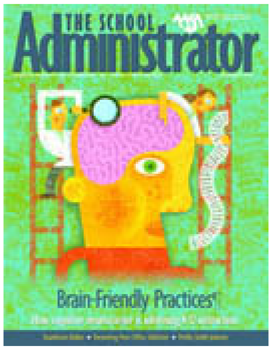

THE SCHOOL Administrator
December 2006

Features

Addressing Literacy Through Neuroscience

With the brain now viewed as a continuously modifiable ‘plastic’ organ, educators have real opportunities to influence students’ experience-dependent learning

By Steve Miller and Paula A. Tallal

What is he thinking?

It’s a typical Monday afternoon and you are talking with a teenage boy about a short story he read in school earlier that day. He seems to be having unusual difficulty expressing his thoughts about the story. Did we read the same story? Why is this so difficult for him? What’s going on inside his head?

Most educators have asked themselves the latter question more than once. And they are right to focus on the head — or more precisely the brain — as it holds the secrets to understanding human behavior.

The brain is the source of all of our thoughts, feelings and emotions. Much of what defines us as humans — our creativity, our use of language, our critical thinking skills — is housed somewhat mysteriously in the brain. Now the mysteries of the human brain are rapidly being elucidated by neuroscience research. In the past few decades, no area of importance to educators has been so significantly transformed than our understanding of the way the brain learns.

New Insights

For more than 150 years, neuroscience has held that most of the brain’s functionality develops during critical periods in early childhood and that once past these critical periods, the window of opportunity for brain modification slams shut. However, today, after decades of research, we’ve abandoned this view of the brain as analogous to a hard-wired computer in favor of the concept that the brain is a continuously modifiable “plastic” organ throughout life.

> *“…we’ve abandoned this view of the brain as analogous to a hard-wired computer…”*

This realisation provides new opportunities for us to explore and develop a more complete understanding of human brain development and cognition and, most importantly to educators, to create neuroscience-informed instructional strategies that enhance the brain’s capacity to modify itself through learning, known as neuroplasticity.

The brain learns at the physiological level of the neurons by looking for consistencies in what we experience, learning to attend to and map those patterns and events that repeat themselves frequently. Those events are usually made up of sensory input coming into the brain from the five senses. The brain's job, beginning at birth, is to code neurally, based on its experiences, what's going to matter and what's not going to matter and also to predict what is going to happen next. This form of learning is known as experience-dependent learning or neuroplasticity.

Photo by Rick McComb

Throughout our lives, as we learn new skills and acquire new knowledge, our brains are continuously being physiologically remodeled, creating selective clusters of brain cells, or neuronal cell assemblies, that respond more and more automatically and synchronously in time to events that come together or follow one another closely in time. Put simply, neurons that fire together wire together. That is, the more often a specific pattern occurs (such as a pattern of acoustic changes that occurs within speech), the more likely that pattern will be neurally coded or represented for easier and more efficient access at a later time.

This fundamental discovery of the role of experience-dependent learning, and specifically the precise scientific learning principles needed to enhance cognitive capacity, has led to major advances in the neuroscience of learning. Over the past 10 years, with the aid of computer technology and the Internet, these advances have been translated out of the research laboratory into classrooms nationwide to help students struggling with spoken and written language skills. This brain-based approach to intervention for struggling students has been shown to rapidly and efficiently enhance the fundamental learning skills (memory, attention, processing and sequencing) that form the foundation upon which efficient learning depends, specifically learning language and reading.

Language to Literacy

Like other complex tasks, reading is not an innate skill that develops spontaneously. Rather, it must be taught, practiced and learned. But before children can learn to read proficiently, they must first be able to understand and produce spoken language in the same language they are learning to read. It's not that you can't learn to read if you are not sufficiently proficient in the language you are trying to learn to read, but it's very difficult.

This language-to-literacy link compels us to explore the components of spoken language, the organization of these components in the brain and the links between them and reading so we can understand how the brain learns to read.

Language is comprised of five basic components: phonology, morphology, semantics, syntax and pragmatics. The first four are essential components of the reading process as well.

Phonology

Phonemes are the building blocks we use to construct words. They are the smallest unit of sound in spoken language that can change the meaning of a word. For example, the word *big* has three phonemes — /b/, /i/ and /g/. Changing one of the phonemes changes the meaning of the word, such as changing the /b/ to /d/ and producing *dig.* English has 44 different phonemes. When the acoustic patterns that make up phonemes repeatedly enter the brain as the infant listens to speech, the brain represents them as an assembly of brain cells (neurons) that fire together closely in time.

These neural representations of phonemes play an important role in learning to talk and subsequently in learning to read. Basically, the brain learns these distinct sounds and packages them as a cluster of neurons that fire in a certain pattern. When learning to read, the child must become aware that it is these patterns that must be extracted from inside of words and attached to letters (graphemes). This is known as phonemic awareness.

It is important to recognize that children are born with the ability to process the phonemes of all languages. After all, the brain does not know which language it will have to learn until it is exposed to it. This is where experience-dependent learning becomes critical. As infants listen to the language(s) spoken around them in the first year of life, their brain forms connections for only the phonemes they hear consistently — those of their native language. Phonemes that do not occur in that language or are too difficult for some reason for an infant to process are not wired into the brain. This has important consequences for understanding the neurobiological basis for reading difficulties later in life.

Following the rapid acoustic changes within the ongoing speech stream, which are critical to discriminating between the phonemes in a language, is one of the fastest things the human brain has to do. For example, only 40 milliseconds at the onset of the word *big* distinguishes it from the word *dig.*

Research has shown that for a variety of genetic as well as environmental reasons, many children who struggle with spoken and written language have difficulty tracking acoustic changes that occur this quickly. This interferes with their ability to map the distinct phonemes of their native language needed in both spoken and written language development. Importantly, if infants do not map distinct representations of each phoneme in the same language that they will ultimately be taught to read (either through lack of experience with that language or because of other factors that create a roadblock in the brain), they will struggle to retrieve the sounds inside of words that must be attached to letters in order to become a proficient reader.

The brains of children who are hearing impaired or have central auditory processing problems have difficulty representing phonemes correctly because their brain does not receive accurate acoustic input. As a result, these children are at risk for developmental language learning impairments, which can include both spoken and written language.

The same is true of children who are not native speakers of English. They do not have all of the English phonemes represented in their brain because they were not “wired in” through their early language experience. Children who struggle to learn to read English can benefit from training programs that are designed explicitly to emphasize the acoustic differences between English phonemes while also strengthening the other components of spoken English (morphology, semantics, syntax) that form the foundation of written English.

Paula Talla is co-founder of Scientific Learning Corp. and behavioral neuroscientist at Rutgers University.

One of the most important ways in which research on neuroplasticity has been translated into the classroom is through the development of novel computer-based intervention programs, such as the Fast ForWord series of language and reading programs that have been shown to improve the rate of acoustic processing and sharpen phoneme perception and phonemic awareness, all critical to reading.

These programs are unique in that they explicitly were designed to employ the scientific learning principles underlying neuroplasticity (which include frequency/intensity of input, individual adaptability, sustained attention and timely reward) to enhance the fundamental memory, attention, processing and sequencing skills on which effective classroom learning depends. Controlled scientific studies have been conducted that demonstrate that these neuroplasticity-based training programs lead to rapid and sustained improvements in English language skills as well as reading skills in struggling learners. (See www.scientificlearning.com/results.)

Morphology and Semantics

Morphemes are the smallest unit of meaning in language. Free morphemes are root words such as cat. Bound morphemes are suffixes, like an "-s" added to a root morpheme to create a plural, and prefixes, like an "un-" added to create an antonym of the root word. Free morphemes can stand alone; bound morphemes must bind to a root word to make sense.

By middle school, morphological awareness becomes more important than phonemic awareness for reading comprehension and for fluent, proficient reading. For children to become better readers in middle school, they may benefit most from programs that have been developed explicitly to enhance their knowledge of multimorphemic words (words such as *unnaturally* or *distastefully*).

Semantics rescues us from gibberish by providing a set of common vocabulary words and definitions that all native speakers of a particular language use to refer to objects or concepts. When we hear one of these words, we look it up in our brain's "mental dictionary" to retrieve its meaning.

Semantics also includes our brain's organization of word categorization systems. Word meanings include knowledge not only of an individual word, but also how that word relates to other words. For example, *cat* can be categorized in the most general sense as an animal. But it also can be categorized specifically as an animal with four legs and even more specifically as a household pet.

Words are stored in the brain together with other words that are related to them phonologically, morphologically and semantically. Interestingly, damage to specific areas of the brain can result in the loss of one category of words (such as all fruit), but spare others (such as all animals). Another interesting finding from neuroscience research is that when two languages are learned simultaneously very early in development, they overlap in the language areas of the brain. However, when one language is learned before another is begun, then they occupy discrete areas next door to each other in the language areas of the brain.

These insights from neuroscience research help inform the development of computer-based training exercises that aim at improving the semantic skills of children learning English as a second language as well as struggling readers.

Syntax

Syntax refers to the part of speech of a word (for instance, noun or adverb), the grammar of language as expressed by word order and grammatical morphemes, and the set of rules for combining words into sentences. Grammar helps us clarify meaning by providing a set of rules for creating explicit relationships among words. We use these rules to indicate exactly who is doing what and to whom. It also allows us to comprehend ambiguous words based on context. For example, we know, based on syntax, whether the word *bark* is referring to a part of a tree or a dog's vocalization. Syntax provides structure for almost everything that we say, write, read or hear.

To read English proficiently, children must understand the grammatical rules of spoken English. This can be particularly challenging when working with children whose native language is not English. Sometimes a student's incomplete knowledge of English is due to a lack of sufficient environmental input (children from low socioeconomic families are exposed to far fewer words than those from professional families) or due to a feature of the student's dialect that causes syntactical errors. But sometimes these errors result from the brain's inability to process sounds quickly enough.

Steve Miller is co-founder an senior vice president of Scientific Learning Corp.

Many grammatical endings in English, such as "-s" for third-person singular verbs or "-ed" for the past tense, are exceptionally brief in sound duration, especially when they occur within a sentence. Many children who are struggling to learn to read have difficulty picking up on the rapidly successive sounds within words, including these brief grammatical morphemes. When a student's neural processing of sounds is slow, the result may be phonological, morphological and/or syntactical errors in spoken and written language.

The Fast ForWord series of language and reading training programs explicitly focuses on increasing students' brain processing speed. These programs also use a patented speech algorithm that finds the brief segments within the ongoing speech stream (be they within phonemes, morphemes or syntax) and enhances these acoustic cues by making them longer and louder. As students progress in phonological, morphological, semantic and syntactic skills, the amount of acoustic modification decreases until they can perform adequately in each of these areas with normal speech.

The Reading Brain

When you are familiar with the basic elements of spoken and written language, it's easier to understand what is happening in your students' brains as they gather information about phonology, morphology, semantics and syntax when listening to or reading sentences or paragraphs.

As the electrical impulses representing each phoneme, morpheme or word course through the temporal lobe and into the frontal lobe of the brain, the brain picks up meaning and associations about the words (semantics) from areas of the temporal cortex. When a student processes grammatical morphemes, her superior temporal gyrus activates. When a student determines whether a word is a noun or a verb, his frontal and temporal regions activate.

Before reading can map onto the language areas of the left hemisphere, the occipital lobe, located in the back of the brain, needs to be activated. The occipital lobe is primarily responsible for vision-related functions and, therefore, must process the visual features of the letters. The brain must learn to recognize the visual form of each letter and store a mental representation based on experience-dependent learning similar to that used for learning representations of each phoneme.

Reading comes together in the temporo-parietal cortex in the left hemisphere, located above and behind the left ear. This is where information about letter shape, word recognition, meaning and sound is integrated in the brain. Damage to this area of the brain can affect reading ability in children or adults.

Rewiring to Read

Students' struggles to read can be caused by any number of factors, including genetic predisposition (language and reading disabilities often run in families), middle ear infections that may lead to blocking sound intermittently getting into the brain when phonemes are being mapped, lack of adequate and consistent exposure to words in the home during early development and/or the language used in the home is not the same as that used at school or for reading.

However, research on neuroplasticity has opened the door for developing novel, neuroscience-informed methods for enhancing basic cognitive and linguistic skills that are critical to reading success. This raises the question of whether the brains of struggling readers actually can be “rewired” to function more like those of normal readers?

To find the answer, Elise Temple, an assistant professor of human ecology, and her colleagues at Cornell University, conducted a study to determine whether the lack of activity in the temporo-parietal cortex of dyslexic readers could be normalized by behavioral training.

The study used the training program Fast ForWord Language. It focuses on auditory processing and spoken language through an intensive and adaptive series of computer exercises. One unique feature of the program is a focus on training the basic acoustic and cognitive skills (memory, attention, processing and sequencing) that are critical to listening comprehension, phonological and morphological awareness and other aspects of both spoken language and reading. The series of computer exercises, designed to mimic experience-dependent learning in the brain, specifically develops the components of spoken language that are most essential for reading.

In the study, children 8 to 12 years old with dyslexia underwent fMRI scans before and after eight weeks of participation. A control group of normal readers underwent two fMRI scans about eight weeks apart to control for practice effects. Both groups performed a phonological processing (letter rhyming) task while undergoing fMRI. Results were compared to a letter-matching task in which the child simply indicated whether two letters were the same or different. By comparing the brain function during the rhyming task with the brain function during the matching task, the researchers could observe the part of the brain that was activated for phonological analysis rather than orthographic (visual) processing of letters.

The results of the study were published in the Feb. 25, 2003, issue of the *Proceedings of the National Academy of Sciences.* During the first fMRI scan before intervention, the dyslexics showed the expected lack of activation in their temporo-parietal cortex compared to normal readers. Also as expected, the dyslexics’ performance on standardized reading tests was outside the normal range for their age. After eight weeks of participation, the dyslexic children’s performance on standardized reading tests improved significantly, moving into the normal range in all areas (word identification, word attack and passage comprehension). Increased activation in the left temporo-parietal cortex was also evident.

This is the first study to use fMRI to document scientifically that the brain differences seen in dyslexics can be “normalized” by neuroplasticity-based training. Perhaps of greater relevance to educators, parents and the children themselves are the accompanying significant increases in reading scores on standardized tests that were also documented as the result of this intervention.

Lifelong Processing

Brain research shows us that literacy problems are not simply a matter of a child not trying hard enough or of poor instruction. Nor are they likely to be solved by providing more traditional reading instruction. Rather, this line of research demonstrates that the biological as well as the experience-dependent aspects of learning to talk and to read require a neuroscience-informed approach to intervention for those students who are failing to make adequate yearly progress using more traditional methods alone.

The exciting news is that the brain remains open to neuroplastic modification throughout life when education and neuroscience work together to attack literacy problems. A third leg of this partnership is the use of advanced technology that allows laboratory research not only to be translated effectively for individualized instruction, but also scaled up so that it can be implemented broadly in a variety of K-12 school settings in a reliable, efficient and cost-effective manner. Because these neuroscience-based discoveries were translated initially for classroom use, they have been made available to more than 750,000 students in 4,000 schools nationwide.

Steve Miller is senior vice president for research with Scientific Learning Corp., 300 Frank Ogawa Plaza, Oakland CA 94612. E-mail: smiller@ scilearn.com. Paula Tallal is co-director of the Center for Molecular and Behavioral Neuroscience at Rutgers University, Newark. They are co-founders of Scientific Learning Corp