STRONG MINDS RISE TOGETHER

The Neuroscience of Education

What can the brain sciences teach us about education?

Overview

The field of neuroscience has undergone tremendous growth in recent years. In this paper, we extract lessons from educational neuroscience, or neuroeducation, to give our readers some tools and perspective that they can use to educate their students. We start by describing neuroplasticity, the brain's way of adapting to its environment, and then proceed with what that means for child development. From there, we chronicle the adverse consequences of poverty and stress on brain development and conclude with a brain-based pedagogical model that arms educators with teaching strategies informed by the neuro- and cognitive sciences.

PREPARED BY

Nicholas Anderson
SMRT Director of Research and Evaluation

February 2016

Table of Contents

	PAGE
Our Most Reliable Muscle	**3**
The Plasticity of Human Development	**5**
Rethinking Poverty	**7**
The Biology of Stress	**8**
Brain-Based Learning	**9**
Summary	**14**

Our Most Reliable Muscle

Neurologists commonly refer to the brain as a muscle because the more we exercise it, the stronger it gets. This view of the brain represents what neuroscientists call brain neuroplasticity. Neuroplasticity refers to the brain's ability to develop and change according to its environment and surroundings. The human brain is particularly unique in its capacity for adaptation. In fact, up to 75 percent of the brain develops outside of the womb (Shore, 2006)! In contrast, chimpanzees, our closet primate relatives, are born with brains that are already 45 percent of their eventual biomass (Shore, 2006).

Neuroscientists caution that the underdevelopment of the human brain at birth is a double-edged sword; it creates both opportunities and risks for child development. The brain adapts to its environment through the activation and development of its neural network. The base unit of this neural network is the neuron, a tiny cell that continuously receives, processes, and sends information to other neurons throughout the nervous system. Babies are born with 100 million neurons, close to all the neurons they will ever need (U.S. Department of Health and Human Services, 2001). When still in the womb, fetal brain development begins by forming neurons and distributing them to the different regions of the brain as needed. Fetal development begins with the brain stem and midbrain, which regulate basic bodily functions like movement and breathing (U.S. Department of Health and Human Services, 2001).

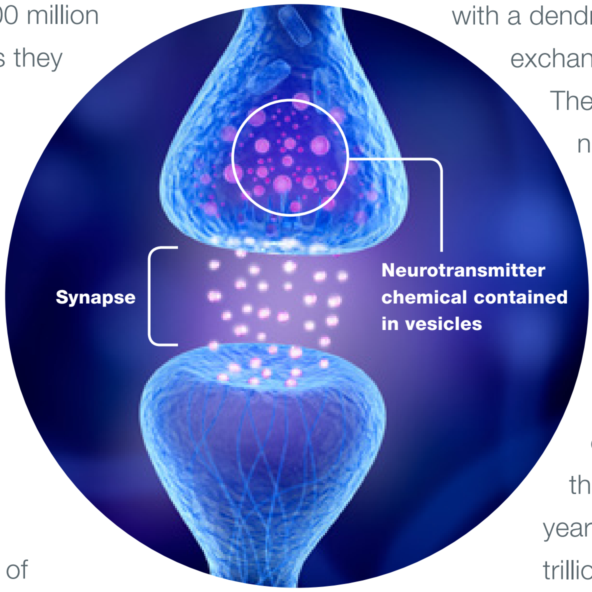

Figure 1: Neuron-to-neuron communication

Some of the last parts of our brain to mature are the limbic system, which regulates our emotions, and the cortex, which handles our abstract- and critical-reasoning skills. The brain operates by assigning functions to different regions using chemical messengers, such as neurotransmitters and hormones, to coordinate its actions (Perry, 2000).

The brain's remarkable capacity for change in the earliest years is supported by maintaining fetal levels of growth post birth so that by three years of age, the brain is 90 percent of its eventual mass (Shore, 2006; Perry, 2000). Since we are born with most of the neurons needed throughout life, brain development then becomes a process of forming or modifying neural connections between different areas of the brain. Neurons were designed with this end in mind. Neurons rely on numerous weblike connections called dendrites to receive incoming signals. Each neuron has an axon that transmits electrical signals to other neurons (Shore, 2006). A synapse is born when an axon pairs with a dendrite so that information can be exchanged between different neurons. The transmission of electrical signals requires a neurotransmitter like serotonin, dopamine, or endorphins. This neuron-to-neuron process of communication is illustrated in **Figure 1**. When information is being transported through these synaptic channels, neurologists say that the synapses are "firing." A 3-year-old will have as many as 1,000 trillion synapses – about twice the number of synaptic connections they will have as an adult (Shore, 2006). While synaptic density is maintained throughout the first decade of life, we begin shedding our synapses during adolescence. This early overproduction of synapses seems to be evolution's answer to the diverse environmental conditions that humans are born into (U.S. Department of Health and Human Services, 2001; Greenough, Black, & Wallace, 1987). This creates both opportunities and vulnerabilities in child development. In the first decade of life the brain produces many more synapses than it will ever need, so the brain must make a choice to leave more room for the connections that are activated more frequently while it must delete neural pathways that are used less often. On the one hand, repeated activation of synapses can make them durable or even permanent neural pathways over time. Conversely, the brain will shed any synaptic connections that are not being activated frequently, leaving more connections that are regularly stimulated. Shore (2006) describes this as a "use it or lose it" process – or one of "pruning" as is commonly said among neuroscientists. To visualize this process, imagine what an elephant-shaped shrub would look like after years of no upkeep. The bush would be overgrown and uneven, hardly maintaining the figure of an elephant. To maintain its shape, a gardener would have to regularly visit and trim the shrub. Any gardener who trims the topiary represents an external force acting to shape it, in much the same way the external environment shapes the human brain. Essentially, this process of synaptic pruning is nature's response to variations in human environments. When it comes to healthy brain development, the trick is to stimulate the synapses that regulate positive social behaviors, while the ones that govern more negative behaviors – like feeling threatened, anxious, or depressed – should not be overworked.

The last thing we need to understand about brain development relates to the existence of "critical" or "sensitive" periods of development. Shore (2006) provides a great description of this concept: "While learning continues throughout the life cycle, there are 'prime times' for optimal development – periods during which the brain is particularly efficient at specific types of learning...Once the prime time has passed, opportunities for forging certain kinds of neural pathways appear to diminish substantially." Shore warns that once the critical periods have passed, subsequent learning becomes more difficult, but not impossible. Most people, for example, are aware of how effortlessly young kids can often master new languages, as compared to adult learners. This is because the critical period of lingual development lies within the first decade of life. In the past two decades, neuroscience has contributed so much to our understanding of how the brain learns that we would be foolish not to use this newfound understanding as an instrument to educate the masses. One of the key lessons is to start early. The illustration in **Figure 2** questions our long-standing policy of waiting until the age of 5 to start investing in our children's education.

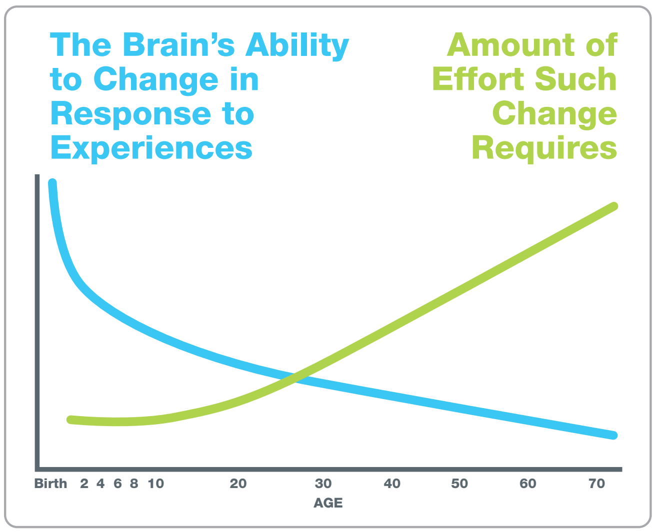

Figure 2: The brain's responsiveness to change

The Plasticity of Human Development

Privileged children benefit more from their environment than most of us are aware of. If a child's caregivers provide consistently warm and responsive care, then pro-social tendencies are more likely to take root. The figure below highlights some of the ways more affluent parents are likely to reinforce the cognitive and socioemotional development of their children (Moe et al., 2015). For example, if you are more privileged at birth, then your vocabulary is twice as large by your third birthday than if you were raised in poverty as seen in **Figure 3**. And you are also affirmed rather than discouraged by a ratio of over 6:1. You are likely to have two parents who can afford to take you to culturally enriching activities, like museums or theater performances. These positive influences support a wider learning environment that is safe for exploration and curiosity. In doing so, neural networks that foster positive development and social behaviors are born. At this point, the early life advantages of economic security and parental engagement translate into a healthier, stronger brain ready to navigate the world – feeding a virtuous circle of growth. But if you are poor, you are not so lucky, as highlighted in **Figure 3**.

If you grow up poor, your parents and family are more likely to be overworked, overstressed, and are less likely to give you the kind of nurturing your brain desires. In fact, research has shown that poorer families are more likely to let their kids endlessly consume television and even when their kids make it outdoors, their parents are only half as likely to know where their children have run off to (U.S. Census Bureau; Ahnert, Pinquart, & Lamb, 2006).

Most of us are aware of the detrimental, often lifelong impairments, that follow childhood abuse, but we are less aware of why this is so. In this case, the brain learns to be more afraid and distrustful of others in its immediate environment. The process of learning is one of pruning; the synapses that regulate healthy attachment to others have been replaced by feelings of insecurity, defensiveness, or even aggression (Shore, 2006). Several studies have shown that early exposure to trauma or abuse increases the risk of anxiety, depression, and the tendency toward violent behaviors, while also significantly impairing their ability to form and maintain healthy relationships with those around them. As Shore notes, sustained childhood abuse can overdevelop the parts of the brain that regulate our automated, biological responses to perceived danger or threats in our environment. This makes one more likely to jump into an aggressive, combative state without careful consideration of the consequences (Perry, 1996; Jensen, 2009).

How You Get Locked Out of the Future by Age 4

	FUTURE STUDENT • I live with both of my parents • My parents are college educated • My family income is in the top 10%	**NO FUTURE STUDENT** • I live with mom – dad is not around • Mom is a high-school dropout • My family is on welfare
Amount my parents spend per year on products and activities that stimulate my MIND, BODY, and SOUL	$6,500 PER YEAR	$1,000 PER YEAR
Time my parents spend with me per day on child care activities	130 MINUTES	90 MINUTES
My parents value instilling "Self-Reliance" in me over "Obedience"	70%	19%
Number of verbal "Encouragements" vs. "Discouragements" I hear from my parents per year	166K ENCOURAGEMENTS vs. 26K DISCOURAGEMENTS	26K ENCOURAGEMENTS vs. 57K DISCOURAGEMENTS
Words I hear per year + my vocabulary by age 3	19M WORDS/YEAR & 1,100 WORD VOCABULARY	5M WORDS/YEAR & 500 WORD VOCABULARY

Figure 3: Adapted from the "2020 Vision: A History of the Future" (Moe et al., 2015)

Shore (2006) shows that healthy brain development depends on forming strong, secure attachments with those around them in their early years. She refers to healthy and secure attachment to caregivers as a "biological protective factor." Supportive, emotionally responsive care is the key. As a child begins to mature and become self-aware, adults who can accurately gauge their emotional state and respond appropriately will reinforce and validate the child's inner self. Repeated interactions build a child who is confident, assertive, and more empathic of those around them, as well as one who is more likely to persist in the face of adversity. As said explained by Harvard University's Center on the Developing Child:

> **Serve and return interactions shape brain architecture. When an infant or young child babbles, gestures, or cries, and an adult responds appropriately with eye contact, words, or a hug, neural connections are built and strengthened in the child's brain that support the development of communication and social skills. Much like a lively game of tennis, volleyball, or Ping-Pong, this back-and-forth is both fun and capacity-building. When caregivers are sensitive and responsive to a young child's signals and needs, they provide an environment rich in serve and return experiences. (Center on the Developing Child)**

In fact, some researchers have even found that infants who are frequently touched and held gain body weight more quickly and show larger gains in head circumference as compared to those who are coddled less often (Shore, 2006). But again, the early years are precarious times for a child's development; a child in poverty certainly pays the full price tag for their socioeconomic condition. As Jensen (2006) says, "The aggregate of risk factors makes everyday life a struggle; they are multifaceted and interwoven, building on and playing off one another with a devastatingly synergistic effect." The result is a vicious circle that takes its toll over time on unlucky children. Indeed, when we look back at **Figure 3**, one can't help but spot the different realties that poorer children live in – they receive, for example, over 100,000 times less encouragement and over double the amount of discouragement than their more affluent peers would each year.

For any educator, administrator, or researcher out there, we highly recommend Eric Jensen's (2006) *Teaching with Poverty in Mind* for a short but dense introduction to the neuroscience evidence on how poverty affects the brain. In it, Jensen tells the story of what poverty does to the brain. Poverty infects the brain like a virus, and the symptoms are likely to manifest themselves in the behaviors of those it affects. Poverty diminishes a human's physical, socioemotional, and cognitive functioning all at once (Jensen, 2009). This why poverty is so harmful to our development – our brain's neuroplasticity feeds off of a web of interconnected risk factors that are right around us. In effect, kids from impoverished environments exhibit more "acting out behaviors," like aggression and rudeness, while being debilitated by weaker cognitive skills like deficits in attentional and motivational skills. Poorer students are also more likely to be absent from school and get ill – keeping them away from a potentially more enriching environment than what they are normally exposed to. But brain neuroplasticity is also why the more advantaged of us are more likely to be able to follow our dreams and passions, because we are insulated in layers of protective factors. Research shows that lower socioeconomic children face less warm and responsive care by their parents, but also show the cognitive underdevelopment that results from an absence of nurturing parents (Jensen, 2009).

Rethinking Poverty

But there is hope. If the brain is a muscle, then we can strengthen it through exercise and stimulation. Jensen (2009) argues that this advice is particularly relevant for schools located in the poorest of communities. As he says, "Brains are designed to reflect the environments they're in, not rise above them." This is why Jensen says educators should expect their students from impoverished home environments to misbehave and act out. Fortunately, the same technologies that are teaching us these lessons can also pinpoint the cognitive deficiencies that poverty produces. This may give schools that already face uphill battles direction for how to invest their scarce resources. We cannot forget that the uniqueness of the human brain lies in its ability to adapt to its environment. At their best, educators or any caring adult can be more than just a protective factor. They can be the inspiration that sets off a spark toward a better life for those they nurture.

> Poverty is... a condition that cultivates a mindset of maladaptive behaviors and thoughts – a mindset of "I can't do"

Is it possible that American society doesn't quite fully appreciate the challenges faced by those in poverty? We at SMRT certainly think so. How often do we hear that the poor are lazy or somehow did it to themselves? These generalizations do more harm than good by ignoring the simple fact that most of us, most of the time, simply reflect the environment around us. We think it is time to recast society's understanding of poverty. And we are not alone.

Jensen (2009) describes poverty "as a chronic and debilitating condition that results from multiple adverse synergistic risk factors and affects the mind, body, and soul." Bryant's (2014) view of poverty focuses on deficits in three areas: "self-confidence, self-esteem, and belief in oneself; role models and environment; aspiration and opportunity." The lack of all three can lead to learned helplessness of individuals or even entire communities. For Bryant (2014), the most dangerous person is a person without hope. He warns that when hopelessness engulfs enough people for long enough, it can hijack the soul of an entire community as a way to lash out from feelings of economic exclusion. After echoing Jensen and Bryant's plea to broaden our view of poverty, economist James Heckman and colleagues (2014) suggest that quality parenting is the "true measure of child poverty" for the "absence of parental guidance, nourishment, and encouragement is the most damaging condition for child development." These three attempts to recast the definition of poverty illustrate the web of complex factors that affect those who find themselves immersed in it. Defining poverty as merely an economic condition misses the point because of how strongly, consistently, and adversely it harms child development. When it comes to reimaging our view of poverty, reflecting the multiple and broad-based impacts of a condition that cultivates a mindset of maladaptive behaviors and thoughts – a mindset of "I can't do" – must be advanced.

The Biology of Stress

A life of poverty also very likely means leading a high-stress life. While small or moderate amounts of stress should be expected and are even healthy, chronic and acute stress can be damaging. A child in poverty is likely to have parents who feel overworked, over-stressed, and overwhelmed by life's demands. And these feelings tend to persist wherever poverty has a hold. Impoverished parents, who may themselves have missed out on an affectionate upbringing, are less likely to provide warm and responsive care to their children. Not only are they less likely to read to their children or to demonstrate interest in what their children are learning in school, but they are more likely to use authoritarian parenting practices and resort to physical punishments to "teach" their children (Jensen, 2009; Evans, 2004; Zuehl, 2001). Jensen warns us that sustained levels of stress threaten nearly every part of a human's psychosocial and physical development.

When our prehistoric ancestors traversed the wilderness, they had to learn how to survive, else they could be dinner for any number of predators. Fortunately for us, evolution doesn't like to take chances, so it developed a stress response system to create a state of arousal called the "fight or flight" response. When our brains receive threatening information from the environment around us, a cascade of physiological reactions is set into motion by our autonomic nervous system – "autonomic" because these reactions occur automatically and effortlessly, outside the realm of conscious thought (Walton, 2010). A key part of this process is the release of adrenaline and cortisol to handle an environmental stressor – a type of resource management response that tells the body to divert all energy toward immediate self-preservation. Adrenaline increases our heart rate and blood pressure as our muscles contract in anticipation of physically exerting ourselves (Hardimna, 2012). The cortisol further puts us on edge, increasing our heartbeat and blood sugar levels should we need to act fast as it travels throughout the body. From there, we are ready to respond in the blink of an eye to a perceived threat. Our ancestors relied on this biological stress response pattern for survival: when they saw a hungry predator their bodies either generated a swift response to safety or they were lunch. As we fled, eventually our body would return to its normal low-stress state. But stress starts to undermine our health when it becomes prolonged.

Modern day stressors are different from prehistoric ones. While our stress response system is activated by life-threatening situations (just substitute a speeding car for a hungry predator), the daily hassles of modern life can activate and even sustain our autonomic nervous system. Modern humans regularly feel social, emotional, or even work-related stress on a daily basis. And poverty seems to come with more than its fair share of stress, whether it's dealing with late fees as you live month to month, living in an overcrowded house, or feeling unsafe in your neighborhood. But our bodies did not evolve under conditions of constant stress, which is why chronic stress takes such a toll on the human body. Chronic stress has been associated with a number of hazards, including decreased life expectancy, depression, a loss of creativity, a weaker memory, worse sleep, and even a diminished ability to learn (Watson, 2010; Lupien, King, Meaney, & McEwen, 2001; Yang, Cao, Xiong, Zhang, Zhoue, Wei, et al., 2003).

Jensen (2009) describes the effects of chronic and acute stress as exerting a "devastating, insidious influence on children's physical, psychological, emotional, and cognitive function – areas that affect brain development, academic success, and social competence," leading to "significant behavioral and academic problems in school." And the more disadvantaged a child grows up, the more exaggerated these setbacks become. Jensen (2009) tells the story of stress on the 30-50 trillion cells within each of us. Basically, each one of these cells grows in either healthy or unhealthy patterns over time. Ideally, the body reaches a state known as homeostasis, where the vital functioning of our body achieves a state of harmony and balance between different bodily systems. But a stressor threatens this balance by giving priority to one's survival instincts. This stunts cell growth by putting them in a "hunker down" mode that tells them to conserve resources for a threatened future (Jensen, 2009). When one's body is constantly besieged, the effects of chronic stress can take a massive toll on us by literally draining our capacity and interest for new learning. But that's not all. Jensen warns that a stressed neuron is a weaker one, producing weaker and fewer signals to nearby neurons. Obviously, a besieged brain constantly trying to conserve resources isn't what anyone wants. But for those in poverty, this innate and automatic response to their surroundings simply cannot be helped.

As educators, you need to be armed with an awareness about the unique environment that is faced by each one of your students

Brain-Based Learning

So, what do we do if we know a troubled soul? If we ask this question from the lens of a parent, then the answer is to love and affirm your child, as we discuss in depth in our white paper on child development. As educators, you need to be armed with an awareness about the unique environment that is faced by each one of your students and how it can impact their performance and behavior in school in different ways. More generally, educators should understand how the brain functions and learns. As pieced together by Mariale Hardiman (2012), we know more today about the type of stimulation that the brain likes than ever before. Through her thorough sweep of educational neuroscience literature, Hardiman (2012) establishes a brain-based pedagogical model which she calls the Brain-Targeted Teaching Model (BTT) model. The BTT is an instructional framework that assists teachers with planning and implementing a program of instruction based on the latest research from the neuro- and cognitive sciences. This pedagogical model can be applied to early, K-12, or adult education. The BTT framework consists of six factors: (1) establishing an emotional climate for learning; (2) creating a safe and engaging physical environment; (3) designing the learning experience; (4) supporting mastery of content, skills, and concepts; (5) providing opportunities for real-world application of knowledge and skills; and (6) evaluation and assessment (Hardiman, 2012).

Brain Target One deals with the relationship between emotions and learning. Until quite recently, the role of emotions in our education was severely underestimated. Hardiman (2012) covers a body of evidence that collectively communicates the critical role our emotions play in learning processes like memory, attention, and higher order cognition. For example, the "fight or flight" response caused by stress creates a state of arousal that makes learning all the more difficult. Researchers Shwabe and Wolf (2010) effectively demonstrated how the learning environment can affect student learning. They discovered that the acquisition of new words drops by about 30 perecent when the learner is in a stressful environment. And engagement of the amygdala, our emotional processing center, has been shown to improve memory, which is why Hardiman suggests to incorporate humor into the lesson where possible (Ferry, Roozendaal, & McGaugh, 1999; Schmidt, 1994). When it comes to creating a positive learning environment, it may be surprising to some that praising a child's accomplishments isn't always a good thing. Research suggests that behavior-specific praise is more effective in reinforcing positive behaviors like motivation to learn, while generalized praise of a student's ability, like "Good job" or "Way to go," actually do more harm than good (Mueller and Dweck, 1998). Carol Dweck argues that praising a student's ability sends the message that they succeeded because they are smart, and while beneficial in the short term, as soon as the student encounters difficulty they are more likely to give up in the future on the grounds that they just aren't smart enough to solve the riddle. But praise of effort does the opposite – it encourages one to work extra diligently when confronted by a challenge.

But probably the most important aspect of her first brain target stresses the importance of developing secure attachment to an adult within school. The National Longitudinal Study of Adolescent Health followed 12,000 7th-12th grade students and found students who reported having stronger relationships with a caring adult in school were "less likely to be involved in every risk behavior tested as a part of the study, including: drug use, cigarette smoking, early sex, violence, and suicidal thoughts," and also had superior academic performance and higher school attendance and completion rates (Hardiman, 2012). Related to this, she also includes social and emotional learning as well as mindfulness training as key ways to advance her first brain target. Lastly, Hardiman echoes Jensen's concerns about the close relationship between childhood poverty and chronic stress, warning of the detrimental effects that chronic stress can have on our cardiovascular, digestive, and immune systems. Hardiman's (2012) decision to make the emotional climate the first part of her Brain-Targeted Teaching model is a recognition of how vital our emotions are in the learning process.

Any teacher that doesn't believe the physical environment affects student achievement will be intrigued by Hardiman's research. Brain Target Two deals with the physical environment, which has been shown to influence student learning as well as their perceptions about school. Novelty in the classroom, for example, helps by triggering the altering and orientation system, which stimulates thought and improves memory retention (Posner & Rothbart, 2007). Students who are exposed to the same old classroom day in and day out get habituated to it, diminishing their levels of attention and interest in the learning environment (Ariga & Lleras, 2001). Furthermore, Zentall (1983) argues that when a student becomes accustomed to their learning environment, they may be tempted to turn to their own novel form of stimulation, such as daydreaming, doodling, etc. One of the most interesting findings Hardiman (2012) presents relates to classroom lighting. In particular, poorly lit classrooms reduce activity of melatonin synthesis which affects our serotonin production, the neurotransmitter which is vital to mood regulation (Ott, 1973). Researcher Heschong (1999) examined the effects of natural lighting on 21,000 student test scores. She found that math and reading assessment scores rose by 20 percent and 26 percent respectively when taken in a setting with natural lighting! Hathaway (1995) uncovered that learning environments with more natural sunlight resulted in improved student health and school attendance on top of higher academic achievement. Scent in the classroom turns out also to have beneficial effects. Student engagement as measured by a reduction in off-task behaviors was found to be higher in classrooms with a scented oil (Gabriel, 1999). Some scents, like lavender and orange, have even been found to reduce anxiety (Lehrner, Marwinski, Lehr, Johren, & Deecke, 2005). Movement within the classroom, as well as general physical activity and exercise, has also been shown to enhance cognition. Ratey (2008) argues that physical movement results in our muscles producing proteins that boost learning, while also bolstering student attention spans. Hardiman also shows how sound, like soothing music, can be incorporated to create a more relaxed learning environment.

> Math and reading assessment scores rose by 20 percent and 26 percent respectively when taken in a setting with natural lighting!

Hardiman's next two brain targets deal with the cognitive processes associated with learning. Brain Target Three tells us that the human brain organizes information around "big picture" concepts – i.e. newly acquired knowledge gets categorized in a logical manner with prior knowledge. The brain is built to identify patterns and associations in the world around us (Posner & Rothbart, 2007). But we have known about the benefits of teaching global concepts by relying on visual representations like concept maps for quite some time (Ausubel, 1960). The wide use of schema in educational settings further shows our longstanding awareness of this pedagogical perspective. Schema teaches students to break down complex information into simpler components to help the learner ground their understanding of the object under study. In particular, this is supposed to help children understand the common elements to the different topics encountered in the world and in school. Poirel, Mellet, Houde, and Pineau (2008) documented the evolution of our visual processing during childhood. While 4-year-old children still focused on the smaller components of bigger concepts, or showed a preference for local processing, by the time these children had reached 9 they began to process the bigger picture in much the same way adults do. Hardiman suggests that the third brain target is all about using different learning activities and visual cues to drive home big-picture concepts.

Brain Target Four focuses in on how we humans process information, clarifying the role that memory plays in the learning experience. While learning simply refers to acquiring new information or knowledge, memory refers to our capacity to access that knowledge. The access of information relies on properly storing and then recalling this information when needed. For the brain to solidify and commit something to our long-term memories, our brains must undergo a process that neuroscientists refer to as consolidation. The more often we access certain pieces of information, the more likely they are to be committed to our permanent memory. In a sense, this refers to the process of synapse pruning described earlier – when some particular neural circuits are repeatedly activated, they become more strongly bound together, making memory retrieval more effortless and long-lasting (Hardiman, 2012). Hardiman offers a number of strategies to strengthen memory recall, including: arts integration, repeated rehearsal, elaboration, physical enactment, visual representation, and the stimulation of emotions. She also points out a few pedagogical tools, like the use of mnemonics, chunking information, and providing adequate challenge for all learners. Whereas Brain Targets Three and Four focus on the learning process, Brain-Target Five shifts its focus on the real-world application of knowledge.

Hardiman's fifth brain target fits nicely within the context of a 21st-century education with its emphasis on creative and innovative problem-solving skills. Creativity, contrary to popular opinion, is quite malleable and susceptible to development. And when we put a child's creative prowess to the challenge, we are actually encouraging measurable changes in brain volume and structure and improved cognition (Andreasen, 2005). Many studies have demonstrated the enhanced brain structure and volume that musicians possess (Schlaug, Jäncke, Huang, Staiger, & Steinmetz, 1995). In fact, one group of 6-year-olds benefited from sizable growth in multiple areas of the brain following a mere 15 months of piano lessons (Hyde et al., 2009). These findings have significant implications for the narrow focus on convergent thinking that our education system has recently embraced. Essentially, convergent thinking emphasizes reaching, or converging to, one single, correct answer. It is usually contrasted with divergent thinking, which involves generating multiple solutions to a single problem. Divergent thinking is catching on because it strengthens an individual's ability to adapt their prior learning and experiences to be useful in other contexts. A group of researchers found that adolescent Brazilian street vendors could execute simple arithmetic problems with 98 percent accuracy. But these same young adults could not perform the same math problem in class (56 percent accuracy (Carraher, Carraher, & Schliemann, 1985). The problem was that these students lacked divergent thinking skills. Many scientists are in agreement that creative thinking in a particular area first requires sufficient mastery of content knowledge (Csikszentmihalyi, 1996). This means that educators must focus on both delivering high-quality content instruction and on encouraging divergent thinking patterns. Finally, Hardiman (2012) concludes her pedagogical model by establishing best practices for providing feedback to students.

Hardiman (2012) warns that "Educators would be remiss if they view testing only as a way to measure learning for testing… testing also has the power to cause learning." This second point is an oft-overlooked aspect of assessment in education. Assessment facilitates learning by forcing students to actively retrieve information stored in their brain as they process the feedback (Karpicke & Rohrer, 2005). One of the best studies to illustrate the power of feedback in the learning process was that of Marzano, Pickering, and Pollock (2001). They found that simply marking a student's answers as correct or incorrect had a negative effect on retention, while providing them with the right answer along with the reasoning was highly effective in boosting student achievement. Finn and Metcalfe (2010) demonstrated that scaffolding feedback, which involves providing incremental hints towards the correct answer, improves long-term memory retention. One of the more interesting findings that Hardiman explores here is the precipitous drop in performance that occurs when students don't expect to receive timely feedback. When Kettle and Häubl (2010) told students that they would receive feedback on an assignment somewhere in the range of 0–17 days, the longer they expected to wait before they received feedback the more their performance suffered. The authors attributed this to a decrease in motivation that grew as students expected to have to wait longer to receive feedback. This underscores that good feedback is not only specific, but also timely.

In addition to encouraging the use of different types of assessments (journals, portfolios, or project-based learning), Hardiman (2012) also covers the importance of "spacing effects" in education. When it comes to assessment, student performance inevitably depends on their ability to recall previously covered material. It turns out that if your objective is to have your students perform well on assessment tests, then providing well-timed reviews can be a powerful weapon in this battle. For example, if your goal is to make sure your students score well on a standardized exam at the end of the school year, then the optimal time to review material is about every month or two after having introduced it to your students. But if your goal is shorter-term memory retention, like for an assessment that is four to six weeks away, then a follow-up review one week after the material was taught would be ideal (Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006). Hardiman cautions educators that the downside of leaving too short of a gap between reviewing old material far outweighs the penalty from overshooting the review timeline. So a note to educators: err on the side of overshooting your review intervals to reinforce your student's ability to recall the reviewed material.

> The BTT model could support a culture of continuous self-reflection, and one that creates a joyful and engaging but challenging learning environment

In many ways, Hardiman's book pioneers the emerging field of neuroeducation by offering a digestible and comprehensible pedagogical model for teaching based on recent neuroscience discoveries. Her first two brain targets set the stage by focusing on the emotional and physical learning environment. Brain Targets Three and Four deal with pedagogy and emphasize that learners absorb "big picture" concepts and demonstrate adequate mastery over the content, skills, and concepts they are expected to learn. But education needs to remain relevant to the learner or we risk creating more disengaged students. This is what Brain Target Five relates to: helping learners apply their knowledge to solve real-world problems. And the sixth part of her model refers to the feedback process. It is concerned with what types of feedback are more likely to encourage careful reflection on the part of the student so that we can reinforce their desire to become lifelong learners. In the end, Hardiman (2012) did a remarkable job at weaving together theories advanced by the likes of Piaget, Vygotsky, Burner, and Watson to create a comprehensive pedagogical model that directs educators to focus on how their students are learning rather than what they are learning.

If correctly implemented, the BTT model could support a culture of continuous self-reflection, and one that creates a joyful and engaging but challenging learning environment. Hardiman (2012) encourages any hopeful schools or educational programs that wish to adopt her Brain-Targeted Teaching model to rely on supportive leadership and collaborative implementation strategies. It is no secret that educators have become very interested in wielding our understanding of the brain as a way to improve learning. It is our hope that the information covered here can help in that battle. Beyond any doubt, we know that the brain has a remarkable capacity for change. And this logic applies to everyone, including those hard-to-reach students. Whether we realize it or not, a student's brain is taking note of everything we do – including the words we say, how we say them, and the actions we take. When educators internalize this notion as they nurture and guide their students, they can change not only the lives of an individual person, but an entire community of people when their colleagues work in concert with them.

Summary

Neuroplasticity refers to the brain's ability to develop and grow according to its environment.

The brain's neural network, which consists of trillions of neurons, are what gives it this adaptive ability.

Neuroplasticity creates both opportunities and vulnerabilities in brain development depending on the circumstances one grows up in.

Poverty and stress present a major developmental challenge to those afflicted by them, especially when spells of poverty or stress are enduring.

Hardiman's (2012) Brain-Based Teaching model is a powerful pedagogical model informed by the brain sciences that can be applied in almost any educational context.

Learn More

For a comprehensive bibliography and other resources, please email us at **science@smrtsolutions.com**.

About SMRT

The SMRT family of companies was conceived with the intent to create an enduring and expanding funding source for ongoing community and educational investments. For free public access to research materials and a complete listing of the bibliography used in the SMRT Research Series, visit **smrteducation.org**. We specialize in helping educational institutions implement the right blend of strategies to strengthen cognitive and non-cognitive skills across all age ranges, delivering research-driven solutions that are both scalable and affordable. Explore our approach, our solutions, and our team at **smrtsolutions.com**.