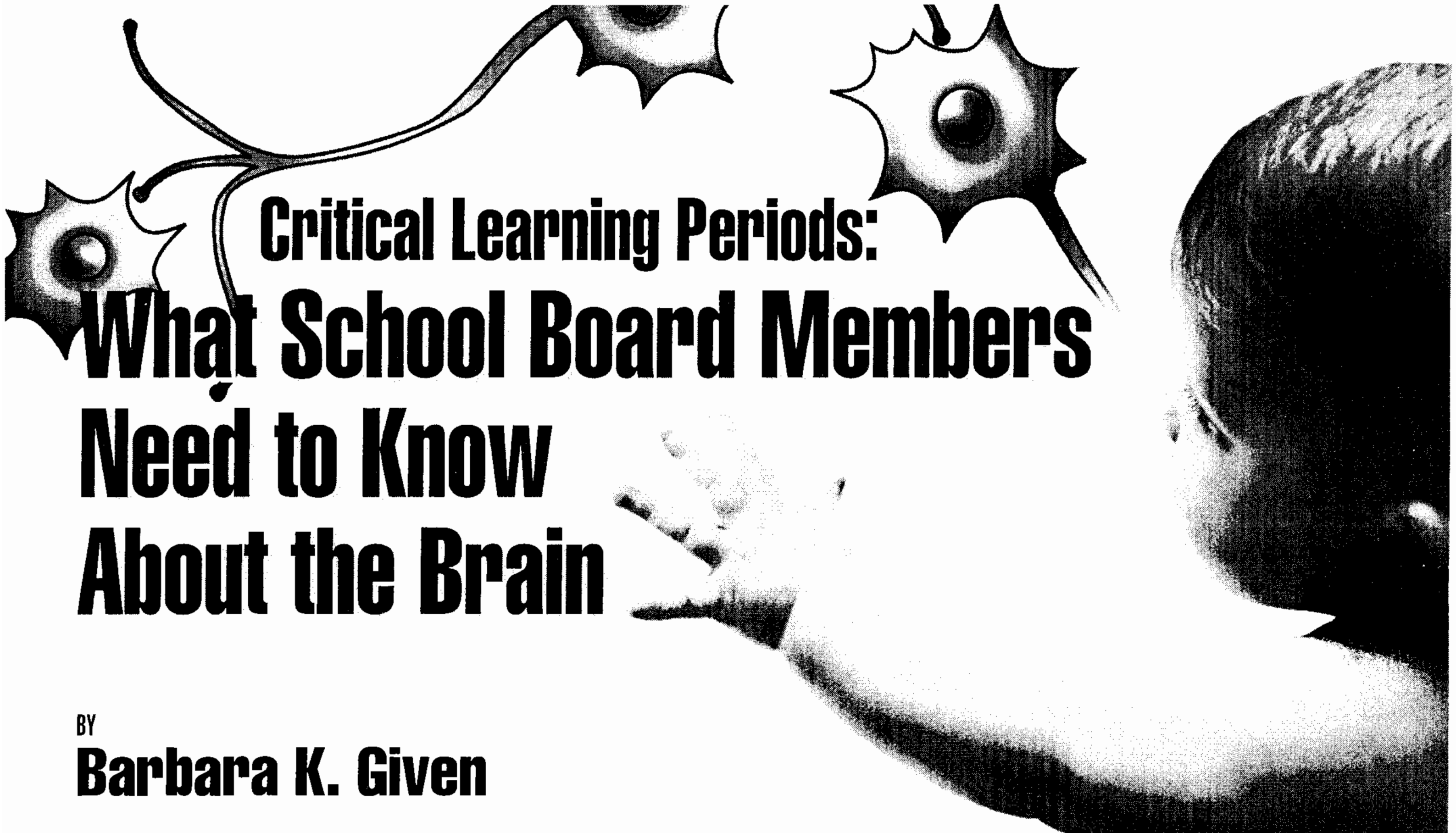

Critical Learning Periods: What School Board Members Need to Know About the Brain

BY

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Brain research tells us that stimulating, healthy environments create healthy learning and thinking routines among children. How can you make your schools stimulating places where authentic learning occurs?

Above all else, society expects school boards to ensure safety and effective learning for all students. Board members, however, rarely possess strong backgrounds in the neurobiology of learning on which school practices increasingly depend.

This should come as no surprise since 90 percent of what is now known about the brain was discovered in the last decade. Reading and assimilating vast quantities of new information, let alone translating it for educational use, is exceedingly difficult; board members cannot be expected to assume that time-consuming role.

Consequently, this article and subsequent ones on related topics provides information board members should know about learning, the brain, and effective practices that support the neurobiology of the brain.

The wonders of the brain. The complexity of learning matches the complexity of the organ that makes it possible — the brain. To make this dramatic point, consider this: The cortical bark-like outer layer of the brain — the thinking/learning part — is about as big and as thick as a good-sized dinner napkin if it were spread out, yet it contains an estimated 10–11 billion neurons (nerve cells) and trillions of supporting glial cells.[1]

Unlike other cells, neurons have fingerettes (dendrites) with spines that receive chemical messages at one end, a cell body that acts like a switch board to convert chemical messages to electrical impulses, and a sending channel (axon) with fingerettes at the other end (Figure 1).

Like little sling shots, electrical impulses "fire" neurotransmitters (chemicals) into gaps (synapses) between neurons. Other neurons temporarily absorb them to continue a chain reaction from neuron to neuron.

While this sounds like a clear case of "stimulate one end, fire from the other," the process is far from that simple. The estimated number of neurons in the human brain[2] ranges from 12 billion to 10^{11} with

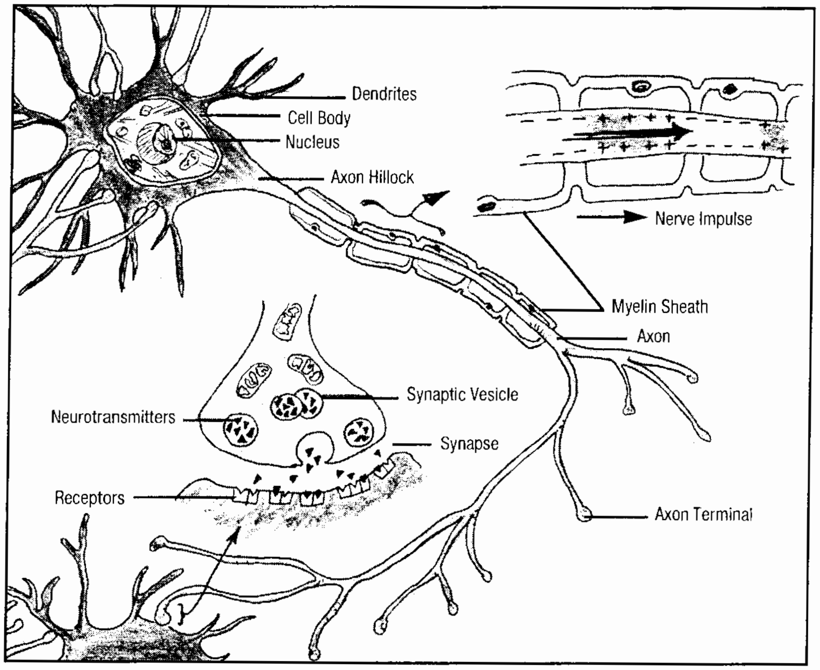

Figure 1. Neuron.

each one making an estimated 1,000 to 10^{14} connections with other neurons. That makes a total number of neuronal connections in the range of 1 million billion in the cortical sheet alone to 10^{14} for the whole brain.

In sheer numbers, this is "hyperastronomical — on the order of 19 followed by millions of zeros"[3] — a number greater than all the stars in the sky or all elementary particles in the known universe.[4] How these estimates were calculated boggles the mind, but Harth's comparison helps:

> "It is as though 100 billion people — 20 times the world's human population — were simultaneously chattering away and listening over telephone lines that connected each to as many as thousands of others at the same time. But that is not all. Not only do neurons listen to the information that comes across their private lines (the synapses from other neurons), they also hear announcements coming over a cerebral public address system consisting of chemical messages that are broadcast through the bloodstream."[5]

Once absorbed neurotransmitters stimulate receiving neurons to fire or to inhibit firing, their work is completed and they are "spit" back into the synaptic space where axon terminals reabsorb and recycle them. When neurotransmitters get lost in the synaptic gap, enzymes come along and break them up for easy reabsorption and recycling.

How this series of events creates learning, memory, and emotion is becoming more and more clear, even though controversy abounds regarding specific details. The translation and application of neurobiological research to education where agreement exists, therefore, is timely.

Let's begin this series of articles with a conversation about critical periods of brain development as a backdrop for promoting effective educational programs.

Fetal period. During fetal growth, cells switch "on" and "off" as they copy themselves from strands of proteins assembled in accordance with their genetic blue print at appropriate times and places to become liver, heart, brain tissue, fingernails, or whatever else they are supposed to become.

The brain begins to form approximately four weeks after gestation as cell division amasses a primitive spinal cord with an enlargement at one end where major regions of the brain are recognizable.[6] By eight weeks, the fetus is about as big as a man's thumb, and by 10 weeks, the forebrain differentiates the left and right cerebral hemispheres with frontal, parietal, occipital and temporal lobes in evidence (Figure 2). Frontal lobe separation (bifurcation) occurs, and the right and left hemispheres form to encase and protect the midbrain.

From this time onward, the hemispheres develop centers to process language symbols, visual and auditory input, movement, and abstract thought.

During the 12th week, the cerebellum or "little brain" at the back of the head differentiates out of the brain stem, and by four months the brain's general structure is present. A surprise to me is the fact that all fetuses are female until the 10th week when sufficient testosterone produces maleness and the brain begins to physically shape for male or female characteristics. Yes, just as you suspected, male and female brains are different.

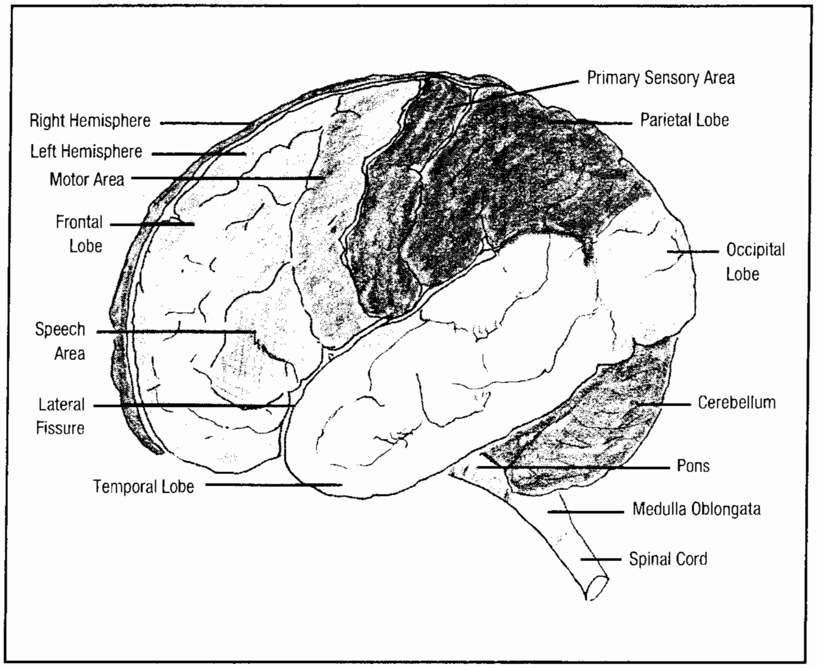

Figure 2. Lobes of the Human Brain.

Neural organization. Throughout the fetal period, newly created neurons adhere to each other and migrate to different areas of the brain where they form into groups and layers that "map" or connect to specific body parts or to external stimulation. Groups of cell bodies organize like peanuts in bowls to carry out vital brain functions such as processing emotion (amygdala), storing experiences (hippocampus), integrating motor activity (basal ganglia), serving as relay stations for incoming sensations (thalamus), and regulating hunger, thirst, sexual activity, goal-seeking behavior, endocrine function, activity of the visceral nervous system (hypothalamus), and so forth.[7]

These structures are found in the brain stem and medial parts of the brain beneath the cortex.

Some neurons form into layers as in the cerebellum, hippocampus (three layers each), and the cortex (six layers). Across layers neurons organize themselves into columns so layers can communicate with each other through dendrite/axon connections like neighbors in an apartment house connected by phone lines from room to room and floor to floor.

Like the lonely widow, some neurons spend considerable energy talking to themselves. Some stay within the layers, "talk" with one another, and never set axon or dendrite outside the cortex; however, some neurons (pyramidal cells) send long axons (fibers) from one hemisphere to the other and create a tight bundle of fibers called the corpus callosum that joins the two sides of the brain and literally allows the left brain to know what the right brain is doing and vice versa.

Layered neurons in the cerebellum and hippocampus function in much the same way to control movement and memory respectively. Neurons that group like wires in a cable are called nerves, and they tract sensory stimulations over long distances such as from the toe to the brain and back again. To keep things running smoothly, each sensory system has its own pathway of neurons that carries messages to different parts of the brain; however, messages that generate conscious awareness go through the thalamic relay station on their way to specific areas — visual, auditory, motor, critical thinking — of the cortex where they are interpreted.

As mentioned above, neurons from the six different layers of the cortex work together in clusters or columns that "map" or connect to body parts. For example, one column of neurons maps to the index finger, another maps to the thumb or big toe, and so forth to take responsibility for sending and receiving messages to and from that part of the body. Neurons that wire together, fire together, and, interestingly, once mapped, neurons are reluctant to relinquish their responsibilities. Columns of neurons that map to various parts of the hand, for example, will continue to act as if the hand were there even if it were subsequently amputated. Eventually, feedback to the "phantom limb" usually disappears as associated neurons join other columns that map with other parts of the body.

Here is another astonishing discovery: As brain mapping continues, some neural columns organize to process color, others process horizontal or vertical lines, some columns map for dogs, objects such as tools, trees, houses, and so forth.[8] Consequently, when we see something like a red rubber ball rolling along the floor, all neural maps associated with that input — including some of the 30 visual maps — operate in unison or parallel so we see a coordinated event rather than separated bits and pieces. Neurons that map to color "see" red, others see round, some process "it's rubber," others identify ball, another column "maps" to the rolling movement, and still others to floor. Simultaneous or parallel firing of neurons across all corresponding maps results in a gestalt image called, "I see a red, rubber ball rolling across the floor." At the same time, other maps process sounds, emotion, and other information associated with the ball as well as tangential input from the background.

Scientists are racing to see who can discover how the brain accomplishes such magnificent feats and what happens in students with learning disabilities when processing is less than smooth.

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Hemisphere asymmetry. In most persons, language centers are found in the left cerebral hemisphere, which is usually larger than the right; however, the cerebral hemispheres of children with learning disabilities often have reversed asymmetry or hemispheres nearly equal in size.[9] What causes faulty symmetry, and what difference does it make?

Researchers believe the problem is created when cells that are designed to die in utero or shortly after birth (approximately 70 percent of those produced) fail to do so.[10] Instead, and in keeping with survival behaviors, they compete for connections. To the victor go the spoils and in this case, the spoils are connections with a sensory system.

When neurons designed to die live on, connection competition seems to create neural confusion and inconsistent firing, which prevents the production of supporting glial cells and axon insulation (myelination) — both are required for the speedy transmission of nerve impulses. Consequently, neurons take longer than expected to fire and may fail to fire simultaneously.

Paula Tallal, co-director of the Center for Molecular and Behavioral Neuroscience at Rutgers University, and Michael Merzenich, chief scientific officer and professor at the University of California at San Francisco, found that some children with reading problems process consonant sounds at 300 milliseconds while achievers process the same sounds in 10 milliseconds.[11] Further, according to their research, non-achievers in reading are generally slower across all sensory systems than achievers. Tallal, Merzenich and their colleagues developed a computer-driven neuronal training program to speed up the rate at which students respond to auditory input. Their results strongly suggest that after six to eight weeks of training (about eight hours per week), reading and other academic achievement increases, making this a breakthrough program based on brain imaging and computer technology; however, replication studies by other researchers are needed to validate their findings.

Causality for this type of brain anomaly is speculative at best, but scientists point to maternal health as a possible contributing factor.

Maternal stress during fetal development. Effective brain development depends on the mother's diet and a healthy fetal environment, where the brain can "wire" itself to itself and to the body. During this busy period, the brain manufactures from 50,000 to 200,000 body and brain cells per second.[12] Thus, maternal use of alcohol, drugs, or nicotine, which sends toxins through the placenta to the fetus, can damage hundreds and thousands of developing cells every second they are in the blood stream. As an aside: Kotulak[13] reported that alcohol abuse is the leading known preventable cause of birth defects and mental retardation.

Maternal stress can also harm the developing brain, because it produces hormones such as adrenaline and glucocorticoids (including cortisol), which raise blood pressure, increase heart rate, raise blood sugar, and send fight-or-flight responses throughout the baby's brain and body. Chronic stress causes the fetus to expect high anxiety so it assumes a fight-or-flight posture in utero and after birth, which is often reinforced by anxiety-producing living conditions.[14]

Playing the Keyboard Is Good for Your Brain

Kindergarten students in the Kettle Moraine School District have been participating in a study that appears to confirm previous research on the connection between early musical training and the development of spatial reasoning. This type of reasoning is associated with the higher order thinking required in reading, writing, and math activities.

In the study, conducted by Drs. Fran Rauscher, a psychology professor at the UW-Oshkosh, and Gordon Shaw of the University of California-Irvine, two kindergarten classes received 20 minutes of piano keyboard instruction each week. Two other classes, serving as the control group, received no musical training. During the study, the keyboards were kept in the classrooms of the students who received instruction, and they were encouraged to play or practice on them as much as they liked.

Both groups were tested in September before the study to evaluate their spatial reasoning skills. The tests involved construction and memory tasks.

When both groups were tested again in January, the students who received keyboarding scored 36 percent higher in speed and accuracy on these tasks compared to the control group. A final post-test was administered last month.

An earlier study of 3-year-olds who received musical training by Rauscher and Shaw found similar results.

The study and the Kettle Moraine students were featured on NBC's *Today Show* in April as part of its "Bringing Up Baby" series.

Because of the positive results of the study, keyboarding instruction will be expanded to include all kindergarten students next year, according to District Administrator Sarah Jerome. "We are very impressed with the positive impact the keyboards have had on student achievement, spatial reasoning, study skills, and self-discipline," she said. "The students and parents are delighted with the improvements."

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Reactions to fetal and preschool stress can be seen in kindergarten children's behavior as they tend to appear either more fearful or more aggressive than other children; they tend to lean forward on their toes ready to protect themselves from danger; and there is a tendency toward hyperactivity.[15] Their systems remain in a constant fight-or-flight mode because, according to neurophysiologist Carla Hannaford, when under stress the tendon guard reflex shortens the calf muscles to lock the back of knees in preparation to fight or run. Chronic stress, she wrote, causes lower back and neck muscles to lock almost perpetually which causes immobility of the spine and decreased flow of natural cerebral spinal fluid to the brain.

Reactions to stress tend to create more stress and a vicious, seemingly endless cycle. Hannaford called chronic stress victims "survival-oriented, stressed-out humans" and warned that without effective stress management, "our ability to be creative, productive, learning individuals throughout life" is limited.[16] What do administrators and teachers in your district do to reduce schooling stress while maintaining high academic standards? Does your district have an adolescent program where students learn about the specific impact of toxins on fetal development?

Birth to Age 3. During the first eight months after birth, neurons continue to connect to each other and back onto themselves at an astonishingly rapid rate, and they strengthen maps as fingers and toes find the mouth, as hands learn to hold a bottle, and mother's smell and sound become recognizable. Neurons not stimulated by voices, environmental sounds, touch, sights, smells, and movement begin to search for something else to do. Those receiving stimulation flourish and grow stronger while unused ones fail to thrive. Thus, in addition to water, salt, and nutrients, the brain, like muscles, needs stimulation to strengthen and build brain mass just as physical exercise builds muscle mass. Healthy sensory stimulation, therefore, is essential for healthy brain development.

"Without question, sensory experience is crucial for neurons to learn what they are to do."

Cell death occurs throughout life, but premature neuronal death can be avoided or greatly reduced by providing enriched learning environments and new learning opportunities. Neurobiologist Marian Diamond[17] found that environmental stimulation can either enrich neuronal growth in animals or hamper it depending on various conditions such as opportunities for new learning, living conditions, and sensory stimulation — conditions she believes affect children in the same ways. Interestingly, too much stimulation, she discovered, is as harmful as too little.

By comparison, Janellen Huttenlocher, a psychologist at the University of Chicago, found that mother-to-baby talk increased children's vocabularies when socioeconomic factors were equal. "At 20 months, babies of talkative mothers knew 131 more words than infants of less talkative moms, and at 24 months the difference was 295 words."[18] Thus, babies need to hear language and lots of it to develop rich vocabularies.

Language for language's sake will not do, however. A baby's language needs to be in short sentences that supplies labels for actions and things — "Bottle. Baby wants a bottle? Mommy will get baby a bottle" — and it needs to be specifically addressed to the baby in calm tones that reassure and reinforce a sense of comfort and well-being rather than adult talk to one another or talk emitted from a radio or television.

Babies who are unable to hear language because of deafness and those with frequent ear infections and intermittent hearing loss either receive no language or they receive mixed auditory input if inflammation and fluids distort sounds. As a result, neurons designed for specific sounds diminish in effectiveness. In deaf babies the 50,000 or so nerve pathways devoted to sound signals wait around until about age 2. Without work, they begin to process sights or other sensory inputs and are no longer dedicated for sound processing.[19]

Even if successful surgery corrects disorders of sound conduction, new auditory input can be highly frustrating and disquieting since language-processing neurons are at work elsewhere and are no longer ready to decipher language; however, neurons dedicated for language can — to some extent — be reprogrammed for language or sound once hearing is available.[20] Unfortunately, the older the child the more difficult it is to reassign neurons to new functions. By comparison, when not used, visual neurons either die or shift to another purpose such as the processing of sound, and they can no longer shift back to sight. That realization has led to immediate surgery on babies born with cataracts.[21]

Touch is also essential for neuronal growth. At one time it was thought that premature babies needed the warmth and isolation of an incubator to develop, but in the 1940s, it was discovered that cuddled and stroked babies survived life in foundling institutions whereas those fed, clothed, and left alone died.[22] Premature babies who were massaged gained nearly 50 percent more weight even though both groups received the same diet. Further, eight to 10 months later, stimulated infants had better mental and physical abilities than the other group. Touch, therefore, whether in the form of stroking, hugs, cuddling, hand-holding, kissing, or licking has beneficial health effects on infants, and touch is also essential for children and adults.

Without question, sensory experience is crucial for neurons to learn what they are to do. Torsten Wiesel, president of Rockefeller University and former Harvard Medical School researcher and joint recipient with David Hubel of a Nobel Prize for discovering the importance of visual stimulation during this early critical period, stated: "There is a very important time in a child's life, beginning at birth, when he should be living in an enriched environment — visual, auditory, language, and so on — because that lays the foundation for development later in life."[23] This creates a dilemma for caring teachers who are forbidden to touch children in appropriate ways.

Age 4 to 12. Brain activity between the ages of 4 and 12 surges as the brain pulsates at levels 225 percent higher than adult brains. Pediatric neurologist Harry Chugani of Wayne State University found that during this third critical period pulsations occur more rapidly, reflecting the brain's eager search for sensory stimulation as it decides which connections to keep and which ones to eliminate.

"It is amazing how much information children eagerly collect when it connects with something they already know and they can construct new meaning from it."

Schooling from kindergarten through fifth grade, therefore, must be richly stimulating with activities that reward the brain's insatiable appetite for meaning.[24] It is amazing how much information children eagerly collect when it connects with something they already know and they can construct new meaning from it. Thematic units, real-world problem solving, well-written literature, creative writing opportunities, and meaningful play are essential and can be used to teach phonics, basic reading skills, and other core academics in pleasurable ways.

Worksheets, repetitive seat work, unimaginative classroom experiences, or a lack of opportunity to take charge of learning within structured parameters soon cause the brain to produce chemicals associated with boredom, fatigue, apathy, and misbehavior. One study found that 80 percent of children feel good about themselves as learners when they enter school but by the fifth grade, only 20 percent do. What happens in school to kill enthusiasm for learning and create such negative results?

After age 12, unused neurons whither and die or join other active networks, because the brain's plasticity allows fluctuations in the borders of maps over time. Nonetheless, learning habits, patterns of inquiry, sense of self as a learner, confidence, self-assurance, and skills of dependence-independence-interdependence, among other personal qualities that affect life for years to follow, gain or lose strength during this period that can last a lifetime.

Without question, the brain needs reasonable challenge, stimulation, and the opportunity to construct itself from environmental experiences and internal thoughts. Do your schools provide reasonable challenge and meaningful opportunities to grow?

As Diamond and her colleagues found, respectful, collaborative, environments where learning is overt, challenging, honored, and pleasurable can build neural networks and brain growth — the opposite can destroy them. What a child experiences and thinks about becomes his or her mental architecture with strong neuronal scaffolding or collapsed potential.

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Ages beyond 12. Around age 12 the brain's neural connections are in place, and learning a language or anything else for which no foundation was established during the previous years becomes more difficult with each passing year. During adolescence, surviving neuronal connections are busy at work with duties initially assigned or otherwise assumed.

Consequently, to learn something for which no network exists means dismantling assembled networks with competing inputs to encourage cells to take on alternative tasks. Once they disconnect themselves from one network, they require extensive stimulation and use if new connections are to be maintained and strengthened. Thus, the tearing down of old connections is necessary before building new, competing ones is possible. This makes learning more time consuming and labor intensive. As Chugani said:

> "Who's the idiot who decided that youngsters should learn foreign languages in high school? We're not paying attention to the biological principles of education. The time to learn languages is when the brain is receptive to these kinds of things, and that's much earlier, in preschool or elementary school. There should be more emphasis on earlier education for key areas — language, music, math, problem-solving."[26]

While most networks associated with the major learning systems are fixed by age 12, neurons assigned to day-to-day operations and new learning can persuade them to adapt at some level, and neural growth spurts during adolescence encourage more complex thinking and learning. The frontal lobes begin to think about others in altruistic ways, they play a key role in inhibiting inappropriate statements and actions, and they help adolescents gradually recognize their parents as having knowledge and common sense previously thought impossible.[27]

Brain chemicals (neurotransmitters) associated with bonding begin to surge during adolescence and love interests occupy more thinking time than prior to frontal lobe development. Oxytocin, the chemical that creates a strong bond between mother and child, once again surges to create new bonds, while serotonin — a chemical associated with leadership and sense of self — pushes the adolescent for group association and leadership.[28]

When a student has little or no opportunity to belong and be accepted in legitimate groups at school or in the community, he or she seeks affiliation with others who may be all too eager to prey on adolescent vulnerabilities. Do you know how your schools provide leadership opportunities for all students and not just the "stars"?

Applying what we know. Human brains allow us to take advantage of the environment, cultivate intellectual interests, and acquire cultural attributes beyond anything imaginable by primates,[29] yet unless children receive ample, healthy stimulation, their learning potential can be seriously depressed. The trick seems to be in devising ways to capitalize on critical periods for creating healthy learning and thinking routines, because once negative, dysfunctional routines are learned and reinforced, chances of substantial change for the individual and society as a whole decrease.

As Martha Pierson of Baylor College of Medicine in Houston stated: "It's just phenomenal how much experience determines how our brains get put together." She went on to say, "You can't suddenly learn to learn when you haven't first laid down the basic brain wiring. ... That's why early education is so important."[32]

While no question arises about the importance of early education from fetal months to school age, teacher influence on brain development during ages 4 to 12 and beyond 12 is substantially greater than previously realized. Knowledge of how the environment — prenatal and postnatal — gears up the brain during critical periods opens up possibilities for schooling environments. Brain research on critical periods gives us reason to say, "The brain likes reasonable challenge, it wants to construct its own knowledge, and it's up to us to make school a stimulating place where authentic learning occurs." Clearly, we can't wait. Society relies on schools for its future, and schools depend upon school boards to lead the way.

"Teacher influence on brain development during ages 4 to 12 and beyond 12 is substantially greater than previously realized."

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