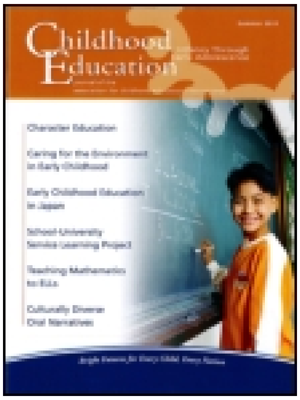

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Review of Research: Brain-Based Teaching Strategies for Improving Students' Memory, Learning, and Test-Taking Success

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Brain-Based Teaching Strategies for Improving Students' Memory, Learning, and Test-Taking Success

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The past two decades have provided extraordinary progress in our understanding of the nature of learning. Never before have neuroscience and classroom instruction been so closely linked. Now, educators can find evidence-based neuroimaging and brain-mapping studies to determine the most effective ways to teach, as advances in technology enable us to view the working brain as it learns.

Watching As Brains Learn

Studies of the brain's electrical activity (EEG or brain waves) and metabolic activity (from specialized PET brain scans measuring glucose or oxygen use and blood flow) show the pattern of movement as information travels through the brain. Synchronization of brain activity occurs as information passes from the data intake areas, through the emotion-regulating limbic system, and into the memory storage regions. For example, bursts of brain activity from sensory receptors in the cortex are followed milliseconds later by bursts of electrical activity in the limbic system. This is then followed by increased electrical activity in the frontal lobe executive function zones and subcortical memory storage regions. This activity constitutes one of the most exciting areas of brain-based memory research, because it gives us a way to see which techniques and strategies stimulate, and which impede, communication between the parts of the brain where information is processed and stored.

Plasticity and Pruning

It was a long-held misconception that brain growth stops with birth and is followed by a lifetime of brain cell death. Now we know that although most of the neurons where information is stored are present at birth, there is lifelong growth of the supporting and connecting cells that enrich the communication between neurons. These "dendrites" sprout from the neuron's arms (axons) or cell body.

Dendrites increase in size and number in response to learned skills, experience, and information. New dendrites grow as branches from frequently activated neurons. This growth is stimulated by proteins called neurotrophins. Nerve growth factor is one of these neurotrophins. Although the brain measurements of neurotrophins are highest during childhood, when the brain's connecting cells are undergoing their greatest growth and development, continued learning elevates neurotrophin activity in the brain region responsible for new learning and new memory formation (Kang, 1997). Once these dendrites are formed, it is the brain's plasticity that allows it to reshape and reorganize the networks of dendrite-neuron connections in response to increased or decreased use of these pathways (Giedd et al., 1999).

Brain plasticity is evident when people repeatedly practice activities controlled by parts of their visual, motor, sensory, or coordination systems for specialized learned activities. Blind people who read Braille, for example, have significantly increased the size of their somatosensory cortex, as the sense of touch in their right finger is employed over and over. Similarly, violin players who use the fingers of their left hands to do the complicated movements along the strings show increased somatosensory regions of the brain's parietal lobe associated with the fingers of the left hand.

A 2004 report in *Nature* (Draganski, Gaser, Busch, & Schuierer, 2004) found that people who learned how to juggle increased the amount of gray matter in their occipital lobes (visual memory areas). When they stopped practicing juggling, the new gray matter vanished. A similar structural change appears to occur in people who learn, and then don't practice, a second language.

This process is called pruning, the term for the decrease in connecting dendrites and other connecting cells that are not used. The loss of native language ability, juggling skills, or learned academic material that is not practiced is the flip side of the brain's growth response to learning. It is the use-it-or-lose-it phenomenon. Pruning occurs when some brain pathways and connections are selectively maintained and "hard-wired," while others are selectively eliminated, or "pruned." Since active cells require blood to bring nourishment and clear away waste, cells that are inactive don't send messages to the circulatory system to send blood. Eventually, these cells self-destruct.

To think about pruning in terms of brain cell growth, first consider the astonishing development of the embryonic brain—by week four, it is producing half a million neurons every minute. During the next several weeks, these cells travel to what will become the brain. It is there that they begin to form branching axons and dendrites, connecting them to each other. The synaptic junctions that are present at each connection between neuron, dendrite, or axon reach a maximum development rate of 2 million per second. This plethora of neurons and neuronal connections is pruned down in the last few weeks before birth. The orphaned neurons that did not form connections with neighboring cells die off; only the neurons that are in networks remain, becoming differentiated into circuits with specific functions (Sowell, Peterson, & Thompson, 2003).

After birth, the brain's gray matter has another growth spurt, with increased gray matter and connections reaching a maximum density at about age 11. This stage is followed by another pruning phase (Seeman, 1999). Without this pruning, too many crowded circuits would prevent the brain from operating efficiently.

The More Ways Something Is Learned, the More Memory Pathways Are Built

When children are between ages six and 12, their neurons grow more and more synapses, or connections between each other that are new pathways for nerve signals. This thickening of gray matter (the branching dendrites of the neurons and the synaptic connections they form) is accompanied by thickening in the brain's white matter (fatty myelin sheaths that insulate the axons carrying information away from the neuron and making the nerve-signal transmissions faster and more efficient). As the brain becomes more efficient, the less-used circuits are pruned away, but the most frequently used connections become thicker with more myelin coating, making them more efficient (Giedd et al., 2004).

Helping Students Grow More Brain Connections

The more ways that the material to be learned in the classroom is introduced and reviewed, the more dendritic pathways of access will be created in the brain. More synaptic cell-to-cell bridges will emerge, and these pathways will be used more often, become stronger, and remain safe from pruning. For example, offering the information visually will set up a connection with the occipital lobes, the posterior lobes of the brain that process optical input. If students can subsequently or simultaneously hear the information, it will hook up a dendritic circuit with the temporal lobes, the lobes on the sides of the brain that process auditory input, and also play an important role in regulating emotion and memory processing. This duplication results in greater opportunity for future cues to prompt the brain to access this stored information.

Multiple Stimulations To Build Memory

The more regions of the brain that store data about a subject, the more interconnection there is. This redundancy means students will have more opportunities to pull up all of those related bits of data from their multiple storage areas in response to a single cue. This cross-referencing of data means we have learned, rather than just memorized.

For example, when we learn about cars, we store the information in brain association areas under multiple categories that relate to the context with which new information about cars is learned. When we see a car, it goes into the visual image cortex. When we see the word C-A-R spelled out, that information goes into a language-association region. After learning about the internal combustion engine, cars are associated in our brain with other engines powered by internal combustion. Later, we build associational memories about cars we've experienced as a passenger or driver.

Because the information about cars is stored in multiple brain areas and cross-referencing occurs among these areas when we think about cars, connecting networks of dendrites sprout among these brain memory storage areas. This circuitry permits multiple cues or stimuli to call forth all our car knowledge instantaneously. Just seeing the word "car" will put our recall systems on notice to provide all the stored data we have pertaining to cars. While we may not need all that information, the associations will activate these circuits and any of the stored information that we do need can be rapidly and efficiently accessed. Therefore, it is optimal to teach important material through multiple learning pathways, such as through several senses (hearing, seeing, touching) as well as through several subjects (cross-curricular topics).

From Enriched Cages to Enriched Classrooms and Curriculum

Neuroimaging laboratory research long ago demonstrated how growing brains are physically shaped by experience. The brain sizes and weights of rats reared in standard cages were compared with those of rats that lived in enriched cages (i.e., there were more objects in their cages that they could manipulate). The rats reared in the enriched environments had brains that were larger and heavier. Their dendrites, neural pathways, and connections were much longer, more complex, and branched out to more areas of their brains.

Chimps living in enriched environments with stable social communities showed an increase in dendrite sprouting and synaptic connections in proportion to their increased ability to perform complex memory tasks, such as learning their way around a new maze. They also appeared to interact more positively with members of their group and to work more tenaciously on tasks and problems.

If a few pieces of metal in a rat cage and a stable community of chimps can do all that, think what educators can do in classrooms and curriculum. Building a supportive social classroom community, with enriched input from the environment, will result in students' brains building more pathways and their brain signals achieving greater speed and efficiency.

Educators As Memory Enhancers—Not Just Information Dispensers

Many classifications of the types of memory exist, and the one presented here is a conglomerate of several existing ones. From the most basic awareness of our environment, our memory skills progress from rote memory, working (short-term) memory, patterning and connections to relational memory, and, ultimately, long-term memory storage.

Rote Memory tasks are, unfortunately, the most commonly required ones for students. Students "memorize," and soon forget, facts that are often of little primary interest or emotional value, such as a list of vocabulary words. Often, these facts don't have obvious or engaging patterns or connections that give them context or relationship to each other or to the students' lives. By understanding brain-based strategies, teachers can use the least amount of rote memorization necessary. The goal of brain-based education is to create and offer lessons that rely less on inefficient and tedious rote memory. Helping students access and utilize more effective types of memory storage and retrieval will literally change their brains.

Working Memory, or short-term memory, holds data for about 20 minutes. The challenge students face is to move information from their working memories into their long-term memories. If they don't do this in about 20 minutes, that information can be lost. (Think about the last time someone gave you driving directions—they seemed so clear when you first heard them, but were lost to you once you made the second right turn.) If this newly learned material is to be retained, it needs to enter the network of the brain's wiring. Teachers help students do this by activating their previously learned knowledge that relates to the new material. This prior knowledge exists in stored loops of brain cell connections (circuits of neurons that are connected by branching axons and dendrites that carry the information as electrochemical signals). Effective teaching uses strategies to help students recognize patterns and then make the required connections to process the new working memories so they can travel into the brain's long-term storage areas.

While it is commonly believed that brain cell growth stops after age 20, that is not completely true. New connecting cells, called dendrites, can be formed throughout life. It is true that the neurons where memory storage takes place are not replenished. However, their extensions, these dendrites, continue to sprout and connect and form new circuits with other dendrites throughout a person's life. These neural networks, similar to electric circuitry, are the roadways that connect various parts of the brain. Just as with traffic flow in a busy city, the more alternate pathways available to connect with a memory, the more efficiently the traffic will flow and the more rapidly and easily that memory will be retrieved when needed.

After repeated practice, working memories are set down as permanent neuronal circuits of axons and dendrites, ready to be activated when the information is needed. When a memory has been recalled often enough, its neuronal circuits become highly developed because of their repeated activation. When neurons fire in sync with one another, they are more likely to form new connections. As the connections grow stronger, by repeated stimulation, a given neuron becomes more likely to trigger another connected neuron (Chugani, 1998).

Practice results in repeated stimulation of the memory circuit. These circuits become more efficient and easier to access and activate. Like hikers eventually carving out a depression along a trail, repeated practice stimulates cells in the memory circuit such that the circuit is reinforced and becomes stronger. This means it can be quickly turned on, and switched on through a variety of sensory cues.

Learning Promotes More Learning

Engaging in the process of learning actually increases one's capacity to learn. Each time a student participates in any endeavor, a certain number of neurons are activated.

When the action is repeated, such as in a follow-up science lab experiment, rehearsing a song, or when the information is repeated in subsequent curriculum, these same neurons respond again. The more times one repeats an action (e.g., practice) or recalls the information, the more dendrites sprout to connect new memories to old, and the more efficient the brain becomes in its ability to retrieve that memory or repeat that action. Eventually, just triggering the beginning of the sequence results in the remaining pieces falling into place. This repetition-based sequencing allows you to do many daily activities almost without having to think about them, such as touch-typing or driving a car.

Very few educators resort to having students learn only by rote memorization or limit instruction to only "drill and kill" worksheets, day after day, in the hopes of imprinting material in students' brains. Teachers know from their teaching experience how briefly that material remains accessible to students. Many teachers can recall occasions when they accidentally gave students a spelling list or math worksheet they had already completed, and yet a relatively large number of students didn't instantly recognize that it was the identical work they did a few weeks, or even days, before.

Strategies abound that keep students interested in what they are learning, thus helping to move information from temporary working memory into memory storage. These lessons activate multiple senses and connect new information to multiple brain pathways into the memory storage areas. Successful brain-based teaching builds more connections and stronger circuits. Students will have more roadways to carry new information into their memory storage region and to carry out the stored knowledge when it is needed.

Brain-mapping Techniques

Scientists can now more easily track what parts of the brain are active when a person is processing information. The levels of activation in particular brain regions determine which facts and events will be remembered. Functional magnetic resonance imaging (fMRI) allows scientists a view of brain activity over time. In one study, Gabriel (2001) and others at Stanford University focused their efforts on visual memories. Subjects placed under fMRI viewed and then reviewed a series of pictures. The researchers found that activity levels in the right prefrontal cortex and a specific area of the hippocampus correlated with how well a particular visual experience was encoded and how well it was remembered.

In another study (Wagner et al., 1998), which focused on verbal memory, subjects were asked to remember words, either by their meaning or by their appearance (upper- or lowercase spelling). Again, activity levels in the prefrontal cortex (but this time on the left, where the Broca's language center resides in over 90 percent of all people) and the same parahippocampal area predicted which words were remembered or forgotten in subsequent tests. Furthermore, the researchers discovered that words were much more likely to be remembered when subjects concentrated on semantics (meaning), rather than on their appearance.

This is an example of how neuroimaging can suggest direct evidence of the type of memory strategy that works best for the information to be memorized. It also adds evidence to biological theory that more complex cognition (student-active learning) increases memory retention.

Some of the strategies suggested by neuroimaging findings are ones that have students personalize information to be learned, thereby further activating the areas of the brain that help form memories. Other strategies encourage students to connect with the information through as many senses as possible. They can visualize an electron orbiting the nucleus of an atom, mimic the buzz of electricity as it whizzes by, or feel the tingling associated with the electron's negative charge by rubbing a balloon against their arm and feeling their hair stand on end. If students then draw a sketch of these actions and verbally communicate it to a partner, or write about it in their own words, their long-term memory will forge multiple brain pathways, because they will have personalized and interacted with the information.

Stimulate Their Senses—Light Up Their Synapses. The brain may appear to be a tangled bundle of nerve cell connections, but they are far from random. Brain mapping demonstrates that specific cognitive activities take place in predictable, tiny regions of the brain. Similarly, imaging has shown us that each of these locations is fed data from brain centers that collect information from the senses and emotions. When teachers help students build their working memories through a variety of activities, they are helping them stimulate multiple sensory intake centers in their brains. When this happens, they build multiple pathways leading to the same memory storage destination. By stimulating several senses with the information, more brain connections are available when students need to recall that memory later on. This means that the memory can be retrieved by more than one type of cue. If the learned information was taught with visual and auditory associations, students can recall it by using either sound or visual memory.

Surprise! Consider the technique of surprise to light up students' brains and illuminate the pathways to memory storage. Start a lesson with an unanticipated demonstration, or have something new/unusual in the classroom to spark student attention and curiosity. It can be anything, from playing a song as they enter to greeting them in a hat, cape, or costume. If students sense novel experiences, from demonstrations, descriptions, anecdotes, or even the enthusiasm in their teacher's voice, they will be more likely to connect with the information that follows. To take advantage of their engaged state of mind, give students opportunities to interact with the information they need to learn. The goal is for them to actively discover, interpret, analyze, process, practice, and/or discuss the information so that it will be processed in the frontal lobe regions devoted to executive function.

This doesn't mean that teachers must have a dialogue with individual students to prompt their being "in the moment" with the information. Strategies that can achieve these goals include partner discussions and Think-Pair-Share. Students can write *dend-rites* (a more enticing name for class notes that gives their note-taking more status). They might add a sketch in their notebooks alongside their comments about the surprise, the new information they learned, and their response to it (What did I see/hear/smell? What did I learn? What surprised me? What do I want to know more about? What did this remind me of?).

Episodic Memory and Experiential Learning. Decades ago, my high school chemistry teacher slowly released hydrogen sulfide (which produces a smell like rotten eggs) from a hidden container he opened just before we entered his classroom. A few minutes after we took our seats and he began his lecture, a foul odor permeated classroom. We groaned, laughed, looked around for the offending source. To an outside observer entering our class at that time, we would have appeared unfocused and definitely not learning anything. This demonstration, however, literally led me by the nose to follow my teacher's description of the diffusion of gases through other gases. It is likely that during that class I created two or three pathways to the information about gas diffusion that I processed through my senses and ultimately stored in my long-term memory. Since then, that knowledge has been available for me to retrieve by thinking of an egg or by remembering the emotional responses as the class reacted to the odor permeating the room. Once I make the connection, I am able to recall the scientific facts linked to his demonstration.

Event memories, such as the one that was stored that day in chemistry class, are tied to specific emotionally or physically charged events (strong sensory input) and by the emotional intensity of the events to which they are linked. Because the dramatic event powers its way through the neural pathways of the emotionally preactivated limbic system into memory storage, associated scholastic information gets pulled along with it. Recollection of the academic material occurs when the emotionally significant event comes to mind, unconsciously or consciously. To remember the lesson, students can cue up the dramatic event to which it is linked.

Can you recall a time when you smelled the perfume a friend or loved one wore, and you remembered other details about that person? Perhaps upon hearing an old song, you've recalled dancing to it years before? You can probably visualize where you were when you heard the World Trade Center had been attacked. When you think of that event, it is likely you remember other details of your environment at that moment. Similarly, experiential learning, such as hands-on/minds-on discovery science, which stimulates students' multiple senses, is not only the most engaging, but also the most likely to be stored as long-term memories. Because each of the senses has a separate storage area in the brain, multisensory input results in duplicated storage and can be retrieved by a variety of stimuli. With strategies that engage the senses, students "become" the knowledge by interacting with it. As a result, a new memory that might otherwise be forgotten is linked to a sensation, movement (cognitive-motor link), or an emotion, and it travels into the memory storage along more than one pathway. This redundancy of pathways means greater memory retention and recall.

It is not, nor should it be, a teacher's role to turn a classroom into a video arcade. We don't want students to be primarily motivated by external rewards. An ideal event memory lesson would be one that stimulated students' brains by having them participate in a challenging and engaging student-centered activity that simultaneously activates multiple sensory systems and executive functions as students strive to make sense of experience. The goal is to provide experiences that enable students to interact with knowledge in ways that arouse their physical senses and positive emotions, or to connect the new information with their past experiences and interests. Teachers can supercharge material to be learned by relating it to students' senses and experiences, and this intensifies their memory building. This process of connecting new information to related experiences or memories is aptly named relational memory.

Relational Memory—Lighting the Pathways. Learning consists of reinforcing the connections between neurons. Relational memory occurs when students learn something that adds to what they already have mastered; they engage or expand on "maps" already present in the brain. This process engages more executive functions as students' brains scan their stored memory banks, seeking relationships that help them put new connections in context.

How does relational memory apply to teaching? Patterning is the process whereby the brain perceives and generates patterns by relating new with previously learned material or chunking material into pattern systems it has used before. Education is about increasing the patterns students can use, recognize, and communicate. As the ability to see and work with patterns expands, executive functions are enhanced. Whenever new material is presented in such a way that students see relationships, they generate greater brain cell activity (formation of new neural connections) and achieve more successful long-term memory storage and retrieval.

Graphic Organizers. Graphic organizers help students see relationships and pattern new information for memory storage. I consider them one of the most nourishing of all dendrite sprout "foods" we can offer to nurture our students' brain growth. Graphic organizers are a creative alternative to rote memorization, because they enable students to make connections, see patterns, access previously stored related memories, and expand upon existing memory circuitry.

Graphic organizers coincide with the brain's style of patterning. When teachers organize and present material in ways that stimulate students' brains to create meaningful and relevant connections to previously stored memories, they can make associations, discover patterns, and sort and store the new data as relational memory and then long-term memory.

Teaching information in patterns can be as simple as presenting material in *chunked* format. Because the working memory has a capacity for immediate recall (with a range from five to nine pieces of unrelated items), students can remember more successfully when information is separated into chunks. Just as phone numbers and social security numbers are divided into chunks of three or four digits at a time, teachers can chunk things, from biologic genus-species names to states and capitals, into groupings of three or four, ideally with some commonality.

When graphic organizers help students cluster information, the process enhances the brain's natural tendency to construct meaning by forming patterns. The best graphic organizers engage the students' imaginations and positive emotions in a creative process whereby they recognize, sort, and discover patterns for themselves. In addition, the use of graphic organizers to connect information in meaningful relationships allows students time for reflecting about the information. The result is that they can ultimately go beyond regurgitating rote memorization and reach the higher cognitive process of using the information in significant ways. The relational memories they store will be available for critical thinking and other executive functions to use for meaningful problem solving.

Conclusion

When memory and retention brain research are applied to the classroom, they not only drive the learning process, but also allow educators to energize and enliven the minds of students. As the research continues to build, it will be up to these professionals to develop and use new strategies that bring the brain-based research to students. That will be a fascinating and exciting challenge to meet.

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