Cortex

The cortex makes up about 40% of the brain's total weight. This highly developed layer of gray matter is only an eighth of an inch thick, and has 20 billion neurons. These neurons are organized into six layers. The cortex covers both the right and left hemispheres of the cerebrum and is characterized by deep folds and groves called sulci and gyri. These dense folds triple the surface area of the cortex enabling increased surface area to fit into the skull. If smoothed out, the wrinkles would cover 2.5 square feet. [29] The cortex enables us to perceive, communicate, understand, and appreciate. This is the part of the brain that is associated with all the thought processes related to consciousness, distinguishing our species as uniquely human. [30] The ability to know one as a "self" and understand ones character in a conscious way is a function of the prefrontal cortex. The intense neural density and connectivity of this gray matter is probably the most important characteristic of the cerebral cortex because they are the anatomical features that produced consciousness and our ability to exercise complex cognition, rationality, and creativity.

Limbic System

The limbic *system* sits underneath the corpus callosum. This system consists of the thalamus, hypothalamus, hippocampus, and amygdala. The structure of the limbic system has roots in primitive evolutionary history. The limbic system sends emotional information to the cortex. The cortex interprets this information on a conscience level. In this way, the limbic system blends the primitive reflexive emotional responses with higher level reasoning functioning in a way that unites the two responses.

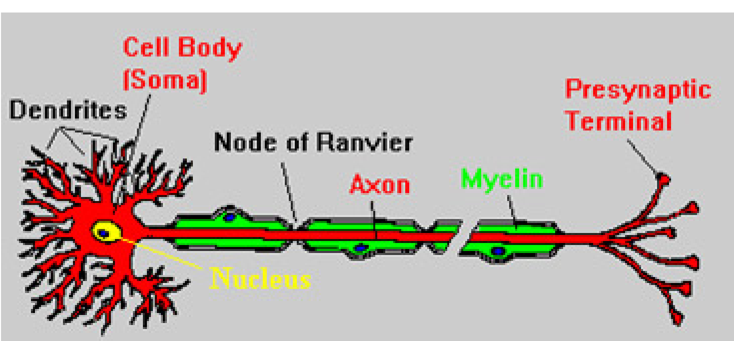
Right and Left Hemispheres

The cerebrum is divided into two hemispheres called the right and left cerebral hemispheres. A thick band of axons connect these two hemispheres. 300 million axon fibers form a bundle of cables called the corpus callosum. It is through the corpus callosum that the two sides communicate. [31] This neural bridge provides the pathway for a continuous dialogue between the two hemispheres. [32] The corpus callosum allows the two hemispheres to share memory and learning, as well as disease. In an effort to help patients with severe epileptic seizures, between 1961 and 1969, Dr. Sperry led a group of doctors that cut the corpus callosum. He studied the effects of this operation on his patients called, the "split brain" patients. It was discovered that the two hemispheres had a separate, distinct, and very different ways of viewing the world. Each hemisphere had no awareness of the other. Each acted independently and had its own kind of perception. [33] Although the right and left hemispheres function in distinctly different ways, together they work together each contributing their part to the whole. Each of the sides processes the same information in two distinctly different ways and responds to the information in equally unique ways. [34] The right side of the brain is often describes as being the artistic hemisphere, while the left side of the brain sees the details and is the verbal and analytic hemisphere. Language is located in the dominant hemisphere, usually the left. These are generalizations, since many functions are shared between the hemispheres.

After Jill Bolte Taylor, a neuroscientist, survived a stroke she provides this description of each hemisphere based on the recollection of her symptoms. During her stroke she experienced the world through each hemisprere of her brain very specifically during her own brain hemorrhage. Taylors describes the right and left hemispheres as having two distinct ways of processing information . She explains that the two hemispheres think about different things and care about differnent things, viewing the world with two very different personalities. The right brain is all about the present moment, the here and the now. It thinks in pictures and learns through the movement of our body, kinisthetically. The right brain interprets the present through the senses, interpreting the present moment through the streams of sensory energy; the smells, feels, tastes, sounds and sights, forming a "sensory collage" of the present moment. The right hemisphere views the world connected to each other as beauiful, and unique creatures, a family- a whole. Here to make the world a better place.

Taylor describes the left hemisphere as thinking linearly and methodically. It is logical. The left hemisphere is all about the past and future, it picks out details from the present to make predictions about the future. The left hemisphere is designed to pick out details from our enourmous sensory collage of the present moment catagorizing and organizing information and associates it with everything in the past that we have ever learned so that it can project the possibilites for the future. The left hemisphere thinks in terms of language, the "brain chatter." It is the little voice in our heads that connect our internal world to the external world. The two sides of our brain living side by side, separate, unique, special, viewing the world very differently, but together they create for each of us our customized perspective of the world we live in.

The Neuron



The neuron is a specialized electrically excitable brain cell. We are born with most of our 100 billion neurons . This cell is able to create, send, and receive messages. There are many different kinds of neurons. Sensory neurons are special structures that detect changes on or inside the body. Motor neurons carry messages to muscles. Interneurons sum up information from sensory neurons before they communicate messages to motor neurons. [35] The neuron is enclosed in a cell membrane and is composed of three main parts; a body or soma, axon and dendrites. Cell growth occurs from increasing the size of dendrites and forming new connections in response to stimulation. [36] These connections are affected by increased and decreased activity. Pathways that are used regularly are "hard wired" while less used pathways are lost or "pruned". Practice makes perfect; use it or lose it. [37] A cell can have tens of thousands of dendrites branching off the soma like branched on a tree, but a neuron has only one axon that branches out at its end. Dendrites receive electrical impulses from other neurons and transmit the impulse through the axon to the next cell. [38] Sometimes, however, messages are not sent. A neuron is often bombarded by thousands of inputs; both excitatory and inhibitory actions. The neuron is able to integrate these actions, sum them up and respond to the greater of the actions. If the dendrite receives enough messages that are excitatory in nature, it fires an impulse, called an action potential through the axon. A fatty substance called the myelin sheath wraps around and insulates the axon. The thickness of the axon and its myelin wrapping determines the speed with which information travels in it - the thicker the nerve fiber, the faster information travels in it. The myelin sheath is absent at regular intervals along the axon. These exposed parts of the axon are called, Nodes of Ranvier. The journey is enhanced by electrical boosts produced along the axon by the nodes. Electrical impulses move down the axon, often at great speeds. Some axons conduct action potentials at 100 meters per second, while others conduct at less than a meter per second. The electrically charged journey propels the neurotransmitters to their final destination, the axon terminal, where they can be released into the synapse. [39]

Synapse

The synapse is the tiny space between the delivering neuron and the receiving neuron. This is the space that the neurotransmitters cross. Neurotransmitters are chemical molecules that allow signals to pass from neuron to neuron. Neurotransmitter molecules are made in the soma. These molecules are transported along the axon by a tube like conveyor belt and packaged into tiny little balloon like packages called synaptic vesicles. When these little synaptic packages come to the end of the axon, they fuse to membrane. When an action potential arrives, they release their contents, the neurotransmitter molecule, into the synapse. After the neurotransmitters are released into the synapse, or tiny space between the two neurons, they bind to the receptors of the receiving neuron. When this binding occurs, it creates a change in potential in the receiving neuron that may allow for it to pass on the message to the next neuron. This can be quite complicating because of the many connections involved within a single neuron, but the action is determined by the stronger of the forces at the time- inhibitory or excitatory. [40]

Neural pathway form and change because of increased or decreased need for these electrical connections and modifications. The adaptability to change structurally is called brain plasticity. At birth, each neuron in the cerebral cortex has approximately 2,500 synapses. By the time, an infant is two or three years old, the number of synapses is approximately 15,000 synapses per neuron. [41] This amount is about twice that of the average adult brain. As we develop, unused connections are deleted through a process called synaptic pruning. When neuronal synapses activate often, they make more connections and they become stronger. The ability of the brain to change in this way is called plasticity. [42]

Cognition

Memory

About 2000 years ago, before books, knowledge was retained by memorizing information. One's ability to remember information was synonymous with one's intellectual prowess. Consequently, elaborate techniques to memorize vast amounts of information evolved. Remembering was an art, encoding information to be remembered into visually elaborate detailed stories with emotional associations attached to meaningful personal experiences. These mental movies created a journey of experiences that included engaging activities in a highly vivid visual sequence of events in one mind's eye, connecting each mental event to the topics to be remembered. This technique was called building a Memory Palace and is used by the mental masters of today. (described by Joshua Foer) These ancient techniques illustrate the fundamental elements of the memory process. We remember what we give our attention to. We remember what we experience through our senses. We remember what we are engage in. We remember what is meaningful and relevant to us. [43]

Our memories are the building blocks of our thinking and learning. They are the framework for our very existence holding the pieces of lives. What we remember and what we know defines who we are. Knowing and remembering allows one to understand. The ability to recall and manipulate, shuffle, reorganize, and recreate, is higher order thinking. Memory is a highly complex multifaceted system involving many areas and functions of the brain working together. Our memories are formed through a series of stages. The way memories are made; stored, recalled, and processed is the foundation of cognition. It is our memories that create the highly sophisticated way we are able to relate to our environment, the global community; a long way from eat or be eaten. We continue to evolve.

A memory is made in stages; sensory, immediate, short term, working and long-term memory. Memories begin as a deluge of experiences streaming in through our senses. Our sensory memory screens this plethora of sensory stimuli. In a millisecond, this information is sifted by its importance, related to survival, at the brain stem in the RAS (reticular activation system) and thalamus. Emotions strengthen memories and increase their importance. Fear and anxiety cause a reflexive response that inhibits cognitive functioning when hormones are released. [44] Immediate memory and short-term memory are temporary and unconscious. Immediate memory holds information for just 30 seconds, and then drops irrelevant data. With further attention, information is sent to short-term memory. The prefrontal cortex is active during this stage of processing. Small amounts of information are held ready and active for seconds to a minute. Information can stay in short term memory for longer periods if it is reintroduced, through rehearsal, or repetition. [45] Working memory is temporary and processes information on a conscious level. Two separate neural circuits are thought to keep information alive in working memory; the phonological loop that encodes audio signals and the visuospatial sketchpad that encodes visual and spatial information. The flow in and around these two systems is controlled by the central control system in the prefrontal cortex. [46] Working memory cannot attend well to both audio and visual input at the same time. Working memory has specific limitations involving time and quantity. Pre-adolescents can spend 5-10 minutes processing in working memory with sharp focus and 10-20 minutes is considered average for adolescents and adults. Fatigue and lack of focus will occur beyond these limits unless there is a change or break in the manner the information is being addressed. Working memory can organize and manipulate data from short-term memory as well as data from long-term storage, but can only handle a few items at once. Working memory can juggle an average of five items for ages 5-14 and an average of seven items for adults, but this capacity can be improve by chunking information together in ways that give meaning. [47] Longterm memory can store large amounts of information for a lifetime. Information worth holding onto breaks out of working memory and travels to the hippocampus where it is encoded permanently through a process called long term potentiation and sent to sensory associated areas in the brain. The more ways information is encoded, the greater the number of memory pathways. This is why presenting information in a variety of ways, involving many of the senses is so effective. It is like learning many different routes to the same location. In addition, when new learning is associated with the senses, recall pathways are strengthened. [48] Memories are stored with associated pre-existing experiences after attention given, making sense of, and giving meaning to the memory. A memory is consolidated when the neural firing pattern is played back and forth often between the hippocampus and the cortex. This repetition causes the memory to move permanently to the cortex, freeing up space for new memories in the hippocampus. Consolidation mostly occurs during sleep. [49]

When a memory is recalled the hippocampus is able to retrieve information from sensory associations and is able to put the parts together as a whole, reconstructing the original experience accompanied with senses and emotions. When recalling an experience, neurons fire in the same pattern that they fired when the experience was encoded, thus reconstructing the episode. Retrieval is the re-creation of a past experiences by the synchronous firing of neurons that were involved in the original experience [50] creating an electrical pathway. When this same memory is recalled repeatedly, the neurons become more strongly connected. Their firing pattern is sensitized, pre-set, and ready to go. If one neuron in the pattern is stimulated and fires, the other neurons will automatically fire the pattern, like a set of dominoes. The memory pathway becomes "hard wired," recalling more quickly and efficiently. [51] An event in the present can also stimulate recall of information to be used to guide a decision or action. When a memory is retrieved, it is integrated into the new information causing a slight change to the memory. [52]

Creative Thinking

Recent studies by Sharon Thompson - Schiller, a neuroscientist at the University of Pennsylvania, have shown that creative thinking occurs under unique conditions. Normally the pre frontal cortex is engaged in focused, rule guided cognitive activity. However, this area acts very differently in a creative mental state when novel ideas are generated. There is a lower state of cognitive control in the prefrontal cortex during the creative mental state when generating novel ideas. In this state, rules and assumption do not "box in" our thinking. It was discovered that the prefrontal cortex became electrically "quiet" when the subject thought with fewer restrictions and was in a state of "blurred" attentional focus. Thompson- Shillers team gave this state a name, they called it *hypofrontality* . [53] This kind of thinking is very different from the mental state of cognitive control and focused thinking involving ridged perimeters, guidelines, and assumptions as when analyzing or evaluating. Additional studies in the 90's supported this hypothesis when brain waves were measured over the prefrontal cortex. While participants generated novel ideas, alpha waves (8 to 12 cycles per second EEG waves) were recorded. The synchronized firing of the neurons in the state of defused attention and relaxed wakefulness is a state of lower cognitive control. Alpha waves denote a synchronized firing of the neurons. Further support for the theory of "*hypofrontality*" was found during the generation of novel ideas, in Schiller-Thompsons most recent study. In this study, participants were asked to find uses for objects. The most creative participants showed minimal activity in their prefrontal cortex but also showed activity in the posterior brain regions, areas of visuospatial skills. [54] These studies suggest that when there is lower cognitive control, thus less filtering of knowledge, one is able to think more creatively. The state of hypofrontality allows one to be more open to possibilities without preconceived notions and assumptions that could stifle thought. The characteristics of the mental state needed to generate novel ideas and facilitate creative thinking is a state that is relaxed, with less cognitive control, and defused attention. However, the mental state needed to become the subject area expert necessary before entering the creative domain requires a mental state of focused attention with cognitive control.

The ability to move back and forth between these cognitive states, from a mental state with high cognitive control to a relaxed state of diffused attention of lower cognitive control, is called cognitive flexibility. In a 2010 study by Zabelia and Robinson, it was discovered that the more creative thinkers showed greater cognitive flexibility when measuring results of the Stroop test, a test that measures cognitive control using color words written in same and different colors than their name. [55]

Creative thinking is our highest cognitive domain. It is the thinking that generates novel ideas and innovations. Creative thinking requires a unique mental state, hypofrontality, a relaxed state with defused attention, and less cognitive control. In addition, the generation of creative ideas and solutions is best accomplished alone, but after it is generated, sharing the idea with others can help develop it. Once a creative idea is generated, however, putting it into action and developing it requires a more controlled, focused cognitive state as needed for assessing and evaluating. [56] Breaking through old thinking styles requires one to exercise cognitive flexibility, an ability to move fluidly between mental states as needed. I believe this skill is worth sharing with our student and structuring learning for this opportunity. With this understanding, students will learn to exercise cognitive flexibility, adapting as necessary to the needs of a particular problem, stretching their mental limits propelling them forward, as thinkers, innovators, and creators.

Common Core Content Standards addressed in this unit:

Scientific Inquiry

· Scientific inquiry is a thoughtful and coordinated attempt to search out, describe, explain, and predict natural phenomena.
Scientific Literacy
· Scientific literacy includes speaking, listening, presenting, interpreting, reading and writing about science.

Lessons and Activities

Daily Journals: Students will record their hypnosis, predictions, procedures, questions, observations, and results of activities. Students should be encouraged to include detailed illustrations in their records.

Activity: Clay Model of the Brain

Objective: Students will build a brain constructing each anatomical feature as it is learned and label with toothpick flags. Students will understand that the brain has a unique anatomy made up of many parts with specialized functions. Each anatomical feature will be a different color.

Materials: modeling clay of varied colors.

Lesson 1: Brainstem: Midbrain- Pons - Medulla

The medulla is an extension of the spinal cord, where the spinal cord changes into the brain. The medulla becomes structurally thicker; the pons is like two thick stalks with bulges on the side near the top of the medulla the size of a large gumball about 2.5 cm. The pons lies behind the medulla and cerebellum connecting the medulla to the midbrain.

Objective: Student will understand the anatomy and functions of the brainstem.

Students will roll out a coil of clay that is thicker at the top to show the medulla extending out of the spinal cord. The length should be about 10 cm. Students will shape a bulge on the side top of the medulla to form the pons, which serves as a relay station of sensory information between the cerebrum and cerebellum and the rest of the central nervous system.

Lesson 2 Cerebellum

Objective: Students will understand that the cerebellum is located at the nape of the neck and behind the medulla.

Students will make a cerebellum with two symmetrical parts (about 4 cm) that look like small clams and know that its main functions involve muscle movement, coordination, and balance. Student will make two oval shapes and attach them to back of the brainstem and label it with a toothpick flag.

Lesson 3 Thalamus

Objective: Students will understand that the thalamus consists of two oval shaped masses that sit above the medulla side by side, one in each hemisphere. Students will understand that the thalamus sorts information from the four senses, sight, hearing, taste, and touch.

Students will make a thalamus by rolling and shaping clay into two ovals, 1.5cm x .75cm. Then, place the two ovals side by side on above the pons and medulla and label with a toothpick flag.

Lesson 4 Hypothalamus- Hippocampus- Amygdala

Objective: Students will understand that the hypothalamus is the size of a dime and is able to keep homeostasis within our body, regulating and controlling autonomic functions and conscience function of behavior and instinct releasing hormones as a result of sensory input. Students will shape an amygdala like a little ball and hippocampus like a seahorse and place it above the thalamus.

Lesson 5: Cerebrum

Objective: Students will understand that the cerebrum is a thin flat organ that has many folds so it can fit in the skull.

Students will roll clay to 12" diameter circle 1/8 inch thick. Cut the circle in half and fold. Wrap each folded half around the each side of the thalamus on top of the brainstem, making the cerebral cortex covering each right and left hemisphere separately. Label with toothpick flag.

Lesson 6: – Evolution of Brain: Timeline

Objective: Students will understand that the brain's anatomy and function has evolved over time.

Hand our pictures of a fish, worm, amphibian, reptile, mammal, and human as well as pictures of their brains. Ask students to match brains with species, then compare and contrast the physical features of the brains with the animal function using what they have learned about that anatomy of the brain. Then distribute reference guides with dates for the development of each species. Divide students into groups. Instruct students to draw a timeline marking dates, and label date with species. Ask students to list characteristic of each group in relation to its environment. Discuss characteristic of each brain in relation to the environment and species. Hypothesis reasons for change, examine evidence. Make predictions. Encourage use of resources during exercise, ie classroom computers and library.

Lesson 7: The Neuron

Objective: Students will understand that a neuron is a special brain cell with unique features designed to communicate messages in electrical neural pathways as they illustrate and act out its function.

Draw two neurons on the board and label the parts while explaining their functions. (Soma, axon, dendrites, neurotransmitters, vesicle, synapse) Illustrate how a message is sent. Ask students draw and label the parts of the neuron in their notebook. Divide the class into groups. Hand out chart paper, scissors, and colored paper for the vesicles with neurotransmitters molecules in them. Ask students to work together to make two neurons sending a message. Outside on the basketball court, ask student to draw several neurons (4-5) with colored chalk. Students will be neurotransmitters and demonstrate a neural pathway as a neurotransmitter moving down the axon, across the synapse to the dendrite of the next neuron. Ask students to make different pathways.

Lesson 8: What is in the Bag? Sensory Integration- Thalamus

Objective: Students will learn that the senses work together gather information.

What's it the bag? Put popcorn in paper bags. Working with a partner, ask students to use their sense to make hypothesis about the contents of the bag. Open bag to verify prediction. Enjoy the contents with multisensory experience. Variations: Senses and objects can vary. Make guesses by feeling what is in the bag

Extended reading: Louis Braille

Lesson 9: Memory: Practice Improves

Objective: Students will understand that when practicing recalling information it creates stronger pathways that are faster and more efficient.

Time each trial and graph results to show improved speed and accuracy. Ask student to write down a sentences then pick one. Line up ten students. Ask only the first person to read the sentence and then whisper the sentence to the next student, passing the message along to the end just like a neural message. Ask the last student to write what was heard after the message passed through the ten of them. Compare the beginning message with the end message. Repeat trial 3 times timing each. Compare the speeds and accuracy.

Lesson 10: Memory- Build a Memory House

Objective: Students will understand that memories are stored in associated sensory areas

Draw a memory house. Pick a significant memory. Illustrate each part of the memory in relation to each of the senses you remember during the experience. Draw a house with each room being a different sense- smells, tastes, feelings, sights, sounds. Draw or list all the related memories associated with each sense.

Lesson 11: Attention/memory

Objective: Students will understand that they will remember what they give their attention to and miss what they do not.

Partner students. Ask students to face each other and each taking turns and ask 5 questions about their favorite foods. Next, tell students to turn around and change 3 things about themselves, physically- secretly. (ex: remove glasses, hold a pencil, roll up sleeves) Ask students to turn back to their partner and ask what changes they noticed. Students will have difficultly as their attention was focused on questioning. Record observations and hypothesis.

Lesson 12: - Thinking Creatively

Objective: Students will understand that creative thinking involves organizing and sorting information in a variety of ways, different uses for an object, new ways to look at things, breaking down ideas into parts and trying new ways to put the parts together.

Give students the Stroop test [57] measuring cognitive control and flexibility. Give students 9 object. Ask them to sort items into categories. Label and explain sorting. Repeat three times. Grouping items in different ways exercises creative thinking. Pass out ordinary objects. Ask student to see how many uses they can you think of for, popcorn, a newspaper, pencil, paperclip, a thumbtack. Share ideas. Thinking of objects in a variety of way exercises creative thinking because helps us see, question, and move beyond assumption.

Lesson 13: Creative Creatures

Objective: Students will apply what they have learned about the brain's anatomy as it relates to function in a novel way by creating fictitious creatures. Encourage, humor and exaggeration, "super human qualities," gently nudging students, "outside the box." Ask student to write a description of what their creature can do and why. Extension: Create super heroes with "super human qualities," with a written description of the abilities and physical characteristics based on anatomy and function of the brain. Ask students to illustrate and describe their character including a magnification the brain structure with captions that describe the super human qualities of this brain anatomy and functions.

Bibliography

Ackerman, Sandra. *Discovering the Brain for the Institute of Medicine National Academy of Sciences* . Washington, D.C., 1992. The book arose from a 1990 symposium organized by the Institute of Medicine to initiate the presidentially declared decade of the brain. Ackerman discuss the brain systems and function on a molecular level describing advances and presenting a clear overview of neuroscience to date in addition to political and improved mental health perspectives.

Carter, Rita. *Mapping the Mind* . Berkeley, Los Angeles: University of California Press, 2010. A fascinating book explaining complex roadmaps of thought and cognitive processes based on most recent brain research; elaborate illustrations and photographs.

Carter, Rita. *The Human Brain Book* . London, England: Dorling Kindersley Limited, 2009. Rita Carter writes with clarity and profound understanding as she describes the anatomy and functions of the brain with explicit detail. In addition, her writing is accompanied by full color illustrations, highly detailed visual explanations supporting Carter's explanations.

Chrysikou, Evangelia G. *Your Creative Brain At Work* . Scientific American Mind , Volume 23, Number 3, August/July: Scientific America, Inc., New York, New York, 2012.

Foer, Joshua. *Moonwalking with Einstein* . New York, New York.: The Penguin Press, 2011. Foers intrique with memory savants carries him on a colorful journey challenging himself to become a memory champion in his own right. He takes you through a query culture of savants and interpreting the science and art of remembering in ways you have never considered. Foer explores the art of memorizing and its relationship to how we think about our memory today giving a new perspective about the way we think about remembering.

Mader,Sylvia. *Human Biology* . New York, New York: McGraw Hill, 2008. A biology text book, The book has proved to be a great reference for the basic biological processes and anatomical structures of the brain. Information is clearly stated and supported with many detailed and informative illustrations.

Marzano, Robert, Debra Pickering and Jane Pollock. *Classroom Instruction that Works* . Alexandria: Association for Supervision and Curriculum Development, 2001. A comprehensive resource of research based teaching strategies that are proven to increase student achievement.

McGregor ,Tanny. *Comprehension Connections, Bridges to Strategic Reading* , Portsmith: Heinemann , 2007. An excellent resource for the application of metacognitive reading strategies. The Trait Mate symbols can be applied to many of these reading strategies.

Sack, Oliver. *The Man Who Mistook his Wife for a Hat* . A collection of stories involving patients with rare and unusual dysfunctions of the brain told through the eyes of a doctor of neuroscience as well as a man with deep compassion, relaying the fragility and resilience of the human mind and spirit with a touch of humor!

Shubin, Neil. *YOUR INNER FISH, A Journey into the 3.5 Billion Year History of the Human Body* . New York,: Vintage Books a Division of Random House, Inc.,2008. Shubin carries the reader through time and species in a scientific journey of discovery connecting our anatomy to species 3.5 billion years ago as he unites us with our inner fish. The extraordinary connections that link us structurally, molecularly and genetically through time and species are described in fascinating detail as Shubin evokes awe and wonder in our direct and explicit connect to the life around us, offering perspective and history of ourselves.

Sousa, David A. *How the Brain Learns, Third Edition.* Thousand Oaks California: Corwin Press, 2006. Sousa uses the latest research in neuroscience to discuss the application of these finds in terms strategies and skills that can be implemented in the classroom in order to improved teaching and student learning.

Williams, Robert, and John Stockmyer. *Unleashing the Right Side of the Brain The LARC Creativity Program, The Systematic Approach for Unlocking Creative Potential.* Lexington, MA.: The Steven Green Press, 1987. In addition to a comprehensive discussion of the left and right brain functions, Williams and Stockmyer describe an innovative look into the undeveloped, undervalued, untapped power of the brain's creative potential and a systematic approach to access creative thinking.

Willis, Judy M.D. *Researched –Based Strategies to IGNITE Student Learning, Insights from a Neurologist and Classroom Teacher.* Alexandria, V.A.: Association for Supervision and Curriculum Development, 2006. Willis combines experience and knowledge and as a neuroscientist with her expertize and passion for teaching offering a insightful guide to brain function and its relation to the academic implications. Willis organizes her writing in a way that can be easily understood and accessed for quick reference. The sections of "Grey Matter" included in each chapter align specific brain function on a neural and chemical level as well as detailed descriptions of anatomy involved in processing the concepts being discussed.

Wooldridge, Dean E. *Sensory Processing in the Brain an Exercise in Neuroconnective Modeling* . London: John Wiley And Sons, 1979. An excellent study of sensory processing through models of neural processes. The text includes operating and circuit characteristics of sensory processing. Each of the senses is addressed, from the simplest- smell and taste to most complex-visual, to which he devotes half the book. Wooldridge lays out his processing data from the perspective of - physical properties and the detailed actions of interconnections. Although extremely technical and detailed, Wooldridge conveys the complexity of neural processing in a way that can be understood to those who seek a deeper understanding of these processes and are willing to take is slowly.

Bloom, Floyd E. *Best of the Brain from Scientific American: Mind, Matter, and Tomorrow's Brain* . Washington: Dana Press, 2007.

Web Resources

http://kidshealth.org/kid/htbw/brain.html

http://faculty.washington.edu/chudler/introb.html

http://www9.biostr.washington.edu/da.html

http://www.med.harvard.edu/AANLIB/home.html

http://www.ted.com/talks/jill_bolte_taylor_s_powerful_stroke_of_insight.html

Endnotes

1. Rita Carter, The Human Brain Book, p

2. Rita Carter, The Human Brain Book, p.48.

3. Rita Carter, Mapping the Mind, p.33.

4. Rita Carter, Mapping the Mind, p. 32.

5. Rita Carter, The Human Brain Book, p 49.

6. Rita Carter, Mapping the Mind, p 32.

7. Maya Pines, Landscapes of the Mind, The Incredible Machine,p.326

8. Neil Shubin, Your Inner Fish, p.80.

9. Rita Carter, The Human Brain Book, p.57.

10. Rita Carter, The Human Brain Book, p. 57.

11. Sandra Ackerman, Discovering the Brain, p.15.

12. Davis A. Sousa, How the Brain Learns, p.18

13. Rita Carter, The Human Brain Book, p.63

14. Sandra Ackerman, Discovering the Brain, p.16

15. Rita Carter, The Human Brain Book, p.245.

16. Sylvia S. Mader, Human Biology, p. 259.

17. David A. Sousa, How the Brain Learns, p.20.

18. Rita Cater, The Human Brain Book, p. 60.

19. Sandra Ackerman, Discovering the Brain, p.16.

20. Sylvia Mader, Human Biology, p.258.

21. Rita Carter, Mapping the Mind, p. 14.

22. Rita Carter, The Human Brain Book, p.160.

23. Rita Carter, The Human Brain Book, p. 157.

24. David A Sousa, How the Brain Learns, p.19.

25. Rita Carter, Mapping the Mind, p 14.

26. Rita Carter, The Human Brain Book, p.180.

27. David A. Sousa, How the Brain Learns, p.16.

28. http://faculty.washington.edu/chudler/functional.html www.Neuroscience for Kids

29. Rita Carter, The Human Brain Book, p 39.

30. Maya Pines, Landscapes of the Mind, The Incredible Machine, p.326 329

31. David A. Sousa, How the Brain Learns, p. 166

32. Rita Carter, Mapping the Mind, p.40.

33. David A. Sousa, How the Brain Learns, p.166.

34. Betty Edwards,, Drawing on the Right Side of the Brain, p.36.

35. Sylvia Mader, Human Biology, p.249.

36. Judy Willis, Ignite, p.1.

37. Judy Willis, Ignite, p.2.

38. David A. Sousa, How the Brain Learns, p.21.

39. Sylvia Mader, Human Biology, p. 253.

40. Rita Carter, The Human Brain Book, p.73

41. Gopnick,, 1999).

42. (Erin Hoiland, Neuroscience for Kids Consultant)

43. Joshua, Foer, Moonwalking with Einstien, p. 13.

44. David A. Sousa, How the Brain Learns, p.45.

45. Sylvia S. Mader, Human Biology, p.260.

46. Rita Carter, The Human Brain Book, p.159.

47. David A. Sousa, How the Brain Learns, p.43

48. Rita Carter, The Human Brain Book, p. 156

49. Rita Carter, The Human Brain Book, p 159.

50. Rita Carter, The Human Brain Book, p.154.

51. Rita Carter, The Human Brain Book, p.154.

52. Rita Carter, The Human Brain Book, p. 154.

53. Evangelia G. Chrysikou, Your Creative Brain at Work, p. 27.

54. Evangelia G. Chrysikou, Your Creative Brain at Work, p.27.

55. Evangelia G. Chrysikou, Your Creative Brain at Work, p.29.

56. Evangelia G. Chrysikou, Your Creative Brain at Work, p. 31.

57. Evangelia G. Chrysikou, Your Creative Brain at Work, p.28.