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

The past two decades has provided extraordinary progress in our understanding of the nature of learning. Never before has 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 because advances in technology enable us to view the working brain as it learns.

Watching As Brains Learn: Studies of the 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. There is synchronization of brain activity 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 is the 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 when information is processed and stored.

Plasticity and Pruning

It was a longtime 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 support and connecting cells that enrich the communication between neurons. These dendrites sprout from the arms (axons) or the cell body of the neuron.

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 neurotropins. Although the brain measurements of neurotropins is highest during childhood when the brain's connecting cells are undergoing their greatest growth and development, as we continue to learn, neurotropin activity is elevated in brain region responsible for new learning and new memory formation. (Kang 1997)

Once these dendrites are formed, it is the brains 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 1999)

Examples of brain plasticity have been noted 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 have significantly increased size of their somatosensory cortex, where the sense of touch in their right finger is processed. Similarly, violin players who use the fingers of their left hands to do the complicated movements along the strings show the increased size of their somatosensory regions of the brain's parietal lobe associated with the fingers of the left hand.

A 2004 report in **Nature** 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 the 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 decrease in connecting dendrites and other supporting brain connecting cells that are not used is called pruning. 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 whereby some brain pathways and connections are selectively maintained and "hard-wired," while others are selectively eliminated, or "pruned."

Just as hedges are pruned to cut off errant sproutings that don't communicate with many neighboring leaves, the brain prunes its own underactive, relatively useless cells. By the time we enter adolescence, our brain has chosen the final neurons it will keep throughout our adult life based on which cells are used and which we are not.

Neurons are pruned when they are not used. 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. This reduced blood flow means that calcium ions that accumulate around the cell and are not washed away. This calcium ion build up triggers the secretion of an enzyme Calpain, which causes cells to self-destruct.

To think about pruning in terms of brain cell growth, consider first the astonishing development of the embryonic brain that by week four is producing 1/2 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, and only the neurons that are in networks remain and now have become differentiated into circuits with specific functions. (Sowell 2003)

After birth, the brain's gray matter has another growth spurt with increased grey matter and connections reaching a maximum density at about age 11. This is followed by another pruning phase. (Seeman 1999). When unused, hopefully unnecessary memory circuits are broken down. If that were not the case there would be too many crowded circuits in the brain (similar to too much working memory on our computer "desktop") for it to be efficient. To continue the computer analogy, if you have lots of data on your desktop, it takes your computer longer to turn on because all that data must be activated before you can start manipulating anything on the screen.

The More Ways Something is Learned, The More Memory Pathways are Built

This brain research discovery is part of the reason for the current notion that stimulating the growth of more dendrites and synaptic connections is one of the best things teachers can learn do for the brains of their students.

When children are between six and 12 the neurons grow more and more synapses, or connections between each other that are new pathways for nerve signals. This thickening of grey 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. (Guild 2004)

Helping Students Grow More Brain Connections

In the classroom, the more ways the material to be learned is introduced to the brain and reviewed, the more dendritic pathways of access will be created. There will be more synaptic cell-to cell-bridges there will be 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 processes optical input. Subsequently or simultaneously having students hear it will hook up a dendritic circuit with the temporal lobes, the lobes on the sides of the brain that process auditory input, as well as playing an important role in the regulation of emotion and memory processing. This duplication results in greater opportunity for future cues to prompt the brain access to 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 strengthens it into something we've learned rather than just memorized.

For example when we learn about our 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 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, the association is made with jet and rocket engines are also powered by internal combustion from that discovery. Later we build associational memories with the cars we've grown up with.

Because the information about cars in 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 line to provide all the stored data we have connected pertaining to cars. We may not need all that information, but because the associations activate these circuits, any of the stored information that we do need will be rapidly and efficiently accessible.

That is the reason for teaching important material through multiple learning pathways such as several senses (hearing, seeing, touching) as well as through several subjects (cross-curricular topics).

From Enriched Cages to Enriched Classrooms and Curriculum

Even before plasticity, neuroimaging laboratory research demonstrated how growing brains are physically shaped by experience. The brain sizes and weights of rats reared in standard cages were compared with those that lived in enriched cages (more objects in their cages that they could manipulate). The rats reared in 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. In addition, building a supportive social classroom community, with enriched input from the environment, will result in more brain pathways and greater speed and efficiency of brain signals.

Educators As Memory Enhancers - Not Just Information Dispensers

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

Rote Memory is unfortunately the most commonly required memory task for students in primary and secondary school. This involves "memorizing," and soon forgetting, facts that are often of little primary interest or emotional value to the student, 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 student's lives. Nevertheless, if teachers understand the brain-basted strategies to use the amount of rote memorization required can be cut, and what remains can be less of a drudge because these strategies help students access and utilize more effective types of memory storage and retrieval. The goal of brain-based education is to structure lessons to ultimately 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 in mind for about twenty 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 twenty minutes, that information can be lost. (Think about the last time someone gave you driving directions which seemed so clear when you heard them, but were lost to you once you made the second right turn.) To keep this newly learned material from slipping away, 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 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 connections required 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 twenty, 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 life. These neural networks, similar to electric circuitry, are the roadways that connect various parts of the brain. Just like traffic flow in a busy city, the more alternate pathways there are 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, its neuronal circuits are highly developed because of their repeated activation. A phrase that describes this construction of connections based on repeated association of one piece of information with another is, "Cells that fire together, wire together." 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)

Like exercising a muscle, these circuits then become more efficient and easier to access and activate. Practice results in repeated stimulation of the memory circuit. Like hikers along a trial who eventually carve out a depression in the road, repeated practice stimulates cells in the memory circuit such that the circuit is reinforced and becomes stronger. This means it can be quickly turned from off to on, and switched on through a variety of cues coming in from the senses.

A Review of Brain Anatomy

To provide background for interpreting brain-based research about the memory storage and retrieval process there are several important areas of brain anatomy worth reviewing. The brain is divided into lobes, each with many functions, each interconnecting to the other lobes through nerve pathways or circuits. For example, areas in the left frontal lobe and both temporal lobes are integral in *executive attention* – alerting the rest of the brain to pay attention or respond to stimuli. In learning, the stimuli are the bits of sensory information students see (through their eyes or by visualization), hear, feel, smell, touch, or experience through movement

There are even more specialized brain regions that have been revealed through neuroimaging and brain mapping during the memory process that are most active during the moments when new information is actively learned and stored. First, there are the *somatosensory cortex areas*, one in each brain lobe where input from each individual sense (hearing, touch, taste, vision, smell) is received and then classified or identified by matching it with previously stored similar data. Next in the sequence of memory storage are the *reticular activating system* (alerting the brain to sensory input that sense receptors in the body send up the spinal cord) and the *limbic system*, comprised of parts of the temporal lobe, *hippocampus* (damage to the hippocampus can result in anterograde amnesia, an inability to form new memories), *amygdala*, and *prefrontal cortex* (front part of the frontal lobe). (Bliss 1993)

Recall the first few times you learned and practiced a new computer process, such as making a webpage or using email. At first you may have followed step-by-step written or verbal instructions. You possibly needed to rely on those instructions multiple times when you repeated the task, until one day, the process became automatic and you could even carry on a conversation while doing the job. That working memory was embedded by repetition into long-term memory, but it still needed periodic repetition for it to remain in your active memory bank, and not gradually fade from disuse. However, even if it did fade when you were away from your computer during summer vacation, the neuronal circuit or brain cell network that was created was still physically present in your brain, just like that hiking trail under the winter's snow. It was just in storage, like data taken off your computer desktop and put into the hard drive, and it took less time to refresh it than it did to learn it the first time.

Learning Promotes 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 (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 is how you are able to do many daily activities almost without having to think about them, such as touch-typing or driving a car. The reason for this ability goes back to the construction and strengthening of those memory pathways in the brain.

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 hopes of imprinting material in students' brains. Teachers know from their own 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 the relatively large number of students who didn't instantly recognize that it was the identical work they did a few weeks, or even days, before.

Now there are more ways to use help students process information from lessons so it travels beyond temporary working memory and into memory storage. These are the strategies that keep students interested in what they are learning. 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

Allow scientists to 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, Gabrieli and others at Stanford focused their efforts on visual memories. Subjects placed under fMRI viewed and then re-viewed 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.

A study, led by Dr. Anthony Wagner when he was at Harvard Medical School, focused on verbal memory. Subjects were asked to remember words, either by their meaning or by their appearance (upper or lower case spelling). Again, activity levels in the prefrontal cortex (but this time on the left, where the Broca's language center is for over 90% of all people) and the same parahippocampal area again predicted which words were remembered or forgotten in subsequent tests. Furthermore, they 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 directly give 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 finding are ones that have students personalize information to be learned, thereby further activating the areas of the brain that help form memories. Others encourage students to connect with the information with 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 a tingling associated with the electron's negative charge by rubbing a balloon against their arm and feeling their hair move. If they then draw a sketch of this and verbally communicate it to a partner, or write about it in their own words, multiple brain pathways will be stimulated to enter long-term memory because they have personalized and interacted with the information.

Build Stronger Memory Circuits

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Stimulate their senses - Light up their synapses

The brain may appear to be a tangled bundle of literally miles of nerve cell connections, but these are far from random. From brain mapping we know that predictable tiny regions of the brain are where specific cognitive activities take place. 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, it can be recalled by the student using their 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, students should have 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 it will move beyond working and 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, although that certainly worked well for Socrates. 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 along side their comments about the surprise, the new information they learned, and their personal 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 reminds me of?)

Episodic memory and Experiential Learning

Decades ago, my high school chemistry teacher slowly released hydrogen sulfide (rotten egg smell) 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 throughout the classroom grabbing our attention. 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. However, this demonstration, literally led me by the nose to follow his description of the diffusion of gasses through other gasses. 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, the associated hitchhiking 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, that stimulates multiple senses in students 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 the external rewards of bells and whistles. An ideal event memory lesson would be one where students' brains are stimulated 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 takes place when students learn something that adds to what they have already 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? We already know that rote memory is inefficient, but now there is visible evidence to encourage helping students make connections and see patterns. 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, the 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.

The more teachers add the science of teaching to their individual styles and arts of teaching, the less students will be called upon to rely on the inefficient and unpleasant process of rote memorization. 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, 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 limited to from five to nine pieces of unrelated items, if information separated into chunks, students can remember more successfully. Just as phone numbers and social security numbers are divided into chunks of three or four, teachers can chunk things from biologic genus-species names to states and capitals, into groupings of three or four, ideally with some commonality that relates them.

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 to 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.

Graphic organizers are intrinsically engaging, as they require students to interpret and interact with the material. When students create their own categories (personal relevance) the connection is increased. However, even if teachers construct a framework for their organizers, they can help them see the logic of the structure they created.

When students make this connection of new to previously stored memories they experience the sentiment described in the quote from Doris Lessing, "That is what learning is. You suddenly understand something you've understood all your life, but in a new way." 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.

References

Alexopoulou, E., & Driver, R. (1996). Small-group discussion in physics: Peer interaction modes in pairs and fours. *Journal of Research in Science Teaching,* 33(10), 1099-1114.

Andreasen, E (1999) *Human Brain Mapping,* 8(4), 226-234.

Antil, L., Jenkins, J., & Watkins, S. (1998). Cooperative Learning: Prevalence, conceptualizations, and the relation between research and practice. *American Educational Research Journal*, 35 (3), 419-454. ASCD Publications.

Ashby, C. R., Thanos, P. K., Katana, J. M., Michaelides, E. L., Gardner, C. A., Heidbreder, N. D. (1999) The selective dopamine antagonist. *Pharmacology, Biochemistry and Behavior*.

Bandura, A., & Schunk, D.H. (1981). Cultivating competence, self-efficacy, and intrinsic interest through proximal self-motivation. *Journal of Personality and Social Psychology*, 41, 568-578.

Bangert-Downs, R.L., Kulik, C.C., Kulick, J.A. & Morgan, M. (1991).The instructional effects of feedback in test-like events. *Review of Educational Research*, 61(2), 213-238.

Bernard, B (1991). Moving Toward a Just and Vital Culture: Multiculturalism in Our Schools*: Western Regional Center for Drug Free Schools and Communities,* Northwest Regional Educational Laboratory, Portland, OR. p. 9.

Bjorkland, D. F., & Brown, R. D. (1998). Physical play and cognitive development: Integrating activity, cognition, and education. *Child Development*, 69(3), 604-606.

Black, J.E., Isaacs, K.R., Anderson, B.J.., Alcantara, A.A., & Greenough, W.T. (1990). Learning causes synaptogenesis in cerebral cortex of adult rats. *Proceedings of the National Academy of Science*, 87, 5568-72.

Bliss, T. V. P., Collinridge, G. L., (1993) A synaptic model of memory: Long term potentiation in the hippocampus. *Nature* 361:31-39.

Boggiano, A (1993). Use of techniques promoting students' self-determination: Effects on students' analytic problem-solving skills. *Motivation and Emotion*, 17, 319-336.

Brophy, J. (1981). Teacher praise: A functional analysis. Review of Educational Research, 51, 5-32.

Bull, B. L., & Wittrock, M. C. (1973). Imagery in the learning of verbal definitions. *British Journal of Educational Psychology*, 43, 289-293.

Calonico,J & Calonico,B, 1972. Classroom Interaction: A Sociological Approach. *Journal of Educational Research,* 66(4) (1972),165-69.

Cameron, J. and Pierce, W. D. (1994). Reinforcement, reward, and intrinsic motivation: A meta-analysis. *Review of Educational Research*, 64 93), 363-422.

Chen, Z. (1999). Schema induction in children's analogical problem solving. *Journal of Educational Psychology*, 91(4), 703-715.

Christianson, S.A. (1992). Emotional stress and eyewitness memory: A critical review. *Psychological Bulletin*, 112(2), 284-309).

Chugani H (1998) Biological Basis of Emotions: Brain Systems and Brain Development. *Pediatrics* 102:1225-1229

Chugani, H. T. & Phelps, M.E. (1991). Imaging human brain development with positron emission tomography. *Journal of Nuclear Medicine*, 32(1), 23-6.

Cohen, E. (1986) *Designing Groupwork. Strategies for the Heterogeneous Classroom.* New York: Teachers College Press, New York, NY.

Coward, L. Andrew (1990). *Pattern Thinking*. New York, NY; Praeger Publishers.

Diamond, M. & Hopson, J., (1998). Magic Trees of the Mind. New York: *Dutton*

Dozier, R. Jr. (1998).Fear Itself. New York: *St. Martin's Press.*

Druyan, S. (1997). Effects of the kinesthetic conflict on promoting scientific reasoning. *Journal of Research in Science Teaching*, 34(10)1083-1099.

Duman, M. (1999). *Biological Psychiatry*. 46(9), 1181-1191.

Dunston, P.J. (1992). A critique of graphic organinzer research. *Reading Research and Instruction*, 31(2), 57-65.

Durkin, K. (1995). *Developmental Social Psychology*. Cambridge, MA; Blackwell, p306-309.

Eich, E. (1995). Searching for mood dependent memory. *Psychological Science*, 6, 67-75.

Erikson, E. (1968). *A Way of Looking at Things*. International Encyclopedia of the Social Sciences, New York: Crowell-Collier, p 286-292.

Fife, J. (May 1999) Response to Pygmalion in the classroom or Pygmalion as an example of the quality principles. *The National Teaching and Learning Forum*. Vol. 8 No. 4.

Flick, L. (1992). Where concepts meet percepts. Stimulating analogical thought in children. *Science and Education*, 75(2), 215-230.

Frank, M. and Stryker, M. (2001) *Neuron*. April 26.

Fuchs, J.L., Montemayor, M., & Greenough, W.T. (1990). Effect of environmental complexity on size of the superior colliculus. *Behavioral and Neural Biology*, 54(2), 198-203.

Gabriel, J. (2001). New Terrain: Mapping the Human Brain. *Neurology Today*, Aug. 01.

Gerlic, I. & Jausovec, N. (1999). Multimedia: Differences in cognitive processes observed with EEG. *Educational Technology Research and Development*, 47(3), 5-14

Giedd, J. N., Gogtay, N., Lusk, L., Hayashi, K. M., Greenstein, D. Vaituzis, A. C., Herman D. H., Nugent, T.F., Clasen, L., Toga, A. W., Rapoport, J.L., Thompson, P. M. (2004). Dynamic Mapping of Human Cortical Development during Childhood through Early Adulthood. *Proceedings of the National Academy of Sciences*, 101(21), 8174-8179.

Giedd, J., Blumenthal, J., Jeffries, N., Castllanos, F., Liu, H., Zijdenbos, A., Paus, T., Evans, A., Rapoport, J. (1999) Brain development during childhood and adolescence: a longitudinal MRI study. *Nature Neuroscience*, 2:861-863.

Goleman, D. (1995) Emotional Intelligence. New York: *Bantam Books.*

Greenough, W.T. & Anderson, B.J. (1991). Cerebellar synaptic plasticity. Relation to learning versus neural activity. *Annals of the New York Academy of Sciences*, 627, 231-247.

Greenough, W.T., Withers, G., & Anderson. B. (1992). Experience-dependent synaptogenesis as a plausible memory mechanism. In I. Gormezano & Wasserman (Eds.*),* *Learning and Memory: The Behavioral and Biloogical Substrates* (p209-229)). Hillsdale, NJ: Erlbaum & Associates.

Hallowell, E. M. & Thompson, M. G. (1993). *Finding the Heart of the Child.* Washington, DC: National Association of Independent Schools.

Healy, J. (1990). Endangered Minds: *Why Our Children Don't Think.* New York: Touchstone.

Hewson, M.G. & Hewson, P.W. (1983). Effect of instruction using students' prior knowledge and conceptual change strategies on science learning. *Journal of Research in Science Teaching*. 20, 721-743.

Introini-Collision, I.Bl, Miyazaki, B., & McGaugh, J.L. (1991). Involvement of the amygdala in the memory-enhancing effects of clenbuterol. *Psychopharmacology*, 104(4) 541-544.

Jancke, L. (2000). *Cognitive Brain Research.* 10(1-2), 177-183.

Jenkins, J.R., Stein, M.L., & Wysocki, K. (1984). Learning vocabulary through reading. *American Educational Research Journal*, 21(4), 767-787.

Jernigan, T.L. & Tallal, P. (1990). Late childhood changes in brain morphology observable with MRI. *Developmental Medicine and Child Neurology*, 32(5), 379-385.

Johnson D., & Johnson, R. (1992). Encouraging thinking through constructive controversy. In Davidson, N & Worsham, T. (Eds.*) Enhancing Thinking Through Cooperative Learning*. New York: Teachers College Press. 120-137.

Johnson, D & Johnson, R (1984). *Learning Together and Learning Alone, Cooperation, Competition and Individualization*. Englewood Cliffs, NJ: Prentice-Hall.

Kato, N. and McEwen, B. (2003). Neuromechanisms of emotions and memory. *Neuroendocrinology*. 11,03. 54-58.

Koechlin et. al, (1999). Relational memory by cross-curriculum. *Nature* 399(6732) 148-151.

Kohn, A. (1993). Why incentive plans cannot work. *Harvard Business Review*, 71(5), 54-63.

Kohn, A., (2004). The Cult of Rigor and the Loss of Joy. *Education Week* 9/15/04.

Koutstaal, W., Buckner, R.L., Schacter, D. & Rosen, B.R. Fourth Annual Meeting of the Cognitive Neuroscience Society, March 23–25, 1997, Boston, MA.

Kumar, D.D. (1991).A meta-analysis of the relationship between science instruction and student engagement. *Educational Review*, 43(1), 40-66).

Lavoie, R. (2005). It's So Much Work To Be Your Friend. *Touchstone Books/Simon & Schuster, Inc.*

Martin, R.C. (1993). Short-term memory and sentence processing: Evidence from neuropsychology. *Memory and Cognition*, 21(2), 173-183.

Martin, S. J., Morris, R. G. M. (2002) New life in an old idea: The synaptic plasticity and memory hypothesis revisited. *Hippocampus* 12:609-636.

McEwen, M (1999). *Annual Review of Neuroscience*. 22, 105-122.

McGaugh J.L., Introini-Collision, I. B., Nagahara, A. H., Cahill, L., Brioni, J.D., & Castellano, C. (1990). Involvement of the amygdaloid complex in neuromodulatory influences on memory storage. *Neuroscience and Biobehavioral Reviews*, 14(4), 425-431.

McGroarty, M. (1989). The benefits of cooperative learning arrangements in second language instruction. *National Association for Bilingual Association Journal*, 13 (2), 127-143.

Meece, J. L., Wigfield, A., & Eccles, J.S. (1990). Predictors of math anxiety and its influence on young adolescents' course enrollment intentions and performance in mathematics. *Journal of Educational Psychology*, 8, 60-70.

Montague, P., Hyman, S., & Cohen, J., (2004).Computational roles for dopamine in behavioural control. *Nature*. 431(1) 460-477.

Mueller & Dweck (1998). *Journal of Personality & Social Psychology*. 75(1) 33-52.

Naime, J. S. (2002). Remembering over the short-term: The case against the standard model. *Annual Review of Psychology*, 53(2), 53-81.

Neisser, Ulric & Harsch, Nicole (1992). Phantom flashbulbs: False recollections of hearing news about Challenger. In E. Winograd & U. Neisser, *Affect and Accuracy in Recall: Studies of "Flashbulb" Memories* (P9-31). New York, NY: Cambridge UP.

Nunley, K. F. (2000). In defense of the oral defense (assessment). *ASCD's Classroom Leadership*, February 2000.

Nunley, K. F., (2002). Active Research Leads to Active Classrooms. *NASSP's Principal Leadership, March 2002, 53-61.*

Nuthall, G. & Alton-Lee, A. (1995). Assessing classroom learning. How students use their knowledge and *experience to answer classroom achievement test questions in science and social studies. American Educational Research Jorunal,* 32(1), 185-223.

Nuthall, G. (1999). The way students learn. Acquiring knowledge from an integrated science and social studies unit. *Elementary School Journal*, 99(4), 303-341.

Olds, James (1992). Mapping the mind onto the brain. In F. Worden, J. Swazey, & G. Adelman, *The Neurosciences, Paths of Discovery*. Boston, MA: Birkhauser.

Olff, P. (1999). *Psychiatry Research*, 85,1, 7-15.

Olsen, 1995, Science Continuum of Concepts for Grades K-6. Kent, WA: *Center for the Future of Public of Education*.

O'Reilly, R. and Rudy, J. (2000). *Hippocampus*, 10(4), 389-397.

Parker, R (2002). A Place to Belong. *Independent Schools Magazine*. 50(2).

Patrick, Skinner, and Connell (1993). What motivates children's behavior and emotion? Joint effects of perceived control and autonomy in the academic domain. *Journal of Personality and Social Psychology,* 65, 781-791.

Pawlak, R., Magarinos, A. M., Melchor, J., McEwen, B., & Strickland, S. (Feb. 2003). Tissue plasminogen activator in the amygdala is critical for **stress-induced anxiety-like** behavior. *Nature Neuroscience*, 168 – 174.

Peterson, P.L., Carpenter, T.P. & Fennema, E. (1989). Teachers' knowledge of students' knowledge in mathematics problem solving: Correlation and case analysis. *Journal of Educational Psychology*, 91(4), 558-569).

Pressley, M. Wood, E., Woloshyn, V., Marftin, V., King,A., & Menke, D. (1992). Encouraging mindful use of prior knowledge. Attempting to construct explanatory answers facilitates learning. *Educational Psychologist*, 27(1), 91-109.

Pressley, M., Goodchild,F., Fleet, J., Zajchowski, R., & Evans, E.D. (1989). The challenges of classroom strategy instruction. *Elementary School Journal*, 89, 301-342.

Pressley, M., Symons, S., McDaniel, M., Snyder, B.L., & Turnure, J.E. (1998). Elaborative interrogation facilitates acquisition of confusing facts. *Journal of Educational Psychology,* 80, 268-278).

Pulvirenti, L. (1992). Neural plasticity and memory: Towards an integrated view. *Functional Neurology*, 7(6), 481-490.

Redfield, D. L., & Rousseau, E. W. (1981) A meta-analysis of experimental research on teacher questioning behavior. *Review of Educational Research*, 51(2), 237-245.

Reeve and Bolt (Sept 1999). Student-centered classrooms and the teaching styles they exhibit. *The Journal of Educational Psychology.*

Reeve, J (1996). The interest-enjoyment distinction in intrinsic motivation. *Motivation and Emotion,* 13, 83-103.

Robinson, D. H., & Kiewra, K.A. (1996). Visual argument: Graphic organizers are superior to outlines in improving learning from text. *Journal of Educational Psychology*, 87(3), 455-467.

Rose, F. D., Davey, M.J., & Attree, E. A. (1993). How does environmental enrichment aid performance following cortical injury in the rat? *Neuroreport*, 4(2), 163-166.

Rosenthal, R and Jacobson, L. (1992) Pygmalion in the Classroom: Teacher Expectation and Pupils' Intellectual Development. *Irvington Publishers*: New York.

Ross, J.A. (1988). Controlling variable*s:* A metaanalysis of training studies. *Review of Educational Research*, 58)4), 405-437.

Rossi, E. L. & Nimmons, D. (1991). *The 20-Minute Break: Reduce Stress, Maximize Performance, and Imporve Health and Emotional Well-Being Using the New Science of Ultradian Rhythms*. Los Angeles, CA: Tarcher.

Ryan, J. (1998) *Journal of Ed. Psychology*, 90, 3, 528-535.

Schab, F.R. (1990). Odors and the remembrance of things past. *Journal of Experimental Psychology*: Learning, Memory and Cognition, 16(4), 684-655.

Schmuck, R.A. & Schmuck, P.A. (1983). *Group Processes in the Classroom.* Dubuque, IA: William C. Brown.

Schneider, W. (1993). Varieties of working memory as seen in biology and in connectionist/control architectures. *Memory and Cognition*, 21(2), 184-192.

Seeman, P (1999). Images in neuroscience. Brain development, X: pruning during development. *American Journal of Psychiatry*. 156:168.

Sirevaag, A.M. & Greenough, W. T. (1991). Plasticity of GFAP-immunoreactive astrocyte size and number in visual cortex of rats reared in complex environments. *Brain Research*. 540(1-2), 273-278.

Slavin, R.E., (1983). *Cooperative Learning*. New York: Longmann.

Sousa, D. (2000). How the Brain Learns: A Classroom Teacher's Guide. Corwin Press. Thousand Oaks, CA.

Sowell, E. R., Peterson, B. S., Thompson, P. M. (2003) Mapping cortical change across the human life span. *Nature Neuroscience* 6, 309-315.

Squire, L. R. (1992). Memory and the hippocampus: A synthesis from findings with rats, monkeys, and humans. Psychological Review, 99(2), 195-231.

Stickgold, R. (2000). *Nature Neuroscience*, 3(12) 1237-1238.

Valleran, Fortier, and Guay, (1997). Self-determination and persistence in a real-life setting: Toward a motivational model of high school dropout. *Journal of Personality and Social Psychology*, 72, 1161-1176.

Van Overwalle, F., & De Metsenaere, M. (1990). The effects of attribution-based intervention and study strategy training on academic achievement in college freshman. *British Journal of Educational Psychology*, 60, 299-311.

Wagner, A. Schacter, D., Rotte, M., Koutstaal, W., Maril, A., Dale, A. M., Rosen, B., Buckner, R. (1998). Building memories: remembering and forgetting of verbal experiences as predicted by brain activity. *Science*: 281,1185-11190.

Wallace, C. S., Killman, V.L., Withers, G.S., & Greenough, W. T. (1992). Increases in dendritic length in occipital cortex after 4 days of differential housing in weanling rats. *Behavioral and Neural Biology*, 58(1), 64-68.

Webb, D. & Webb, T. (1990). *Accelerated Learning with Music*. Norcross, GA: Accelerated Learning Systems.

Webb, M. W., Nemer, M. N., & Chizhik, A. W. (1998). Equity issues in collaborative group assessment: group composition and performance. *American Educational Research Journal*, 17, 607-651.

Werner, E & Smith, R. (1989). *Vulnerable But Invincible: A Longitudinal Study of Resilient Children and Youth.* New York: Adams, Bannister, and Cox.

Wiersma, U. J. C. (1992). *The effects of extrinsic reward on intrinsic motivation: A meta-analysis.* Journal of Occupational and Organizational Psychology, 65, 101-110.

Willoughby, T., Desmarias, S., Wood, E., Sims, S., & Kalra, M. (1997). Mechanisms that facilitate the effectiveness of elaboration strategies. *Journal of Educational Psychology,* 89(4), 682-685.

Wolfson, A. (1998). *Child Development,* 69(4) 875-887.

Woloshyn, V.E., Willoughby, T., Wood, E., & Pressley, M. (1990). Elaborative interrogation facilitates adult learning of factual paragraphs. *Journal of Educational Psychology,* 82, 513-524.

Wunderlich, K., Bell, A., & Ford, A. (2005) Improving learning through understanding of brain science research. Learning Abstracts, 8(1)
http://www.league.org/publication/abstracts/learning/lelabs200501.html