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Brain-Based Learning for Adolescent Science Students A Review of the Literature

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by

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Abstract

This literature review addresses brain-based learning and synthesizes research about the brain and how it learns. This paper examines the use of brain research to explain how brain health and development contribute to learning and memory. Also addressed are strategies for the classroom that consider the current brain research. Finally, recommendations are made for the application of brain-based learning in a ninth-grade science classroom. Brain-based learning is a term used to describe the strategies that educators use to create learning environments that are aligned with the way the brain naturally learns. It has been revealed that a person's memory and learning is highly affected by brain development and brain health. Teachers who become educated on these concepts can use this information to design classrooms that are student-centered and brain-friendly. This type of learning environment assists adolescent students in forming a deeper understanding and increased retention of information.

In dedication to my grandfather, Raymond F. Arzy, who passed away this year; he taught his family about unconditional love, hard work, and true dedication

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Chapter 1

Introduction

The brain and how people learn has received considerable attention over the past few decades (Bransford, Brown, & Cocking, 2000; Immordino-Yang, 2011; Willis, 2007). Scientists and educators alike have focused on how the brain works and how learning occurs. In the 1980s, improvements in neuroimaging and technology developments, such as Magnetic Resonance Imaging (MRI), and the Electroencephalogram (EEG), allowed scientists to look inside the human body to observe how the brain functions (Giedd, 2008). This technology provided information about perceptual, cognitive, and emotional functions, which caused excitement among science and education researchers. These events sparked further interest in the mechanics of learning because researchers were able to view what was happening in the brain during learning instead of speculating about what was occurring (Giedd, 2008). Educational theorists were attracted by the concept of using this science to support learning theories and quickly became involved. Also in the 1980s, there was a shift from the study of behavior in educational psychology to a focus on constructivism and cognition theory (Tokuhama-Espinosa, 2011). Von Glasersfeld (1989) wrote that knowledge is actively acquired not passively obtained; "…the function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality" (p. 114). These changes lead to better understanding about how people create their own knowledge base by experiences and that those experiences translate into learning (Immordino-Yang, 2011).

By the end of the 1980s, the term neuroscience evolved to describe the field of study that deals with the structure and function of the brain and the nervous system. Teachers began to move away from the outdated model that students were vessels to be filled with non-relevant and unrelated material. Instead teachers moved towards an approach that was more brain-compatible, considerate of multiple intelligences, and challenged students to think creatively (Radin, 2009). One can find examples of this in the work of Freire (1968). His work has helped educational theorists understand that each student brings his/her own background, culture, and family knowledge into the classroom and that this knowledge affects their learning. Freire (1968) stated in *Pedagogy of the Oppressed* that education consists of acts of cognition, not transfers of knowledge. During the educational reforms that took place from the 1960s through the 1980s, teachers became more willing to relinquish some of the control in the classroom and allow students to work in groups on projects and solve problems in unique ways as a means to deepen knowledge and create opportunities for learning to move toward cognition and metacognition.

Later, the 1990s became known as *The Decade of the Brain* because thousands of new findings and theories about the brain and learning were developed during this time (Radin, 2009). Scientists were looking for ways to make this new found information more teacher-friendly so that educators could put this knowledge to use into classrooms around the globe. Because of the emphasis on brain-based learning, the work of Vyotsky gained interest again and his book, *Education Psychology*, was reprinted in 1997. Vygotsky (1997/1926) stated that student activity need be the focus in the educational process and the teacher serve as the facilitator, not the master of the student and environment. In addition, community and social factors play an important role in learning and "meaning making" (Vygotsky, 1997/1926). In the 1990s, mind and brain education seminars and university programs became more common place in several countries from the U.S. to Germany to the U.K. (Tokuhama-Espinosa, 2011). Teachers began to seek out seminars and publications in an effort to help them meet all students' learning needs.

In the 2000s, scientists worked to refine ideas about the developmental processes linked to learning, which led to many books and journal publications about teaching and learning by neuroscientists and educators (Tokuhama-Espinosa, 2011). The interest and applicability of this research has not waned as many researchers continue to explore connections that help learners understand and retain information in a way that is more natural to the way the brain learns. As a result, strategies such as Differentiated Instruction, as described by Tomlinson (1999), have emerged to provide educators with methods for teaching students who have varied learning styles. This strategy recognizes students as individuals and teachers begin where the students are, not at the beginning of a curriculum guide (Tomlinson, 1999). Furthermore, in order to have a clearer understanding of the expectation for student learning, *Common Core State Standards* (CCSS) (2012) are becoming more widely adopted by the states. This compilation of standards has been adopted by 45 states in an attempt to bring about an alignment of grade-level expectations and benchmarks on a national level. These standards are designed to be robust and relevant to the real world, allowing students to obtain the knowledge and skills they need for college and successful careers (CCSS, 2012).

The decades of mind, brain, and education research have shaped the definition of brain-based learning. This term was coined to describe the application of strategies that can assist learners in understanding and retaining information in accordance with the way we now understand how the brain functions while learning (Jensen, 2008). Research suggests that understanding how the brain works will assist teachers and administrators in helping students to make strides in education (Caine & Caine, 1995; Jensen, 2008; Tokuhama-Espinosa, 2008; Willis, 2009). Additionally, another term emerged to describe the scientific confirmation of the best pedagogy and the art of teaching with studies of the human brain called Neuroeducation. Neuroeducation is the overlap of cognitive science and brain-based teaching and learning (Tokuhama-Espinosa, 2008). Teachers are using this information to bring about better learning environments for their students— creating safe, stress-free classrooms and designing lessons that involve active learning and project-based learning for better student retention and deeper understanding (Caine & Caine, 1994).

Many researchers have been dedicated to sharing their findings with those in the field of education. One such researcher is Dr. Judy Willis, a former neuroscientist turned middle-level teacher. Willis brought a background of neuroscience into the classroom to educate students about brain development and function. Willis used lessons about the brain, showing students diagrams and pictures of the brain and dendrites. She also mapped out each part of the brain and its job, to instruct students on how they can make this knowledge work for them in their learning. Another researcher, Dr. Jay Giedd, National Institute of Mental Health neuroscientist, has conducted studies using MRI and EEG technology to view the development of the adolescent brain and obtain a deeper understanding of what happens during this time period, such as a reassembling of the network of nerve cells and a phase of reorganization (Dobbs, 2011). In addition, Dr. Mary Helen Immordino-Yang, neuroscientist and human development psychologist at Harvard University studies how emotions, self-awareness, and cultural norms apply to human development and education. Lastly, Geoffrey Caine and Renate Caine, education consultants, have worked to refine *Twelve Brain/Mind Principles of Natural Learning* (Appendix) and bring these principles to the attention of educators.

Prior to these research findings, many educators had limited knowledge about the brain and how it functioned while learning. The knowledge base at the time was primarily formed from studies concerning special needs students, not students of normal cognitive function. As new discoveries are made in the future, educators can continue to gain a better understanding of how the brain learns. This body of research and the research of many neuroscientists demonstrate that memory and learning are related to brain development, brain health, emotions, physical activity, and sleep.

This literature review addresses literature on brain research conducted by neuroscientists focused on brain development and health and addresses literature on the educational applications suggested by brain-based learning research. The brain research section of this paper focuses on neurogenesis, the growing of new neurons; neural plasticity, the change, repair, and improvement of the brain; and allostasis, dealing with one's stress. The applications section of this paper focuses on models that are used to explore brain-based learning in the classroom. One such model is the *Brain-Based Learning Integrated Learning-Teaching Model* developed by Caine and Caine (1990). Other suggested applications that will be addressed are active learning, where the students are engaged in the learning process, and project-based learning, where the students work through real-world problems to enhance learning.

Conceptual Framework

The conceptual framework for this study was Constructivism. The theory of Constructivism informs us that learners gain knowledge and understanding of the world through experiences and reflection upon those experiences. New information is then reconciled with previous knowledge and the learner changes his/her beliefs or discards this information because of its lack of relevance to the learner. This theory suggests that learning is a matter of reflecting, questioning, and exploring the world. Von Glasersfeld (1989) developed the theory of Radical Constructivism. His theory suggested that individuals construct reality based on actively gained knowledge and meaning is then interpreted by the individual. Teachers using this theoretical framework want their students to make sense of the world, therefore to make errors in learning and to deviate from the expected path is acceptable.

Vygotsky (1997/1926) proposed that individuals form meaning and purpose in their learning. Vygotsky suggested that society impacts an individual's learning and at the same time the individual can impact society. Teachers using Vygotsky's work as their model would take the role of facilitator over master of student and education so that students can deepen their learning and scaffold the instructions to meet the needs of students.

Lastly, one could look at the work of Freire. Freire (1968) used the metaphor of banking to describe the interactions that take place in traditional teaching and learning. Teachers make a deposit in the student's brain, and then expect to make a withdrawal later. Freire posited that education should be about acts of cognition, and that learners are influenced by their culture, background, and family. As learning occurs, the individual's world is transformed and then the educated can then change the world.

Statement of the Problem

The problem faced by educators is creating a brain-friendly classroom where all students are engaged. An overwhelming amount of considerations have emerged from current brain research. Unfortunately, not all educators are aware of these findings. This sometimes creates an unbalanced prospect for teachers to provide maximal learning opportunities for all students, which requires creating positive emotional connections to learning in order to form long-term memories and learning to be transferred to the real-world (Immordino-Yang & Damasio, 2007). Also, students cannot learn if they feel unsafe, stressed, or are experiencing a low-cycle of brain activity (Weiss, 2000).

Conventional methods might be problematic; for example, lectures may not be the best way to convey information even if it is a popular teaching technique. According to Sousa (2006), students, on average, retain only five percent of information delivered through lecture twenty-four hours later. Lecture is a strategy teachers can use to deliver information quickly and is a method most are familiar with because it is what they experienced in school as students. Roehrig, Michlin, Schmitt, MacNabb, and Dubinsky (2012) stated "…most preservice teachers rarely experience inquiry-based instruction in their undergraduate science courses" (p. 414). In turn, the teacher often then replicates the lecture-based approach in his/her own classroom (Roehrig et al., 2012). Lecture also is used as a classroom management technique, allowing the teacher full control over the interactions taking place. This type of delivery may not be effective, however, because the lack of interaction can cause a loss of relevance and retention among students (Sousa, 2006). Teachers may assume what they have to say has meaning and value to the students because it holds meaning and value to the teacher; however, this is often not the case. Delivery methods that are more brain-friendly may be a way to increase the effectiveness of teaching and learning (Aziz-Ur-Rehman & Bokhari, 2011; Duman, 2010; Saleh, 2011).

Purpose

The purpose of this paper is to synthesize current educational and brain-based research into a single document and use this information to create applications bridging cognition and metacognition in the classroom. By gaining a better understanding of this process, teachers can apply the findings to create safe, stress-free classrooms that will engage the minds of students.

In my own teaching, I have struggled to understand why my students have had difficulties with the science concepts in the ninth-grade curriculum when I was certain I was effectively teaching these concepts. Students have had little trouble repeating many of the general ideas, but when it came time to apply these ideas in real-world situations, they struggled. The goal of this literature review on brain-based research is to better understand how the brain works and how employing brain-based strategies might help students better retain and understand the concepts presented in science class. By analyzing this research about the brain and learning, I will become a better teacher, gaining greater insight into the human brain, especially the brain of a teenager. Through the careful application of strategies developed from this research my students will retain and understand the content taught in ninth-grade science.

Research Question(s)

This literature review is guided by the following research questions:

1. What does research literature reveal about brain development, brain health, memory and learning?
2. How can educators use this information to teach science to adolescent students for better understanding and retention?

To answer these research questions, I examined books and articles related to brain development and brain health as well as brain-based learning and natural learning. Reviewing this literature on brain research addresses the above questions with an emphasis on science classrooms. This paper suggests recommendations for applications that incorporate brain-based teaching strategies for science, such as active learning and project-based learning as suggested in the literature.

Background and Rationale

In the eighteen years that I have been an educator, thirteen of them in my current assignment, I have rarely administered the same unit lesson plan as the previous year. I know several educators who, year after year, continue to give the same lectures, notes, projects, and assignments. I have always searched for better ways to teach science to my students. As an effective teacher this is my responsibility. Some methods worked, and I used them in the years that followed. Some failed, and I am left to look for something new. In my search for something new, a coworker loaned me a book entitled *Teaching with the Brain in Mind* by Eric Jensen (2005). It contained many ideas of interest: how the brain matures and works, how stress impedes the learning process, how physical activity can improve brain function; and how emotions play a large part in decision making. Then, Jensen guided the reader through ways teachers could use this information to help their students grow in their understanding of information taught in school.

As I delved further into the research about brain-based learning, I found studies about the adolescent brain. I learned about the age group of the students with whom I work. I began to get a better picture of how their brains grow and develop, how that process lends itself to the behaviors my students display, and why they make certain decisions that baffle the adults in their lives. I also discovered research that suggests how to make the classroom environment more brain-friendly, and how lesson design and implementation improves student comprehension and understanding.

Key Terms and Definitions

There are numerous terms and definitions that are associated with brain-based learning. Understanding these terms is critical to being able to justify the importance of the research behind brain-based learning.

Brain-based Learning: Strategies used in education to assist learners in deeper understanding and greater retention of information (Hileman, 2006).

Neuroscience: The scientific field of study that deals with the nervous system (Tokuhama-Espinosa, 2011).

Neuroeducation: A scientific field of study that melds together cognitive neuroscience and education (Tokuhama-Espinosa, 2008).

Neurogenesis: The brain's ability to grow new neurons derived from information that is used and reused (Jensen, 2005).

Neural Plasticity/Neuroplasticity: The brain's ability to change by organizing and reorganizing as it receives stimuli (Nunley, 2003; Willis, 2009).

Allostasis: The ways in which the brain deals with stress (Jensen, 2005).

Relaxed Alertness: An optimum state of the brain for learning (Caine & Caine, 1995).

Orchestrated Immersion: Learning environments that fully immerse the learner in the educational experience (Caine & Caine, 1995).

Active Processing: Information is internalized and consolidated by the learner in a personally meaningful and coherent fashion (Caine & Caine, 1995).

Active Learning: An educational strategy where students participate in the learning process (Bransford, Brown, & Cocking, 2000).

Project-Based Learning: An educational strategy that engages students in collaborative, real-world investigations (Crawford, 2007).

Chapter 2

Review of the Literature

This literature review explores the use of brain-based learning, discusses brain health and development, and reviews the applications of brain-based learning. The review focuses on two main topics. The first focus is on a synthesis of literature that addresses the inner workings of the brain. The second focus is on literature that explores brain-based applications in the classroom and proposes brain-based learning strategies to help students understand science topics. The focus of the paper is on adolescents because that is the population of interest and relevance to the author.

Brain-Based Learning

Hileman (2006) stated, "Learning is innately linked to the biological and chemical forces that control the human brain…Brain-based or naturalistic learning considers what is natural to our brain, and how the brain is impacted by circumstances and experiences" (p. 18). Caine and Caine developed the *12 Brain/Mind Learning Principles* (Figure 1 and Appendix) to be applied in education in 1990 and refined these ideas in 1991 and 1994. These principles of natural learning are still being used in books and educational programs conducted around the world today. The Caines claimed that learning engages the physiology of the learner, involves both the conscious and unconscious self, and requires both focused attention and peripheral perception. Learning is developmental and complex while being enhanced by challenge and thwarted by threat and fatigue (Caine & Caine, 1990). The brain/mind is uniquely organized, social, and constantly searching for meaning through patterning; it processes parts and wholes at the same time (Caine & Caine, 1990).

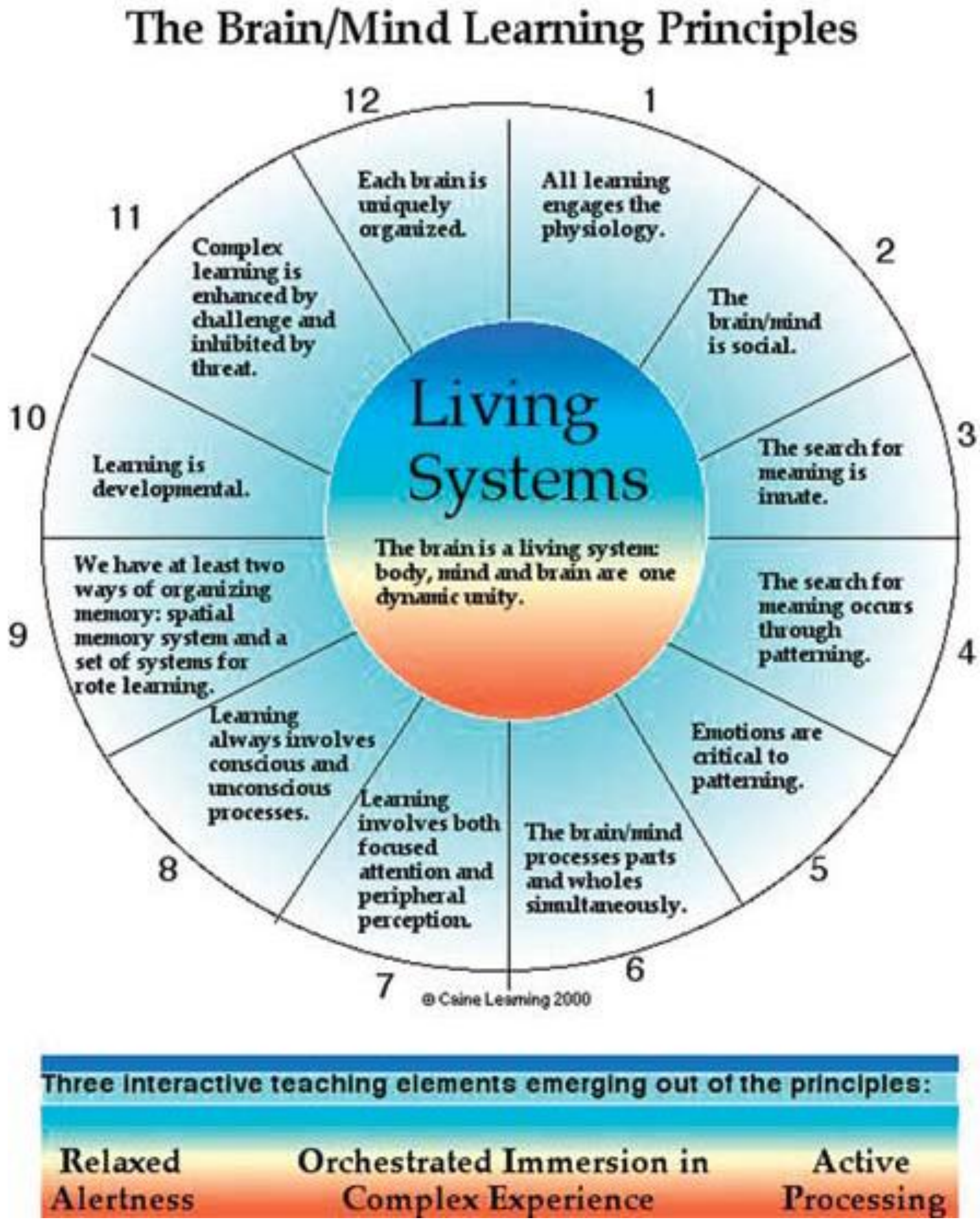

Figure 1. A visual representation of the 12 Brain/Mind Principles. Reprinted with permission from Caine and Caine.

Jensen (2008) supported Hileman and Caine and Caine by stating that brain-based learning is the application of strategies that can assist the learner in understanding and retaining information in accordance with the way the brain is designed to learn naturally. Because of the work of these educational theorists and others, educators have begun to look at learners in a new way. If educators accept these findings, then the focus must be altered from what is taught (content) to who is taught (students) and how. This appears to be true, as evidenced by the multitude of new programs being adopted by school districts. These new programs are touted as teaching to multiple learning styles. Brain research has created a paradigm shift in education from traditional content-based classrooms to more student-centered classrooms.

The research indicates that an educator must use a variety of strategies to create synaptic connections (Willis, 2007). For example, a student will have deeper meaning of the material if he/she can demonstrate knowledge of a process through acting it out or creating a model or movement of the process. Kaufman, Robinson, Bellah, Akers, Haase-Wittler, and Martindale (2008) reiterated this idea stating, "The field of brain-based learning encourages educators to capitalize on the associations the brain must make to create synaptic connections and anchor learning through contextual experience" (p. 51). Thus, learning and memory are connected to brain health and brain development.

Brain Health and Development

> The nervous system sets up a large number of connections; experience then plays on this network, selecting the appropriate connections and removing inappropriate ones. What remains is a refined final form that constitutes the sensory and perhaps cognitive bases for later phases of development. (Bransford, et al., p. 116)

Brain development is central to learning. Hileman (2006) declared, "Researchers have discovered that synapses are not static; they constantly adapt in response to activity" (p. 19). The brain grows and changes asynchronously throughout life (Bransford, et al., 2000). Jensen

(2006) stated that healthy, young brains may have a maturation variation of anywhere from six to eighteen months in the size of the tissues and the speed at which it grows. This maturation variation creates a complex, heterogeneous situation for the educator where students are in different developmental stages, thus demanding differentiated instruction in the classroom (Tomlinson, 1999).

As an embryo, the human brain generates about 15 million brain cells per hour (Wagner, n.d.). However, as incredible as that growth sounds, according to Franklin (2005) in *Education Update*, most brain growth occurs during the years of five to eighteen. In these developmental years, the brain is creating millions of connections to gain understanding of the world around it. Because the brain is growing so much during these formative years, brain health is crucial.

Bransford et al. (2000) argued that there is an overproduction of synapses happening until a person is five or six years of age, and then the pruning of the excess occurs over the next five years or so, in contrast to the synaptic addition and modification, that occurs throughout one's life. Franklin (2005) reiterated that pruning between the ages 10 and 11 occurs when unused connections are shed to make the brain more efficient and allows room for high-level thinking and problem solving. This stage continues until about the age of 20 when the brain is nearly finished forming (Franklin, 2005). Educators take advantage of this growth and pruning process by creating learning activities that enhance brain growth and development. The introduction of similar information in many different ways causes dendrites to work over and over again.

What about the adolescent brain? Adolescence is a particularly interesting time in brain development. "Adolescents are likely the most developmentally varied group of learners in the education system" (Crawford, 2007, p. 2). The physiological development of the body and brain of a teenager and their personal challenges overlap, infringing on their learning needs (Crawford, 2007). Prior to the surge in brain research, scientists and the general public thought that teenage antics were due solely to hormone changes. It is now hypothesized that adolescent brain development contributes to their behaviors more than previously thought (Giedd, 2002; Nelson, 2002; Sylwester, 2007). The frontal lobe of the brain is still very immature in adolescence, and there is a large growth spurt in the frontal cortex just before puberty (Giedd, 2002).

According to Sylwester (2007), the brain is designed to grow and develop in a pattern: right to left and back to front. The right side of the brain processes novel challenges and creative solutions. It is also in charge of exploratory and rapid responses. The left side is the stable processing system that establishes routines when a familiar challenge presents itself. The back part of the brain is the occipital (seeing), parietal (touch), and temporal (hearing) center, while the front part of the brain is responsible for making decisions, predicting consequences, and constructing proper responses. Sylwester (2007) noted that responses are categorized as either reflexive, in response to danger and survival, or reflective, in response to thorough thinking. Adolescents are usually reflexive because of their slow frontal lobe development (Sylwester, 2007).

> An adolescent with immature frontal lobes can thus be sufficiently mature to design and carry out a complex action, but not really realize until perhaps years later that the action was inappropriate and immature. Knowing how to do something isn't the same thing as knowing if you should do it. (p. 4)

This immaturity leads to adolescents speaking before thinking and acting before rationalizing the consequences of the action. Teachers have witnessed students blurting out inappropriate answers or cheating or skipping school before they have reflected on what would be the outcome of these actions.

In addition, Dobbs (2011) reported in National Geographic:

> The first full series of scans of the developing adolescent brain - a National Institute of Health (NIH) project conducted by Dr. Jay Giedd studied over a hundred young people as they grew up during the 1990's - showed that our brains undergo a massive reorganization between our 12th and 25th years. As we move through adolescence, the

> brain undergoes extensive remodeling, reassembling a network and wiring upgrade. (p. 55)

The educational implications of this research re-emphasize the need for educators to provide practice and repetition of skills as well as multiple ways for students to learn new skills. As students' brains continually shuffle and re-shuffle information, they require concentrated and varied access to the knowledge so learning does not get lost in the reassignment of the data within the brain.

The brain, especially the adolescent one, is preoccupied with survival-eat, fight-flight, sex, and peer acceptance (Crawford, 2007; Nunley, n.d.). "One of the frustrations with adolescents is due to the fact that hormones, environment, and learning, make this survival region of the brain a 'hot area' in adolescent brains" (Nunley, n.d., para. 3). Recent research has focused on the adolescent brain and ways that educators can reduce the instinctual survival mode prominent in the adolescent brain. Adolescents tend to be highly motivated by social rewards: the more risky an action or the more novel a behavior, the bigger the payout among peers (Dobbs, 2011). "Some brain-scan studies, in fact, suggest that our brains react to peer exclusion as much as they respond to threats to physical health or food supply. At a neural level, in other words, we perceive social rejection as a threat to existence" (Dobbs, 2011, p. 55). Social rejection at the junior high and high school level can cause students to make decisions and act in ways that are detrimental to their success. Behaviors related to social rejection are commonly demonstrated through student taunting, teasing, and underperformance in the classroom due to peer pressure.

Jensen (2008), as well as other researchers suggests that the overall health and development of the human brain is linked to neurogenesis, neural plasticity, allostasis, emotions, physical activity, and rest. An examination of these concepts demonstrates their importance to the learning process and memory.

Neurogenesis. Willis (2006) supported Jensen, noting that behaviors can regulate the process of neurogenesis. Learning experiences cause the growth of brain cells; new dendrites grow in response to the experiences and information that enters the brain (Willis, 2007).

Bransford, Brown, and Cocking (2000) suggested that a person retrains their brain through repetitive, challenging activities. The repetition of an act strengthens neural connections. An example of this can be understood by recalling that a pitcher will practice over and over to throw the perfect pitch. When a person is continually exposed to information and uses recall, neural connections in the brain are strengthened. Bransford et al. (2000) cited studies conducted using laboratory rats that were able to change the weight and thickness of their brains by repetitive practice. These results suggest that not only does memory increase through repetitive practice, but that the brain can actually be physically altered by repetition.

While some neurons are being developed and connections are being strengthened, others are being "pruned" away as a result of lack of usage (Nunley, 2003). The brain determines that these unused connections are not imperative to its survival, so it sheds these unneeded neurons (Sylwester, 2007). Tokuhama-Espinosa (2008) refers to this process as *Use It or Lose It*; active synapses are strengthened while less active synapses are weakened and sometimes cut away. When this occurs, the brain can maximize its efficiency by only focusing on the tasks performed most often. Furthermore, Bransford, Brown, and Cocking (2000) stated, "Alterations in the brain that occur during learning seem to make the nerve cells more efficient and powerful" (p.118).

Interrelating emotions and memory can strengthen these connections as well (Immordino-Yang & Damasio, 2007). People rarely forget things associated with strong positive and negative emotions. The more positive an experience is, the better the emotions surrounding the experience and the better the retention of the information (Crawford, 2007). Immordino-Yang and Damasio (2007) noted that emotions and thought are intertwined. In other words, certain emotions will enhance the thought process. A concern for creating emotionally safe classrooms has been studied by researchers such as Danielson (2007), who developed a model called *The Framework for Teaching*. This research-based set of components for instruction is aligned to the Interstate Teacher Assessment and Support Consortium (INTASC) standards, and is grounded in a constructivist view of learning and teaching. School districts and schools can use *The Framework for Teaching* as a foundation for mentoring new teachers, professional development, and teacher evaluations to help teachers become more attentive practitioners (Danielson, 2007). Danielson (2007) stated that by clearly identifying the teacher's responsibilities, teachers can then focus on how to improve student learning.

Von Glasersfeld (1989) explained that it is necessary to consider student understanding (learning) rather than student behavior (training). Meaning is interpreted by the individual based on the knowledge that a person gains from the world around them. Therefore, the teacher wants the student to interpret the world around him or her and is interested in the student's mistakes and deviations from the expected path (Von Glasersfeld, 1989). The notion of teaching a concept and moving on without knowing students have understood it is flawed. Educators now accept they must provide multiple pathways to learning. Teachers must revisit content often and scaffold new learning onto prior knowledge, otherwise pruning will occur (Nunley, 2003). One example in education of *pruning* is when teachers learn their students' names, but after students have moved on that knowledge is no longer needed and soon forgotten. However, if there is a strong connection or like or dislike of a student, that same teacher might remember the student's name due to the emotional response and the relationship between the teacher and the student.

Neural Plasticity. Sousa (2006) posited, "The brain is a dynamic creation that is constantly organizing and reorganizing itself when it receives new stimuli. More networks are formed as raw items merge into new patterns" (p. 135). This research brings hope for individuals who have suffered head trauma, strokes, and other physiological damage to the brain; there are even some implications for those with dyslexia and Alzheimer's disease (Nunley, 2003). It was previously assumed that the brain could not change or repair itself, however current research is indicating that the brain has the ability to change, improve, and repair itself (Willis, 2007). Bransford et al. (2000) noted examples of the human brain being reorganized functionally in stroke patients or those who have had parts of their brains removed. These people, with the right instruction and a great deal of practice, have been able to regain some or all of their lost functions. More to the point, this concept of an evolving and de-evolving brain leads to some exciting educational implications. Educators are faced with focusing on designing curricula that is novel and engaging to offer multiple entry points of learning for the brain. According to Weiss (2000), the environment in which a person lives changes the structure and chemistry of the brain. Brain and nerve cells become stimulated by new experiences and exposures thus growing new dendrites, the receptive surfaces of the nerve cell. This is an inverse of the *pruning* that takes place. In continuing the garden metaphor, new growth can happen and spread to those damaged areas (Weiss, 2000).

Rosenzweig and Bennett (1978) and Black, Sirevaag and Greenough (1987) documented studies where researchers placed rats in different cages: some in small individual cages with no added frills; some in large cages with other rats, and still others in complex cages with not only other rats, but with toys and obstacles that were often changed to avoid boredom. The researchers discovered that the rats raised in the complex cages seemed to be smarter than those raised in the simple cages; performing better on complex tasks and producing 20-25% more synapses causing them to have larger brains as well (Rosenzweig & Bennett, 1978). This research is addressed in the book *How People Learn* where Bransford et al. (2000) reiterated brain health can improve, and those educators who are providing complex, engaging activities that are accessible to all students may be improving student cognition.

Willis (2007) affirmed that the brain and intelligence could change. Emphasizing that dendrites grow when people learn new information and get enough sleep, Willis helped her students understand how physical health, emotions, and ability to focus their attention affected their learning. Willis pointed out whether or not new information makes it past brain filters into the *thinking brain* is dependent on these pieces being in place. Willis (2009) demonstrated to students how negative emotions or behaviors affect the ability to learn, and after students participated in these practices, they were better engaged in their learning and were more confident learners. This indicated that the brain was making improvements based on the stimuli (Willis, 2009).

Allostasis. Today, stress is commonly referred to as *complete overload* (Philp, 2007). This overload contributes to brain health and is referred to as chronic stress or allostatic load. A stressor can be an illness, injury, or emotional turmoil caused by relationships or family conflict. If students arrive at school after having a fight with their parents or friends, this stress could make learning difficult. This stress may be episodic or it may become chronic. Much of the current research is focused on students who live and learn with impaired cognitive ability as a result of daily stress; these students have an impaired memory retrieval and ability to focus (Nunley, 2003). This type of interference in cognition is apparent in bullying research (Olweus, 2011). National research on school absences links kids who are being bullied to high absenteeism. According to Olweus (2011), fifteen percent of these stressed students stay home to avoid these stressful situations at school, and one in ten students change schools or drop out due to bullying. This can create a co-morbid situation, low ability to focus at school and a high absentee rate, which leads to failing and at risk students (Olweus, 2011).

Stressors throw the body out of allostatic balance. When a person is constantly exposed to stressful situations with no opportunity to recover, they become chronically stressed (Jensen, 2008). Philp (2007) proposed that ongoing stress becomes toxic to the brain and body. The on-going stress causes an overproduction of cortisol in the brain (Sousa, 2009). Cortisol is a steroid hormone released by the adrenal gland in response to stress. Too much cortisol has been linked to many cognitive and behavioral problems, such as difficulty with problem-solving and decision-making skills, a lack of social skill development, and an increase in the occurrence of substance abuse (Sousa, 2006). The overproduction of stress hormones damages and kills brain cells; which creates memory loss by damaging the hippocampus, the part of the brain that forms, organizes, and stores memories. This damage can cause a person to be less receptive to new ideas and unwilling to take risks (Sousa, 2009). Furthermore, people with chronic stress often feel overwhelmed, depleted, and ill due to their immune system being weakened by the extra stress hormones (Philp, 2007; Ratey, 2008). Adolescents specifically have a difficult time finding healthy coping mechanisms for stress and are susceptible to the use of and reliance on drugs, alcohol, and food as ways of dealing with stress (Sylwester, 2007). Weiss (2000) agreed that one's level of stress is influential in how one learns. "In high stress situations, physiologically the information takes a primary pathway" (p. 29). People can memorize singular facts, but not process critically. When learners feel threatened, helpless, or fatigued, they "respond with either [a] primitive mode of behaving or [to] rely solely on earlier programmed behavior" (p. 29). This leads to classroom behavior management problems manifested by the brain reacting to the stress and lack of interactive engagement that the brain requires.

However, not all stress is bad. In high stress situations where the learner feels some control or choice in the matter, the person exhibits higher-order thinking (Willis, 2006). Additionally, in low stress situations, learners are able to reflect and think analytically as well as synthesize new information with older internalized information (Weiss, 2000). Students need to learn how to deal with stress. For example, students can be taught to use relaxation meditation, such as deep breathing and visualization to reduce hormones associated with stress (Caine & Caine, 1994).

Personal challenges can bring about stress, but this stress is less damaging to the brain and body (Ratey, 2008). This is because, when a situation arises that is a challenge that can be resolved, the body produces adrenaline and noradrenaline stress hormones that raise blood pressure and cause the liver to release glucose to help a person prepare to deal with the stress of the situation. These hormones are released for a short time and allow the body to recover. The brain determines if it is good stress or bad stress by deciding if the person can adapt to the change successfully and see a solution (Caine & Caine, 1994). "Assuming that the stress is not too severe and that the neurons are given time to recover, the connections become stronger and our mental machinery works better" (Ratey, 2008, p.61). Weiss (2000) further explained that learners that are determined or sense accomplishment may be able to reflect, think analytically, and synthesize new information with older information (Weiss, 2000).

Emotions. According to Philp (2007), emotions lead to attention and attention leads to learning, memory, problem solving, and nearly everything else people do. The emotional area and cognitive area of the brain are strongly connected; most of our decisions are influenced by how we feel (Immordino-Yang & Damasio, 2007). Further, creating an emotional component is necessary to get information into the brain's long-term memory (Sousa, 2006). Educators who build a positive classroom environment in order to construct positive emotions create connections to deeper learning.

Emotions play a significant role in the production of dopamine in the brain. Dopamine is a neurotransmitter that works for the brain's rewards and emotions center. It manages a person's emotional responses and movements by stimulating the prefrontal cortex. When something is determined as rewarding, dopamine enables the actions to obtain the reward (Sousa, 2009). Since an increase in dopamine makes better memories (Weiss, 2000), Hileman (2006) determined, "For a student to internalize a new behavior or piece of information one must feel that something is true before one believes it is true. The more intense the emotional state, the more likely for one to remember the event" (p. 20). Most people can vividly remember events of their school life that were swirled with intense emotion. Immordino-Yang and Damasio (2007) stated this in a similar manner. In order for a learning event to have impact on the learner, it must contain a significant emotional base in order for transfer from school to real-world decision-making skills (Immordino-Yang & Damasio, 2007). This school to real-world decision-making skill is one of the basic tenets of the *Common Core State Standards*. CCSS is a series of standards that has been adopted by a majority of states in an attempt to create nationally aligned curricula. Content is designed with an expectation that the skills acquired in school will become part of life outside of school.

According to Langelier and Connell (2005), adolescents are often exposed to a wide range of negative emotions. These feelings often interfere with their education and their social lives and make it difficult for them to function in these settings. "As adolescents struggle to cope with the challenges of identity development, learning to effectively respond to the emotional demands they encounter from day to day is essential to their success in school, work, and social settings" (Langelier & Connell, 2005, p. 1). Some students become consumed with what their peers think of them causing them to participate in behaviors like substance abuse, eating disorders, and other detrimental behaviors which obstruct school and home life. Goleman (1998) declared that people who have strong emotional intelligence, those who are self-aware, do better in school and life. They have better cognition, problem-solving skills, association, memory and decision-making skills, as well as fewer discipline problems (Goleman, 1998). To increase emotional learning, educators should boost content relevance, which will then enhance students' emotional intelligence skills.

When learners feel threatened, helpless, or fatigued, they can remember singular facts, but cannot process critically (Weiss, 2000). Langelier and Connell (2005) described a similar event called "downshifting" as the *emotional brain* or limbic system, located deep in the brain takes control over the *thinking brain* or frontal lobe. This memory fatigue is witnessed when a student who lacks interest, or is experiencing stress caused by frustration, appears to give up or engage in disruptive classroom behavior. When this occurs, people enter into a "fight or flight" mental state, and little effective cognitive reasoning can take place in the brain.

According to Goleman (1998):

> Cortisol steals energy resources from working memory. . . When cortisol levels are high, people make more errors, are more distracted, and can't remember as well - even something that they have just recently read. Irrelevent thoughts intrude, and processing information becomes more difficult. (p. 76)

Therefore, emotions determine what learners pay attention to and thus influence what is to be learned (Philp, 2007), and clearer thought processes require lower stress and a calmer limbic system (Langelier & Connell, 2005).

Physical Activity and Sleep/Rest. In addition to environmental factors, physical activity plays a role in brain development. "Physical motion strengthens learning by activiating multiple neural pathways" (Philp, 2007, p.106). At the same time that physical education and recess times are being pushed out of schools, Jensen (2008) reported that many researchers, from disciplines ranging from cognitive science and exercise physiology, have found that there is an important link between physical activity and cognition. Educators acting upon this research have discovered the importance of providing brain breaks. Many classrooms incorporate movement and physical state changes as a means of deepening cognition (Jensen, 2005). Echoing Philps' findings, Ratey (2008) contended that physical activity is significantly associated with neurogenesis and that activity also improves learning and memory and decreases depression. Researchers, including Sukel (2010) and Ratey (2008), have found that physical activity causes changes to the brain's structure and function and leads to better cognitive function. These researchers also noted that exercise can help lessen depressive symptoms and act as a neuron builder. Ratey (2008), noted in the book, *Spark*, "When students…go for a mile run in the gym, they are more prepared to learn in their other classes: their senses are heightened; their focus and mood are improved; they're less fidgety and tense; and they feel more motivated and invigorated" (p. 35).

Dwyer, Sallis, Blizzard, Lazarus and Dean (2001) conducted research studies that found that both classroom behavior and academic performance improve with exercise. They reported that even though the added exercise reduced the amount of student study time (exercising 375 minutes per week), the students showed better academic performance by earning better grades on their report cards and higher scores on standardized tests than the control group (those that exercised 90 minutes per week). This indicates cognitive increase is multifaceted. Educators need to provide not only time for new learning but must also attend to the enviroment, activating multiple neural pathways through movement and understanding of how hormones influence the body.

As important as movement is to learning, so, too, is a healthy sleep pattern. According to Giedd (2009), the brain needs rest to function properly. In order to strengthen learning, students need to get enough Rapid Eye Movement (REM) sleep. During sleep, the brain consolidates information and processes understanding. Caine and Caine (1994) stated that without enough rest, one becomes irritable and lacks engagement and concentration. Educators see many students who suffer from chronic lack of sleep. Students report when asked, they stay up late playing video games and using social media to communicate with friends. This creates a situation where students have trouble focusing and deepening their understanding of information.

During adolescence, sleep patterns drastically change, and sleep deprivation is more prevalent among this age group (Hagenauer, Perryman, Lee, & Carskadon, 2009). Teenagers experience variation in their circadian rhythm, which brings about a later onset of sleep (Hagenauer et al., 2009; Sylwester, 2007). Hagenauer et al. (2009) reported that over 45% of U.S. adolescents do not obtain enough sleep. Lack of sleep causes students to struggle to absorb new information, are less creative, and lack the ability to effectively learn in the classroom (Caine & Caine, 1994). Teens may require more sleep to catch up on the activity in their brain. During sleep, the brain, especially an adolescent brain, organizes and stores new learning (Wolfson & Carskadon, 1998).

Giedd conducted research studies using MRI and EEG technology on healthy subjects from ages 10-30 years. In Giedd's studies (2009), a link was found between sleep and behaviors that manifest during adolescence; such as the risk versus rewards behaviors that Sylwester (2007) discussed in the book, *The Adolescent Brain: Reaching for Autonomy*. Teenagers often know the risks of their behaviors but have a sense that the rewards, especially in the eyes of their peers, are worth taking (Dobbs, 2011). In addition to these behavioral changes, Giedd (2009) suggested a connection between adolescent sleep changes and depression, substance abuse, and accidents. Lack of rest leads to extensive pruning in the brain. This increase in pruning decreases the activation of the rewards anticipation and outcomes of the brain. When persons obtain the proper amount of sleep, they experience less pruning and are able to process decisions (Sylwester, 2007). Decision processing lends to better choices and possibly lowering the chances of substance abuse and accidents, as well as depression.

While much of the research indicates a need for more sleep, school schedules rarely accommodate this. Secondary schools often start early in the morning, meaning that students come to school lacking the optimum amount of sleep they need to function well in a learning environment. This deficit of sleep can leave students suseptible to mood swings, depression, lack of ability to focus and therefore learning problems.

Brain Health and Development in the Classroom

Educational researchers have studied the impact of brain development and health in the classroom. One such research team, Caine and Caine (1990) described the idea of "Brain-based Learning" in an *Educational Leadership* publication. In that article, the Caines' wrote:

> The greatest challenge for educators does not lie in understanding the anatomical intricacies of brain functioning but in comprehending the vastness, complexity, and potential of the human brain. What we are beginnning to discover about the role of emotions, stress, and threat in learning and about memory systems and motivation is challenging basic assumptions about traditional education. Fully understood, this information requires a major shift in our definitions of testing and grading and in the organizational structure of classrooms and schools. (p. 66)

Caine and Caine (1995) and others argued that there are *Three Essential Elements of Great Teaching* (Figure 2). In order to experience success in applying brain-based strategies these elements need consideration. Each essential element plays a role in making the classroom more brain-friendly to encourage better understanding and retention of material learned.

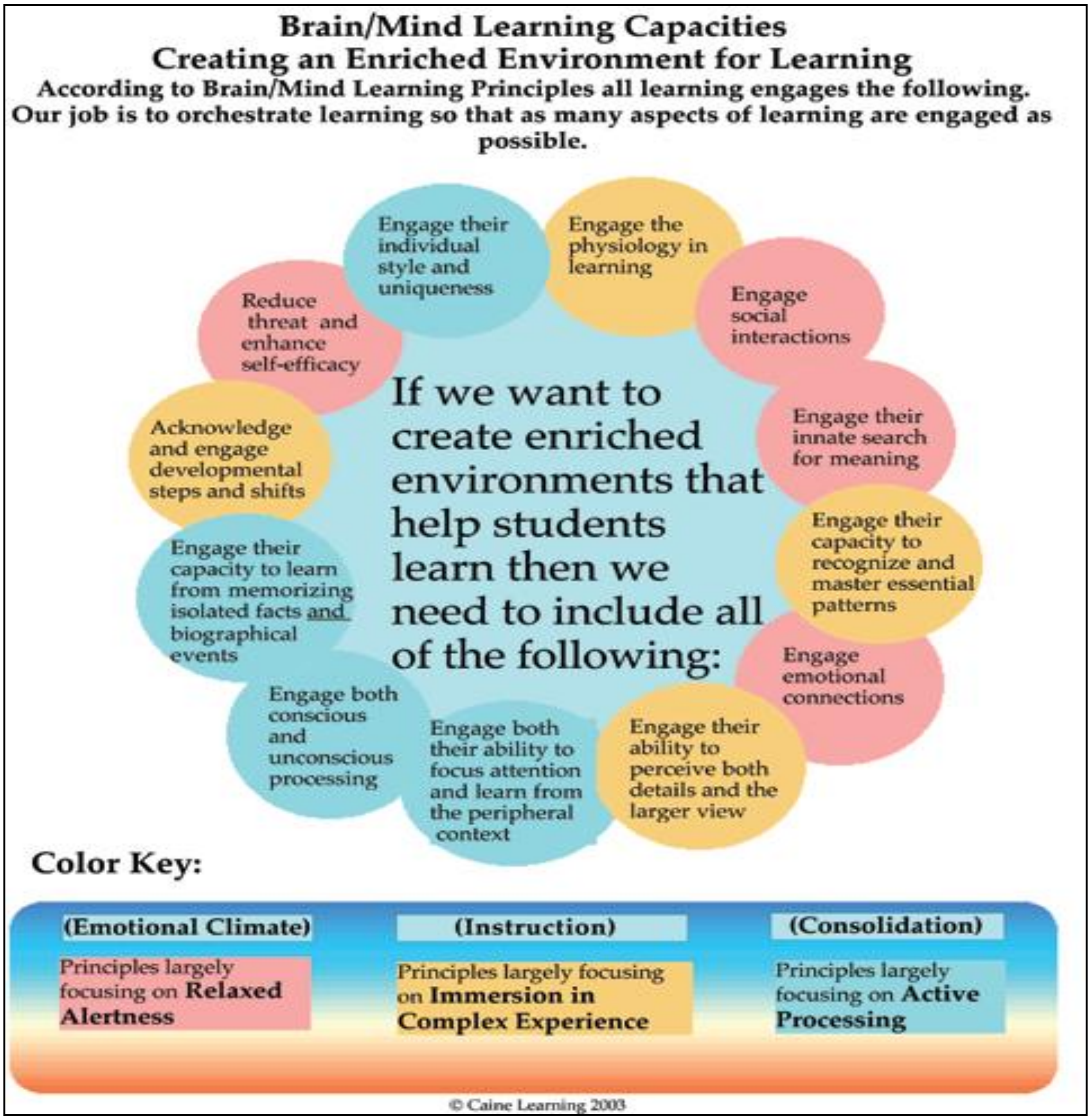

Figure 2. A visual representation of the three key elements:
Relaxed Alertness, Orchestrated Immersion, and Active Processing.
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In most people’s experience, school consists of sitting quietly and listening to the teacher (Roehrig et al., 2012). Early in a teaching career, this method can give a new teacher an anchor to the subject matter before using a more active learning or project-based learning approach. “Unfortunately, in spite of the central role of inquiry in the national and state science standards, inquiry-based instruction is rarely implemented in secondary classrooms” (Roehrig et al., 2012, p. 413). According to Jennings (2004), active learning is better for deeper understanding and more permanent learning to take place. Active learning is a process where students become vigorously engaged in assimilating or synthesizing the content rather than absorbing the facts and using simple recall (Bransford, Brown, & Cocking, 2000). Henningsen and Stein (1997) suggested five factors associated with maintaining student engagement for active learning; (1) tasks built on students’ prior knowledge, (2) scaffolding, (3)sustained press for explanation and meanings, (4) appropriate amounts of time in activities, and (5) modeling high-levels of performance. “Learning is the brain’s primary function, it’s constant concern, and we become restless and frustrated if there is no learning to the *(sic)* done.” (Jennings, 2004, para. 34).

> The inner workings of the human brain are complex and diverse. Yet, the strategies that teachers can use to motivate and engage learners are relevant and practical. As teachers, we must remember to apply what we currently know about the brain to help students learn. (Hileman, 2006, p. 20)

Jennings (2004) suggested four basic principles of brain function in order for brain-based learning to occur. They are as follows:

1. Teachers provide a rich and stimulating environment and learning requires ample stimuli.
2. Learning must be active and meaningful.
3. Teachers create safe and non-threatening environments.
4. Teachers should provide accurate and timely feedback (n.p.).

If one examines these four principles, a correlation emerges to neurogenesis, neural plasticity, allostasis, and emotions, which have previously been described.

Neurogenesis in the Classroom. Neurogenesis, the brain's ability to grow new neurons, is evident in the secondary student. If not stimulated, the brain will atrophy and become starved for information (Tokuhama-Espinosa, 2008). Educators that immerse students in real events, projects, and other activities that bring the real world into the classroom stimulate the student's brain. Teachers can employ strategies like ochestrated immersion and active processing to encourage the process of neurogenesis in the classroom.

Orchestrated Immersion. Teachers can create the best opportunities for learning by immersing the student in the learning process (Caine & Caine, 1990). When students are immersed in the learning their brain is stimulated and can form new neurons. "The hands-on learning of laboratory experiences is an effort to engage the physiology in the learning process. When students perform a task, their brains retain information about the task in much more detail and for a longer period than if they just answer questions about the subject" (Kaufman et al., 2006, p. 54). In order to achieve orchestrated immersion in the classroom, students decide on the topics to be studied within the unit. Students become teachers by giving presentations, as well as building graphics and posters for display to create an enriched environment (Duman, 2010).

Science education uses the strategy of discovery learning. This strategy emphasizes allowing students to explore concepts and environments via teacher facilitation. Jennings (2004) suggested taking students on field trips, introducing them to guest speakers, forming clubs, and creating activities of interest. For example, students can benefit from actively participating in field trips to a planetarium or a star-gazing excursion to learn about astronomy.

Teachers should use project-based learning which allows for student choice in the types of projects and improves student understanding of the curriculum (Jennings, 2004). Kaufeldt

(1999) suggested that students should be involved in goal setting. Goal setting helps the brain attend to the task at hand. Much of what the brain does is subconscious, but being goal-oriented makes what we are learning and doing come to a conscious level (Kaufeldt, 1999). Educators who set the criteria and then allow students to make decisions on how to accomplish the learning objective, find students more involved and focused on the learning and the information gained from the learning (Bransford et al., 2000).

Further, Jennings (2004) posited students can engage their brains by working in teams to investigate complex tasks. Franklin (2005) claimed that because the brain is social, teamwork and cooperative grouping are good for brain growth. Students enjoy working with others and sharing their knowledge to reach the goal. Science in particular is a subject that uses teamwork as a mode to discovery. Most science in the real world is not a solitary endeavor. Scientists often work in research teams, using the strengths of each individual to focus the research within a specific topic. Currently, there is an emerging field of inquiry called *Team Science* or the *Science-of-Team-Science*. An example of Team Science comes from the National Cancer Institute. In 2005, NCI established the Transdisciplinary Research on Energetics and Cancer (TREC). This team of scientists was brought together to perform a cross-disciplinary collaboration to solve major public health issues, such as cancer, obesity, and lack of physical activity (Hall, Stokols, Moser, Taylor, Thornquist, Nebeling, et al., 2008). As health issues and diseases arise so does the need for collaboration among scientists from varying fields and backgrounds to solve the problems that the public and private sector face (Bennett, Gadlin, & Levine-Finley, 2010). Science educators should build these skills in their students; skills that are necessary in order to create future scientists that are capable of collaborative scientific inquiry.

Another way teachers can take advantage of neurogenesis is to allow students the opportunities to play the role of the teacher. Based on the learning pyramid published by

National Training Laboratories, Sousa (2006) suggested that students who teach or deliver information to their peers retain 90% of the information, as opposed to retaining only 5% of what is delivered in a lecture format from the teacher, or even 50% when the teacher adds audiovisuals and/or discussion to the lecture after a 24-hour period. Educators who use student presentations in class are creating a pathway to learning that will deepen the student's understanding. However, educators need to be aware that the overuse of presentations, such as PowerPoint, can create boredom and decrease learning. Educators must be cognizant of the need for novelty, even in student created presentations. Therefore, a variation in learning modalities is best (Sousa, 2006).

Active Processing. Teachers can create the best practices to consolidate learning (Caine & Caine, 1990). According to Kaufman et al. (2006), "Students should be given the opportunity to reflect on their experience, draw connections to key concepts, and share their conclusions with others." (p. 54). Kaufeldt (1999) suggested that teachers need to allow for processing time in order for understanding and meaning to form. Emotional connections to learning can take time. Kaufeldt (1999) concluded that before it "sinks in," students may need to discuss the learning with others. In this manner, students are creating new neural connections that they can draw from at a later time.

Kaufeldt (1999) recommended bringing in current ideas and events into the lesson to help students make connections. Currently, teachers can use multimedia, such as digital microscopes, and laptop computers to provide access to videos, lectures, and virtual labs to bring current events into the classroom. Science educators can look to *Current Science* and *National Geographic* journals for featured stories and current ideas in science. There are many websites that make current science events available for use in the classroom, as well as lessons that go along with the information. Current events and ideas are important, however it is just as important to bring the past into the classroom (Sousa, 2006). Teachers who pose the question, "Remembering when you learned about … tell me what that looked like, felt like, what do you remember about it?" are deepening understanding by bringing student's past experiences to the present and then building on those ideas. Sousa (2006) stated:

> Meaning often depends on context…Past experiences always influence new learning. What we already know acts as a filter, helping us attend to those things that have meaning (i.e., relevancy) and discard those that don't…If we expect students to find meaning, we need to be certain that today's curriculum contains connections to their past, not just ours. (p. 50)

By studying past events, one is made aware of societal changes and how they have informed current practices, especially in educational reform.

Neural Plasticity in the Classroom. The brain reshapes and reorganizes as it receives information (Willis, 2006). Willis (2009) posited that a teacher's lesson should focus on instruction that can change a student's brain, such as meaningful and coherent repetition of the information through multiple learning pathways. Jensen (2005) also recommended allowing for greater differences in instruction, curriculum, and assessment. Students should be given greater choice and exposure to social instructions and technology methods. When teachers employ technology, arts integration, multimedia, and knowledge of multiple intelligence or learning styles as a way to enhance learning, students become engaged in the learning. This engagement brings about better cognition and retention for learning. These same modalities can be implemented as assessments, offering students multiple ways of showing what they know (Willis, 2006).

Working memory does not hold on to new material very well because of the lack of coding. In order for memories to *stick* they must move to the hippocampus, the part of the brain that forms, organizes, and stores memories (Nunley, 2003). If information is received too quickly or there is too much, it will not be stored in memory (Sousa, 2006). It is imperative that teachers take a break in the learning to make information *stick*. Short journal sessions or pair-share sessions can be used to allow new information to reach the hippocampus. Jensen (2005) recommended the following teacher actions: repeat and review often, increase oral group responses, and allow for brain breaks or time-off-task to offer opportunities for the information to be seated in long-term memory and retained.

It is also crucial that students are allowed opportunities to use the information that they have obtained. It is not enough, for example, to see, hear, and recite Newton's First Law of Motion; students need to apply this new information by conducting and explaining a lab that might consist of toy cars involved in a mock accident. According to Willis (2007), "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" (p. 314).

Lessons in Willis' classroom were designed to help students understand that "they can literally change their brains by improving how they approach learning and how they study" (Willis, 2009, para. 4). She taught her students about the brain and dendrites and then told them to go home and explain the ideas to their families. Willis (2009) also encourages her students to apply different learning strategies and to try studying in different environments to determine what works best for their individual learning styles to make the most of improving neural connections.

Dougherty, Scheck, and Nelson (2005) recommended that when students' self-study they use the process of making *judgments of learning* (JOLs) to make study time more effective. JOLs indicate that a learner can predict the likelihood that they will be able to retrieve the correct answers from their memory (Dougherty et al., 2005). It was determined that "…JOLs are highly correlated with the probability of final recall, participants can use their JOLs to determine which items need to be studied more; for example, items with lower JOLs should receive a higher percentage of study effort than that devoted to high-confidence items" (Dougherty et al., 2005, p. 1113). According to Kornell and Bjork (2007), knowing what to study and when to stop studying is a JOL that self-regulated studiers grapple with. "When metacognitive judgments are faulty, study decisions based on such judgments are faulty as well" (Kornell & Bjork, 2007, p. 220). In other words, teachers will need to educate their students about self-regulated study in order to be effective and efficient in their studies. Kornell and Bjork (2007) suggested that learners pick the time and space that best works for them personally, learners need to self-test, and decide if material can be dropped from further study. The metacognitive process of judgment may then have an effect on how well information is stored in memory (Dougherty et al., 2005).

Patterning and Chunking. Patterning connects the chunks of information into organized groups instead of isolated pieces of information that have little meaning to the learner (Philp, 2007). The current class schedule in school does not allow for the patterning that the brain desires to fully develop. Students move from one class to the next without any connections being made. Therefore, students find what is taught in each separate class meaningless and lacking impact on their long-term memory (Philp, 2007). Educators who use cross-curricular instruction or Professional Learning Communities (PLC's) in order to build a cohesive curriculum are employing a crossover of skills (DuFour, 2004). This enables students to create deeper meaning with pattern development and allows the brain time to develop patterns. This process allows students to deepen the learning and move information from new knowledge into practice. The brain is constantly working on developing patterns and programs to make decisions (Bransford et al., 2000).

Executive Function. Willis (2007) also contended that pattern building can lead to building executive function in students.

> The frontal lobe executive functions that students use to think critically and analytically and to prioritize and organize in their school subjects are the same higher thinking skills that can help them make good decisions when faced with the emotional stressors and ethical dilemmas of their lives outside of the classroom (Willis, 2006, p. 70).

Teachers can assist students in building their executive function by providing authentic and meaningful activities which help students to develop a network of working memory that allows for easier access and application. Teachers who ask thought-provoking, open-ended questions are building students' executive function (Willis, 2006). Also, when students are taught how to organize and prioritize, they make better use of new information (Philp, 2007). Because students are limited in their capabilities to set goals and monitor their own progress, teachers should teach these skills (Willis, 2006). Once students master these higher-order thinking skills they will discover how to separate essential and non-essential information and decide how to use the information gained (Philp, 2007). As students enter the junior high school, they lack organization and prioritization skills. Many schools provide students with a planner and block out a time for teachers to instruct students in the effective use it. Once students learn how to use their planners effectively, their executive function improves. There are other methods for improving executive function such as teaching note-taking skills, keeping lists of due dates posted on the board, and handing out study guides. As students hone these skills and begin to think more critically, they will be able to change their brain and intelligence (Willis, 2009).

Allostasis in the Classroom. Recall that allostasis is how the brain deals with too much stress. Teachers can help students avoid some anxiety and stress. Students may arrive at school already stressed or anxious due to issues that arise outside of the school, so teachers need to try to eliminate as much of this as possible because stress inhibits learning. "When stressed, students cannot learn the academic content being offered because their limbic system is pulling blood and oxygen away from their neocortex. Their heart rate increases, and the adrenal glands secrete the stress hormone cortisol into the blood" (Langelier & Connell, 2005, p. 4). Schools that implement advisory programs where teachers show interest and concern for the students not just as learners but as people, create a better learning environment.

***Relaxed Alertness*.** Teachers can create better emotional climate for learners (Caine & Caine, 1990). Kaufman et al. (2006) suggested, "In an effort to promote the brain-based learning element of Relaxed Alertness, teachers must consider the emotional climate of the learning situation" (p. 53). In this way, stress is low and challenge is high (Caine & Caine, 1990). Duman (2010) used activities that supported a state of relaxed alertness. Duman's lessons started with music and students were permitted to take brain breaks when necessary. Students were taught how to manage their stress, challenge themselves, and then monitor and adjust to accommodate for their personal learning goals (Duman, 2010). In this study, students worked in cooperative groups to discuss topics and brainstorm ideas (Duman, 2010).

Kaufman et al. (2006) argued that even though circumstances outside of the school influence the classroom climate, good teachers overcome these challenges by creating positive emotional connections in the classroom to decrease stress. Langelier and Connell (2005) claimed that schools need to meet students' emotional and safety needs before they consider what is needed to meet their cognitive needs. Saleh (2012) contended that when teachers employ the relaxed alertness technique in class, learners have limited-to-no fears, thus the challenges are high, and students can then take risks.

On the other hand, when children's interests are ignored, it fosters resistance, resignation, and apprehension (Wagner, n.d.). Teachers can discover students' interests and gear the lessons to fit the subject matter and the needs of the students, thus creating a supportive, courteous, and respectful environment. Discovering student interests can be accomplished through learning style surveys, multiple intelligence surveys, or games that focus on likes and dislikes.

Wagner (n.d.) stated that teachers need to create a safe environment that infuses lessons with an emotional element. Immordino-Yang and Damasio (2007) added that in order for learning to transfer to the real-world, teachers must link the learning to emotions. Without an emotional connection, learning lacks meaning and motivation. An example of this in the science classroom is dissections. Because of students' varying background and interests, some have positive emotions about dissecting an animal, and some have negative emotions concerning this event which causes an increase in the student's allostatic load. The challenge for a teacher who conducts dissections is to help the students with negative feelings come to terms in order to complete the dissection. If the stressors are so deeply seated that there is no way to overcome them, the teacher must find alternative assignments, such as a virtual dissection, using a plastic dissection model, or allowing the student to create a written or audio report on the benefits and detriments of dissections.

Sousa (2006) recommended including humor in the classroom to lower allostatic load. Laugher allows more oxygen and dopamine to the brain and causes a surge in endorphins, the body's natural pain killer which stimulate the brain's frontal lobe (Willis, 2006). "Scientists have found that humor decreases stress, modulates pain, decreases blood pressure, relaxes muscle tension, and boosts immune defense" (Sousa, 2006, p.63). As a teacher plans a lesson, these concepts of safety, respect, and humor need to be built into the lesson to lower student stress.

Emotions in the Classroom. Sousa (2009) claimed that a key contributor to students' positive emotions and motivations is feedback; people have a need to feel valued, and positive feedback is one way to fill that need. When a student is given even the smallest amount of feedback, the brain provides the learner with the correct information to be used in the future (Sousa, 2009). Teachers can help students by coaching, facilitating, and offering authentic feedback. Students need to hear encouraging words on how to make their work better (Jennings, 2004). It is not enough to simply offer *nice job* or *add more detail*. Students need specific feedback to make the proper adjustments in their work and to know what is expected of their finished product. Teachers can hold one-on-one conferences with students to design explicit objectives for each student and his/her individual learning needs, and thus make clear the expectations (Kaufeldt, 1999). Educators can use standardized test scores such as Measured Academic Progress (MAP), to determine student strengths and weaknesses and then work with the student to set goals and expectations for the school year. Kaufeldt (1999) and Jensen (2005) suggested that teachers allow opportunities for self-assessment or peer-review. These processes require high levels of thinking and reflecting (Kaufeldt, 1999). These processes allow students time to be cognitive and metacognitive.

It is important to celebrate student achievement to contribute to the positive emotional climate of a classroom (Jensen, 2005). During celebrations, hand out awards and play music. Franklin (2005) noted "The need to have fun and enjoy learning is something the brain never outgrows. .. the use of music can resonate with learners of all ages" (para. 18). However, Jensen (2005) cautioned teachers to hold celebrations that acknowledge accomplishments instead of rewarding students monetarily or with food. Kohn (2001) supported Jensen's warning by reporting that if food and coins are the focus of the action, not the pleasure of creating or accomplishing, then the actions become less valuable, and the adult reaction becomes of greater value. "Studies have shown that the brain is naturally curious and willing to seek new experiences without any perceivable external rewards. This natural curiosity breeds internal motivation to learn" (Wagner, n.d., para. 30). In the science classroom, intrinsic motivation can be seen when teachers consider students' interests and approaches to inquiry. Students decide how to solve problems and take ownership of their results. In science, many times the product of learning is not a singular answer but how the students discovered a plausible explanation and whether the student could support it with evidence. This approach makes student success possible, which brings about intrinsic motivation and a feeling of satisfaction.

Physical Activity and Rest in the Classroom. Franklin (2005) took the approach that physical and kinesthetic activities in the classroom help students connect concepts to movement and thus helps them to visualize the processes and outcomes to create better understanding. Jensen (2005) stated that even having students stand up and stretch every so often in class can raise the heart rate and blood flow by five to eight percent. A brain compatible classroom is one where subject matter is woven with physical activity. Some of the best things teachers can do to keep kids active are the simplest. Jensen (2005) suggested small breaks for stretches, role-playing or charades, and quick games like a ball toss for review. Jensen (2005) also recommended goal setting while on the move; this means getting the children up and moving to a new destination as the teacher instructs the students on the next task while they are in motion. This causes students to be thinking about the next activity and not about where they will sit and who they will be working with. These little things keep energy levels up and allows oxygen rich blood to flow to the brain for better performance (Ratey, 2008). Thus, physical movement both in and out of the classroom can be an effective strategy to enhance learning and memory (Hileman, 2006).

Another issue that teachers commonly face is students suffering from a lack of sleep. While teachers cannot control the amount of sleep students get per night, they can encourage their students to get enough rest and educate them about the downfalls of lack of sleep (Willis, 2009). In addition, teachers can offer relaxation times during class if the need arises, such as before performance assessment or even if students are feeling the effects of lack of sleep or frustration. Teachers can instruct their students on how to do deep breathing, visualization, or meditation (Caine & Caine, 1994). A fellow educator recently recounted an event in the classroom where the teacher had the students close their eyes, breathe deeply, and visualize themselves doing well on their exam. The students exceeded the teacher's expectations as well as their own. On a subsequent exam day, the students requested that the teacher take them through this relaxation activity again because it helped calm their nerves, and they could *think better*. These relaxation activities can help students refocus and reenergize and only need to take a few minutes of class time (Willis, 2009).

In conclusion, the literature indicates students must be immersed in their own learning through a process of discovery, reflection, and meaning making. This process is active and ongoing, leading students to deeper understanding of content.

Studies that Support Brain-Based Learning

In 1995, Caine and Caine took their theory to Dry Creek Elementary School in Rio Linda, California. They worked with the teachers for five years in a study of brain-based learning. They started with the teachers. To instill the notion of relaxed alertness, the Caines encouraged the teachers to explore ideas without judgment. The teachers were encouraged to use all kinds of resources to teach lessons. However, some teachers in the beginning decided not to share information and reverted to *traditional* methods of teaching (lectures and textbooks) when they felt stressed. This reversion to old ways is often called *downshifting* and is a shift into defense mode (Langlier & Connell, 2005). To avoid this, participation in the study and making the change to a brain-based approach was not mandatory. As a result, the staff felt as if they had a choice to become involved or not. And, by the end of the study, nearly all staff members were participating (Caine & Caine, 1995).

The teachers were immersed in workshops, writing groups, and working groups. The learning that took place was from the entire experience and physical context; every meeting the teachers attended was about ways of implementing brain-based learning at Dry Creek Elementary. The teachers then spent many hours together dicussing what they wanted their school to look like (Caine & Caine, 1995).

Finally, Caine and Caine (1995) discovered that the acceptance of open-ended experimentation made for continuous active processing. There was a culture of on-going change and experiences to consolidate the emerging mental model. This change brought about a new staff learning community that was reflective and processed ideas of brain-based learning in a social setting (Caine & Caine, 1995). Eventually, there would be a trickle downeffect within the school where student learning was being improved by this new educational approach (Caine & Caine, 1995). At the time of this report, no student data had been obtained.

Another study that supports brain-based learning is Aziz-Ur-Rehman and Bokhari's 2011 study called *Effectiveness of Brain-based Learning Theory at Secondary Level*. This study examined conventional teaching methods versus brain-based learning methods. The researchers based their study on the *Twelve Brain/Mind Principles of Natural Learning* mentioned earlier. Sixty ninth-grade math students were selected for this study. Thirty students were placed in the control group; these students used the textbook to memorize information, the teacher was the authority delivering the information via lecture, and students were expected to learn by listening and note-taking. The other 30 students were placed in the experimental group. This group was in an enriched, non-threatening environment. The learning in this group was based on student activity, patterning, varied learning activities, and novelty (Aziz-Ur-Rehman & Bokhari, 2011).

The researchers gave a pre- and post-test to the 60 students involved in the study, and they claimed an improvement in student achievement occurred among the students in the experimental group. As a result of this study, the researchers discovered that there was a continuum of different faculties of the brain that benefited the students in the experimental group. The continuum showed that as the students in the experimental group used parallel processing, unique ideas were formed; this uniquness led to the construction of parts and wholes by the students; then students experienced an innate search of meaning which allowed them to discover patterns (Aziz-Ur-Rehman & Bokhari, 2011). This continuum created better retention and understanding amongst the students in the brain-based learning group (Aziz-Ur-Rehman & Bokhari, 2011).

Duman (2010) conducted a similar study that looked at the *Effects of Brain-Based Learning on the Academic Achievement of Students with Different Learning Styles*. Duman placed 68 university students into one control group and four experimental groups based on their personality types. The control group was taught using traditional teaching methods; lecture and question/answer sessions. The experimental groups were taught using a brain-based learning method that the researcher called The Conditions of the Brain, which was based on the work of Caine and Caine (1990). Duman (2010) gave all students a pre- and post-test to measure the effectiveness of this strategy. In this study, the researcher found that brain-based learning "…more significantly increased the students' academic achievement when compared to traditional teaching methods" (p.2095). The experimental group showed a 47.25% increase from the pre-test to post-test, whereas the control group showed an increase of 21.75%. There was no connection found between the learning style of the student and the increased achievement; therefore, the method was determined to be successful for all students in the experimental group. Duman (2010) explained "BBL (brain-based learning) involves accepting the rules of how the brain processes, and then organizing instruction bearing these rules in mind to achieve meaningful learning" (p. 2080).

A study conducted by Barron, Schwartz, Vyc, Moore, Petrosino, Zech, and Bransford (1998) determined that problem- and project-based learning assisted fifth graders in understanding, using, and presenting geometric concepts among other benefits to the students such as goal-setting, self-assessment, responsibility, and ownership. Sixty-four students were divided into two groups: the control group's lesson was to design and build an imaginary playhouse and then sell it to an imaginary customer, and the experimental group was to design and build an actual playhouse and sell it to a real customer. Pre- and post- tests were given; the experiemental group scored approximately 1 level higher in each of the following categories than those in the control group: Expenses, Ticket Price, Total Revenue, and Profit (Barron et al., 1998). "In closing, we provided examples of how the process of reflecting on one's own learning and improvement can be facilitated by the provisions of resources and the encouragement to take responsibility for one's learning" (Barron et al., 1998, p. 305).

Studies that Support Brain-Based Learning in the Science Classroom. In 2012, Saleh found that by using the Brain-Based Teaching Approach, improvements could be made in the student's understanding of Newton's Laws. Saleh conducted a research study called *The Effectiveness of the Brain Based Teaching Approach in Enhancing Scientific Understanding of Newtonian Physics Among Form Four Students*. Saleh wanted to improve student understanding of physics and choose this method of instruction because it was more learner-friendly. Saleh (2012) stated that "…the challenge, really, is for teachers to vary their methods of teaching and shift the paradigm from 'one fits all' to an 'enriched environment' for each and every student" (p. 109) Saleh divided 100 students into two groups. One group of 50 students was taught using the Brain Based Teaching Approach (BBTA) and the other was taught using Conventional Teaching Methods (CTM). CTM was not defined by the author, but it was implied that lecture and textbook work is CTM. Saleh used the three instructional strategies suggested by Caine and

Caine (1995); relaxed alertness, orchestrated immersion, and active processing. The researcher reported that the BBTA group showed improvement in their understanding of Newton's Laws over the students in the CTM group. In the BBTA group, 42 out of the 50 students in the group were able to answer test questions correctly, as opposed to 39 out of 50 correct answers given by the students in the CTM group. Saleh (2012) stated, "Therefore, it can be concluded that the Brain Based Teaching Approach [was] effective in enhancing students' conceptual understanding in learning Newtonian Physics" (p. 117). However, one should note that this is not a significant improvement, therefore more research is needed.

Two studies have come from the BRAIN U program at the STEM Education Center at University of Minnesota. MacNabb, Schmitt, Michlin, Harris, Thomas, Chittendon, Ebner, and Dubainsky (2006) conducted a study instructing teachers how to use neuroscience in middle schools. Roehrig et al. (2012) conducted a similar study teaching science educators about neuroscience. These two studies were designed to teach educators how to incorporate neuroscience into the classroom. The researchers wanted the teachers to gain inquiry-based strategies and neuroscience information that they then would pass on to their students and create an excitement for science. MacNabb et al. (2006) stated that the study involved 170 fifth- through eighth-grade teachers and nearly 9,000 students. Because of the large number of teachers and students involved and the newness of the program, those that were involved were asked to evaluate the effectiveness of the program. A large number of the participants rated the program as being effective; teachers stated they knew more about neuroscience and changed their teaching style to inquiry-based strategies (35%), and the students stated they grew in their knowledge of the brain and learned how to design and conduct as experiment (36%) (MacNabb et al., 2006).

Roehrig et al. (2012) reported a similar study with science teachers. Forty-one science teachers completed 160 hours of professional development on neuroscience. These teachers were the experimental group and twelve additional classroom teachers were used for a comparison group. The comparison group was to continue teaching in their normal routine while the experimental group was to introduce neuroscience to their students and use inquiry-based lessons (Roehrig et al., 2012). Pre- and post-tests were given to each group to assess their knowledge of neuroscience. The teachers involved in the BRAIN U programs knowledge of neuroscience went from 53.6% to 78.7%. Observations were conducted in both types of classrooms to determine time spent in activities designed for inquiry. The percentage of time for inquiry in the comparison classrooms was 21% and 39% in the experimental classrooms. These results mark changes in neuroscience knowledge and teaching and learning methods for both teachers and students as a result of the education that BRAIN U provides (Roehrig et al., 2012).

Applications of Brain-Based Strategies for Science

As *Common Core State Standards* (CCSS) represent the new criterion for learning, these benchmarks stress students' facilitation and application of their learning as they apply it to real life. CCSS requires that teachers become facilitators of learning, working with the students to create a rich and relevant learning environment (Roehrig et al., 2012). This holistic learning environment was stressed by the theorist Vygotsky in 1926. Vygotsky (1997/1926) suggested that the teacher be the guide of the student and the educational process and that education should never consist of a one-sided endeavor; both teachers and students should be active learners. The goal is that transfer of knowledge and skills should be utilized in the classroom to incorporate real-world applications for the success of students. *Next Generation Science Standards* (2013) bring this task into clearer focus for science educators as it requires a curriculum that is rich in content and practice that science students can take with them into the next chapter(s) of their lives.

Next Generation Science Standards (NGSS) were released in April 2013 and are expected to be adopted by states around the country. "The NGSS focus on a smaller set of Disciplinary Core Ideas (DCI) that students should know by the time they graduate from high school, focusing on deeper understanding and application of content" (Next Generation Science Standatds, 2013, para. 3). These benchmarks are based on current research in science and science learning conducted by the National Research Council. According to Next Generation Science Standards (2013), "The NGSS architecture was designed to provide information to teachers and curriculum and assessment developers beyond the traditional one line standard" (para. 4). The goal is to ensure that all science students receive an education that is rich in content and preparation that allows them to become successful in the science careers of the future. One way science teachers can prepare students for this new trend in science is to create opportunities for more active learning in the classroom.

Active Learning. Active learning requires setting goals, planning, and revisions (Bransford et al., 2000). The key is to engage students in the learning process, while working in small groups toward a common goal. This is in contrast to traditional methods such as lecture where the students are passive participants in the learning (Prince, 2004). Prince (2004) claimed that student involvement is one of the best predictors of a learner's success in school. Active learners are seeking to understand the complex information that they have learned in the classroom and apply it to other situations. Active learners judge when they have *got it* and when they need more information to make connections and understand (Bransford et al., 2000). This determination of *got it*, is an example of a JOL that improves a learner's recall of the memory later (Dougherty et al., 2005).

One simple suggestion Prince (2004) made to make learning more active for college students is for lecturers to take a few minutes to pause while students discuss notes with a neighbor or clarify notes previously taken. Henningsen and Stein (1997) cautioned teachers that it is important to attend to not only the nature of the instructional task but also to the classroom procedures surrounding the task. In their research Henningsen and Stein (1997) found that "…even though students were actively engaged during the task (as opposed to being passive recipients), teachers still had an important role to play in proactively supporting students' high-level engagement" (p. 534).

Active learning is used when students conduct experiments in the science classroom. Students are to develop a hypothesis based on a question or a problem. They plan and conduct an experiment to test their hypothesis and gather data to support or dispute their claim. After, they form a conclusion that discusses what was learned from the experiement, then they should give supporting evidence for their findings. This form of active learning helps students to take charge of their education and to discover applications for learning outside of school (Bransford et al., 2000).

Project-Based Learning. A more complex example of active learning would be project-based learning where the students are active and engaged because they are directing the learning that takes place (Prince, 2004). Crawford (2007) suggested using project-based learning in the science classroom because it supports understanding through inquiry and team work. "In science education, inquiry-based approaches to teaching and learning provide one framework for students to build these critical thinking and problem-solving skills" (Roehrig et al., 2012, p. 413). In these learning situations, students are afforded opportunities to be problem solvers and use their scientific knowledge in authentic settings. Because the students are creating their own projects, they can more easily search for meaning in the learning and also find emotional connections to the learning (Philp, 2007). Project-based learning allows students to learn by sparking their interests and engaging them through creative inquiry and exploration (Philp, 2007). Thomas (2000) explained project-based learning as organized learning centered around complex tasks, and it is driven by open-ended questions. If students are not given a *driving* question, they are often unclear about learning targets and how to direct their own learning within the content (Barron et al., 1998).

The students work in cooperative groups to construct their investigation. The teacher allows for autonomy while being a facilitator, not the director (Vygotsky, 1997/1926). Learning is maximized here because the content resembles real life and what is learned can be applied elsewhere (Barron et al, 1998). In addition, students are motivated by focusing on the learning and the mastery of the content. When this happens, the students *stick with it* longer and are more determined to learn than those wishing to complete the task and get a grade. When problem solving is used in the learning context, information is more likely to be retained and applied than when the activity takes the form of task completion (Thomas, 2000). According to Barron et al. (1998) project-based learning is about "learning by doing" and "doing with understanding." Students are taught how to recognize the goals, make assessments, and then monitor and adjust their learning. They are expected to employ this method of learning, as well as take on more responsibility and ownership of their learning. Project-based learning allows students to accomplish two tasks at once: design the activities for learning the content and reflect on their work and their understanding. "We want them to understand why they are learning" (Barron et al., 1998, p. 306).

Summary of the Literature

Brain-based learning has been addressed by scientists and educators these past twenty to thirty years in the extant literature. Many approached this topic from a different perspective.

From the literature, one can gain an understanding of the influence of brain health and brain development on brain-based learning and the educational implications it offers to teachers. First, discoveries in brain research have brought about evidence that the brain can grow new neurons, and it also repairs itself (Bransford et al., 2000; Nunley, 2003; Weiss, 2000; Willis, 2009). Second, it has been revealed that stress and emotions plays a large role in learning and memory (Crawford, 2007; Immordino-Yang & Damasio, 2007; Langelier & Connell, 2005; Philp, 2007; Sousa, 2009). Third, physical activity and sleep have been shown to influence brain function as well (Dwyer et al., 2001; Giedd, 2009; Jensen, 2008, Ratey, 2008; Sukel, 2010).

The adolescent brain brings unique challenges to school, home, and social setting (Crawford, 2007; Langelier & Connell, 2005). This is due to all of the changes the brain is undergoing at this stage of growth and development. Information concerning this massive reconstruction in the adolescent brain brings to light explanations for behaviors that often seem inexplicible to adults (Nelson, 2002; Sylwester, 2007). Better insight into this area of brain growth and development can lead to a better understanding of the adolescent.

In the classroom, strategies like relaxed alertness, orchestrated immersion, and active processing are more brain-friendly (Aziz-Ur-Rehman & Bokhari, 2011; Caine & Caine, 1995; Duman, 2010; Hileman, 2006; Saleh 2012). Educators committed to teaching and learning the way the brain naturally learns can employ the 12 principles provided by Caine and Caine (1990). There are certain teaching applications that are grounded in the idea of brain-based learning, such as active learning and project-based learning (Bransford et al., 2000; Crawford, 2007; Roehrig et al., 2012; Prince, 2004; Thomas, 2000). These applications and strategies allow teachers to create successful acquistions of learning targets, mastery of CCSS, and form a deeper understanding of content.

For educators, the concept of brain-based learning is important to the design of the classroom environment and the developing and scaffolding of lessons (Bransford et al., 2000; Caine & Caine, 1990; Tomlinson, 1999). The justification for using brain-based learning is to parallel the way the brain naturally learns by patterning and chunking to link past and present information together (Willis, 2007). By making emotional connections to learning, educators can help the brain to better retain information (Immordino-Yang & Damasio, 2007; Philp, 2007). The brain learns best when stress is reduced and optimal sleep is obtained (Giedd, 2009; Langelier & Connell, 2005; Philp, 2007, Weiss, 2000). Finally, research supports that memory and learning can be improved by incorporating physical activity into the classroom (Dwyer et al., 2001; Jensen, 2008; Ratey, 2008).

Gaps in the Literature

This review of the literature uncovered three examples of action research comparing brain-based learning in the classroom to conventional teaching methods. A fourth study compared conventional teaching to project-based learning, which is considered to be brain-friendly. Only one of these studies was specific to science, however it was at the university level. Two action research studies were found that addressed teaching educators about neuroscience and the benefits of changing teaching strategies to benefit students with more active learning. These studies were based on a specific program developed at the University of Minnesota. This localization of the program results in the benefits not being available to teachers in other parts of the country. Due to the lack of studies from the secondary classrooms, the data are limited.

Studies on laboratory animals, such as lab rats, for concepts like physical activity and sleep were found. This information might provide a link to how students may or may not behave in certain situations, such as increased amounts of exercise or lack of sleep. Some studies about physical activity and its connection to learning and memory were derived from physical education programs, which claim a benefit to better learning in many subject areas, not just science (Dwyer et al., 2001; Jensen, 2008; Ratey, 2008; Sukel, 2010). The studies found on sleep related information concerning how sleep affects teens in all aspects of their lives, not just school (Caine & Caine, 1994; Giedd, 2009; Haugenauer et al., 2007; Sylwester, 2007; Wolfson & Carskadon, 1998).

Educational literature found for this project was of a practical nature. As a result, this literature is a secondary source of information rather than the primary sources that usually arise from scientific research. However, scientific research literature was used as well, resulting in a balance of primary and secondary sources in this literature review.

Chapter 3

Discussion

This project synthesizes current brain-based research and the resulting educational implications offering strategies and classroom curricula suggestions to educators. This synthesis of material is designed to build awareness of how the brain functions and how to engage the learner based on brain research so as to reach all learners in a science classroom.

Literature from scientific and educational research was considered. There is a growing body of literature that crosses science and education, which is designed to help educators understand how the brain grows and develops, and how these processes can be put to use to gain deeper understanding to work with students in the classroom.

Findings

The brain grows and changes throughout one's life. However, no two brains develop at the same rate. New neural connections are based on information that is used and reused over time. The brain also appears to prune connections that are not being used because it (the brain) considers these connections as not useful to its current state or job or through the lack of practice. There are specific stages conducive to creating new connections. Additionally, there are age-based stages when pruning takes place. Research indicates there is a surge in new neuron connections in infancy as well as in pre-adolescence followed by notable pruning during adolescence.

Due to the efforts of the brain to organize and reorganize incoming data the brain repairs and improves itself. This understanding is in contrast to the previous notion that once brain or nerve cells were damaged, all function was lost. This new awareness brings hope for those who have suffered brain trauma, and offers opportunities for educators to develop strategies designed to create deeper meaning.

Research also implies that high levels of stress impedes learning and causes the brain to downshift like an automobile that slows or stops. This downshift causes the brain to function only at lower levels of cognition and impedes higher levels of thinking and learning. In addition, the over-production of the stress hormone, cortisol, damages and kills brain and nerve cells. The results suggest learning strategies designed to assist students to cope with stress through relaxation, meditation, or physical activity.

Emotions affect the brain. Humans make decisions based on their emotions. Positive feelings elicit one response whereas negative ones elicit another. When positive emotions are connected to information received by the brain, that information is more easily embedded and stored in the long-term memory. This process of connecting emotions to information is useful to teachers as they plan and deliver lessons.

Physical activity and sleep are important for proper brain function. Just as exercise provides better oxygen flow to the muscles of the body, it also provides better oxygen flow to the brain. When teachers provide brain breaks that involve movement or physical activity as part of the lesson, learning and memory are improved. This physical activity has also been found to have an impact on mental health, such as lessening the effects of depression. During sleep the brain consolidates information it has learned and works to make sense of the information by linking it to previous knowledge. While in REM sleep, research indicates the brain organizes information in order to create patterns. The brain searches for patterns to make sense and meaning of the information it is receiving. Adolescents need sleep but often do not get enough rest because of their natural circadian rhythms that keeps them up late and sleeping late in the morning. Early start times for school do not accommodate for these biological needs.

Adolescents experience difficulty with learning and memory formation. During this age, the prefrontal cortex is still developing and pruning; resulting in difficulties in thinking critically and problem solving. Many adolescents find themselves behaving reflexively as opposed to reflectively. During this time, they respond with emotions, and often times these emotions interfere with a teen's ability to function in school and in social settings.

Recommendations

How can teachers use this information? In the classroom, strategies like relaxed alertness, orchestrated immersion, and active processing are more brain-friendly and may create better opportunities for learning. One resource available to educators committed to teaching and learning the way the brain naturally learns is the 12 principles developed by Caine and Caine. There are teaching applications grounded in the idea of brain-based learning, including active learning and project-based learning. These applications and strategies allow teachers to successfully acquire learning targets, master CCSS, and form a deeper understanding of content. There are simple changes educators can make in the classroom to accommodate for better student cognition and metacognition.

Environment. Consideration must be given to the room environment before students arrive for the first day of class. Because the brain is highly social and learning needs to be active, desks should be arranged in pods or groups so that students can work together and hold discussions. The desks do not always need to be in this arrangement. Seating can be flexible and fluid. Because the brain seeks novelty, teachers may consider colored paint for the walls or wall art, such as pictures and posters. Teachers may also want to use differing colors of chalk or markers in order to provide emphasis. Another consideration in planning the space is how physical activity will be used in class. One such consideration is to create a space without chairs using only tall tables so that students can stand, fidget, and shift their weight more easily during work time. Music can also be a helpful addition, providing both a fun and novel element to the learning environment.

Curriculum. The curricula should be student-centered and provide enriched content that is engaging, fun, and novel. Worksheets and constant fact memorization does not lend to deeper understanding of information. Educators need to ask driving questions that allow the students opportunities to discover possible outcomes, thus increasing students' cognitive and metacognitive skills (Barron et al., 1998; Thomas, 2000). In addition, created curricula needs to be connected to the real-world. This process of solving real-life problems leads to the development of transferable skills the students can use outside of the classroom (Immordino-Yang & Damasio, 2007).

Making Connections. The brain attempts to find patterns. Therefore, when teachers from different subject areas form Professional Learning Communities (PLCs), a learning environment where information in each of these classes is connected to the other is created. If a math teacher and science teacher in a PLC connect the material in their respective classes, patterns are made and long-term memories are formed (DuFour, 2004). This idea of connecting subject matter from class to class is one of the main proponents of PLCs and CCSS. Also, this situation more resembles the connections people make in their lives outside of school.

Lesson Planning. Educators should design lessons that are actively engaging. Many students learn by doing. Choices should be provided for the learning activity and in order for them to demonstrate their deep understanding of the knowledge. This manner of differentiated instruction allows students to show what they know through their unique learning styles and intelligence.

Feedback. Teachers need to build in opportunities to give immediate and specific feedback to students. Students do not learn what is expected by receiving comments such as *good job* or *needs more*. Once students have received authentic and individual feedback, their brain will make the proper adjustments for the next learning experience. Student self-assessment is another important part of being a successful learner. Reflection on learning, behavior, and attitude is an improtant life skill. "Self-monitoring can increase students' feelings of competence and control and, in turn, their motivation to remain engaged with a task at a high level" (Henningsen & Stein, 1997, p. 527). A good way to accomplish this metacognative skill is to teach students how to journal and build time in lessons to allow for this process to unfold. Additionally, students involved in peer-review can develop the skill of looking at the work of others and of themselves through a critical lens. This process is not meant to tear down students but to build them up, so it is important that the peer groups are carefully chosen and assigned tasks during each session. Lastly, student achievements, such as personal bests or notable improvements, should be celebrated. Celebrations should focus on certificates or other congratulatory efforts not on food or monetary rewards. If these types of rewards are used, then the teacher's response becomes the focus, not the achievement itself.

Implications for a Ninth-Grade Science Classroom

As a result of this research project there are changes that I am looking forward to implementing in ninth-grade science. I intend to create a more student-centered classroom by considering brain development and health when developing curricula. This will include creating new curricula planned to meet the students' needs for novelty, patterning, and multiple learning access points in a low-stress environment.

Because the brain is wired to recognize and focus on novelty and stimulation in learning, I will design lessons that offer new ways of addressing the curriculum. I will focus delivery on demonstration and sharing of my own examples. For example, when studying Newton's Laws, students will do several experiments on each of the laws. They will be asked a driving question, such as "How can you demonstrate Newton's First Law?" Multimedia will be incorporated as a novel way to show Newton's Laws in action. *Teacher Tube* and *Discovery* both are online presentations that provide good video examples for educational use. A science website called *Smarter Every Day*, is a site created by a science teacher who explores different questions each day. Finally, students might create their own videos, PowerPoints, or Prezi's to share their knowledge of Newton's Laws.

One method I will use to ensure that the students are actively engaged is to also allow them to make some of their learning decisions. My guidance will help to facilitate this journey. Through surveying my students' learning styles and multiple intelligences, both the students and I could become aware of the types of learning activites they enjoy and how they learn best.

To help students form patterns, I will connect new information to previous knowledge (Vygotsky, 1997/1926). For example, in the Newton's Laws unit, I will build on the knowledge of what happens to people being thrown from vehicles when not being restrained by a seatbelt, and pair this knowledge to how these laws contribute to the act of skateboarding or riding a bike. I plan to create deeper patterns by working with the math teacher to demonstrate Newton's Laws mathematically. This helps students see that subject matter is connected in school and in real life, leading to a deeper understanding of the information and better retention.

I will also plan for connections to the real-world. In this way, students will obtain entry points to the knowledge they will use later in life. Activities will be planned that are project-based. Students will be expected to answer open-ended questions that require the need to explore and formulate answers. Their responses will provide me the opportunity to give students immediate feedback.

Physical activity will become a large part of the activities in this student-centered classroom. I intend to add the practice of giving instructions while my students are in motion. I also plan to use more brain breaks, such as a ball toss for review. This will be a fun way to get students in motion, go over material, and do a quick formative assessment of student learning.

Finally, I plan to give students *down-time* from the constant stream of information. When students are experiencing a long session of work that requires deep thought and understanding, they may need a break to reflect upon the learning in order for it to become part of their knowledge and memory. I will incorporate opportunities for students to read through notes and observations, discuss their understandings with a neighbor or journal, or possibly take a walk. This will help seat the information in long-term memory. Further de-stressors in the classroom will include relaxation and meditation, especially before summative assessments. Deep breathing and visualizations can assist students in lowering stress that might arise on test day and allows students to have easier access to retained information.

These plans for change will create a more brain-friendly, student-centered classroom. Students will feel safe, have lower stress, and form deeper understanding of the content. If I, as well as other educators, consider brain growth and development in the design of curricula and lesson plans, students will have better retention and comprehension and be able to transfer this knowledge to the real world.

Limitations

The limitations to this project is that there were very few examples of action research being done within a secondary science classroom. Because of this, it is difficult to examine how the concepts and strategies described in this paper will impact the students in a secondary science classroom. Another limitation to this study is that some sources used were of a practical nature for educators as opposed to scientific research, resulting in these sources being secondary sources instead of primary sources. However, both scientific and educational sources were used to create a balance of information obtained from the literature.

Ideas for Further Research

Now that I have gained this knowledge, the next step will be to use these concepts and strategies, especially active learning and project-based learning, in teaching science to ninth-grade students. Observations of these ideas and practices in action could lend to a better understanding of how to create a more meaningful learning environment for adolescent students. Also, one could create an action research project to discern the value of brain-based teaching and learning versus current teaching methods. Lastly, a deep exploration of this topic could reveal further information on brain-based learning to benefit student learning and retention.

References

Aziz-Ur-Rehman, & Bokhari, M. (2011). Effectiveness of brain-based learning theory at secondary level. *International Journal of Academic Research*, *3*(4), 354-359.

Barron, B. J., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., & Bransford, J. D. (1998). Doing with understanding: Lessons from research on problem- and project-based learning. *The Journal of the Learning Sciences*, 271-311.

Bennett, L.M., Gadlin, H., Levine-Finley, S. (2010). *Collaboration and team science: A field Guide.* National Institute of Health Office of the Ombudsman, Center for Cooperative Resolution. Retrieved from http://www.bumc.bu.edu/facdev-medicine/files/2011/03/TeamScienceNIH.pdf

Black, J. E., Sirevaag, A. M., & Greenough, W. T. (1987). Complex experience promotes capillary formation in young rat visual cortex. *Neuroscience letters*, *83*(3), 351-355.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How People Learn: Brain, Mind, Experience, and School.* Washington, DC: National Academy of Sciences.

Caine, R., & Caine, G. (1990). Understanding a brain-based approach to learning and teaching. *Educational Leadership*, *48*(2), 66-70.

Caine, R. N., & Caine, G. (1994). *Making Connections: Teaching and the Human Brain.* Menlo Park, CA: Addison-Wesley.

Caine, R., & Caine, G. (1995). Reinventing schools through brain-based learning. *Educational Leadership*, *52*(7), 43-47.

Caine, R., & Caine, G. (2006). The way we learn. *Educational Leadership, 64*(1), 50-54.

Common Core State Standards. (2012). Retrieved from http://www.corestandards.org/.

Crawford, G. B. (2007). *Brain-Based Teaching with Adolescent Learning in Mind.* Thousand Oaks, CA: Corwin Press.

Danielson, C. (2007). *Enhancing Professional Practice: A Framework for Teaching*. Alexandria, VA: Association for Supervision and Curriculum Development.

Dobbs, D. (2011, October). Beautiful brains. *National Geographic,* 37-59.

Dougherty, M.R., Scheck, P., & Nelson, T.O. (2005). Using the past to predict the future. *Memory & Cognition*, *33(6),* 1096-1115.

DuFour, R. (2004). What is a" professional learning community"? *Educational leadership, 61*(8), 6-11.

Duman, B. (2010). The effects of brain-based learning on the academic achievement of students with different learning styles. *Educational Sciences: Theory and Practice*, *10*(4), 2077-2103.

Dwyer, T., Sallis, J. F., Blizzard, L., Lazarus, R., & Dean, K. (2001). Relation of academic performance to physical activity and fitness in children. *Pediatric Exercise Science, 13*(3), 225-237.

Franklin, J. (2005, June). Mental Mileage: How Teachers are Putting Research to Use. *Education Update.* Retrieved from http://m.ascd.org/publications/newsletters/education_update/jun05/vol47/num06/Mental_Mileage.aspx

Freire, P. (1972). *Pedagogy of the Oppressed.* 1968. Trans. Myra Bergman Ramos. New York: Herder.

Giedd, J. (2002, January 31). *Inside the teenage brain*. FRONTLINE, Interview.

Giedd, J. (2008). The teen brain: Insights from neuroimaging. *Journal of Adolescent Health*, *42*(4), 335-343.

Giedd, J. N. (2009). Linking adolescent sleep, brain maturation, and behavior. *The Journal of Adolescent Health: official publication of the Society for Adolescent Medicine*, *45*(4), 319.

Goleman, D. (1998). *Working with Emotional Intelligence.* New York: Bantam Books.

Hagenauer, Perryman, Lee, & Carskadon. (2009). Adolescent changes in the homeostatic and circadian regulation of sleep. *Developmental Neuroscience*, *31*(4), 276-284.

Hall, K.L., Stokols, D., Moser, R.P., Taylor, B.K., Thornquist, M.D., Nebeling, L.C., Ehret, C.C., Barnett, M.J., McTiernan, A., Berger, N.A., Goran, M.I., & Jeffery, R.W. (2008). The collaboration readiness of transdisciplinary research teams and centers. *American Journal of Preventative Medicine*, *35(2),* 161-172. DOI: 10.1016/j.amepre.2008.03.035

Henningsen, M. & Stein, M.K. (1997). Mathematical tasks and student cognition: Classroom-based factors that support and inhibit high-level mathematics thinking and reasoning. *Journal for Research in Mathematics Education*, *28(5),* 524-549.

Hileman, S. (2006). Motivating students using brain-based teaching strategies. *Agricultural Education Magazine*, *78*(4), 18.

Holubova, R. (2008). Effective teaching methods: Project-based learning in physics. *US-China Education Review*, *5*(12), 27-35.

Immordino-Yang, M. H., & Damasio, A. (2007). We feel, therefore we learn: The relevance of affective and social neuroscience to education. *Mind, Brain, and Education*, *1*(1), 3-10.

Immordino-Yang, M. (2011). Implications of affective and social neuroscience for educational theory. *Educational Philosophy And Theory*, *43*(1), 98-103.

Jennings, W. (2004). Breakthroughs in learning from brain based schools. *School Transformation*. Retrieved from http://www.waynejennings.net/brain_pages/20040722173147.html

Jensen, E. (2005). *Motivation and Engagement: Teaching with the Brain in Mind.* Alexandria, VA: Association for Supervision and Curriculum Development.

Jensen, E. (2005). *Teaching with the Brain in Mind*. Alexandria, VA: Association for Supervision and Curriculum Development.

Jensen, E. P. (2008). A fresh look at brain-based education. *Phi Delta Kappan*, *89*(6), 408.

Jensen, E. (2008). *Brain Based Learning: The New Paradigm of Teaching.* Thousand Oaks, CA: Corwin Press.

Kaufeldt, M. (1999). *Begin with the Brain: Orchestrating the Learner-Centered Classroom.* Chicago: Zephyr Press.

Kaufman, E. K., Robinson, J., Bellah, K., Akers, C., Haase-Wittler, P., & Martindale, L. (2008). Engaging students with brain-based learning. *ACTEonline.*

Kohn, A. (2001). Five reasons to stop saying "Good job." *Young Children*, *56*(5), 24-28.

Kornell, N. & Bjork, R.A. (2007). The promise and perils of self-regulated study. *Psychonomic Bulletin & Review, 14(2)*, 219-224).

Langelier, C. A. & Connell, J.D. (2005). Emotions and learning: Where brain based learning and cognitive-behavioral counseling strategies meet the road. *River College Online Academic Journal*, *1*(1).

MacNabb, C., Schmitt, L., Michlin, M., Harris, I., Thomas, L., Chittendon, D., Ebner, T.J., Dubinsky, J.M. (2006). Neuroscience in middle school: A professional development and resource program that models inquiry-based strategies and engages teachers in classroom implementation. *CBE-Life Science Education, 5*, 144-157.

Nelson, C. (2002, January 31). *Inside the teenage brain*. FRONTLINE, Interview.

Next Generation Science Standards. (2013). Retrieved from http://www.nextgenscience.org/sites/ngss/files/Final%20Release%20NGSS%20Front%20Matter%20-%206.17.13%20Update_0.pdf.

Nunley, K. (2003). *A Student's Brain: The Parent/Teacher Manual*. Kearney, NE: Morris Publishing.

Nunley, K. (n.d.). How the adolescent brain challenges the adult brain. *Help4Teachers.com.* Retrieved from http://help4teachers.com/prefrontalcortex.htm

Philp, R. (2007). *Engaging 'Tweens and Teens.* Thousand Oaks, CA: Corwin Press.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of engineering education*, *93*(3), 223-231.

Radin, J. L. (2009). Brain-compatible teaching and learning: Implications for teacher education. *Educational Horizons*, *88*(1), 40-50.

Ratey, J. J. (2008). *Spark: The Revolutionary New Science of Exercise and the Brain.* New York: Little Brown and Company.

Roehrig, G. H., Michlin, M. M., Schmitt, L. L., MacNabb, C. C., & Dubinsky, J. M. (2012). Teaching neuroscience to science teachers: Facilitating the translation of inquiry-based teaching instruction to the classroom. *CBE - Life Sciences Education*, *11*(4), 413-424.

Rosenzweig, M. R., & Bennett, E. L. (1978). Experiential influences on brain anatomy and brain chemistry in rodents. *Studies on the development of behavior and the nervous system*, *4*, 289-327.

Saleh, S. (2012). The effectiveness of the brain based teaching approach in enhancing scientific understanding of Newtonian physics among form four students. *International Journal of Environmental and Science Education*, *7*(1), 107-122.

Sousa, D. (2006). *How the Brain Learns.* Thousand Oaks, CA: Corwin Press.

Sousa, D. (2009). Brain-friendly learning for teachers. *Educational Leadership*, *66*(9).

Sukel, K. (2010, July). *Exercise offers direct benefits to the brain.* The Dana Foundation. Retrieved from http://www.dana.org/news/features/detail.aspx?id=28758

Sylwester, R. (2007). *The Adolescent Brain: Reaching for Autonomy.* Thousand Oaks, CA: Corwin Press.

Thomas, J. W. (2000). A review of research on project-based learning. *Autodesk Foundation*. Retrieved from http://www.ri.net/middletown/mef/linksresources/documents/researchreviewPBL_070226.pdf

Tokuhama-Espinosa, T. (2008). *The scientifically substantiated art of teaching: A study in the development of standards in the new academic field of neuroeducation (mind, brain, and education science).* Doctoral dissertation, Capella University. ProQuest Dissertations and Theses, 624-n/a. Retrieved from http://search.proquest.com/docview/250881375?accountid=14793. (250881375).

Tokuhama-Espinosa, T. (2011). A brief history of the science of learning: part 2 (1970s-present). *New Horizons for Learning.* Retrieved from http://education.jhu.edu/PD/newhorizons/Journals/Winter2011/Tokuhama5

Tomlinson, C.A. (1999). *The Differnetiated Classroom*. Alexandria, VA: Association for Supervision and Curriculum Development.

Von Glasersfeld, E. (1989). Constructivism in education. Husen T. & Postlethwaite T. N. (eds.) *International encyclopedia of education. Supplement Volume 1.* Pergamon Press, Oxford, England: 162–163. Retrieved from http://www.vonglasersfeld.com/114

Vygotsky, L.S. (1997/1926). *Educational Psychology*. Boca Raton, FL: CRC Press LLC.

Wagner, K. (2012, December 2). Teach the mind. *Teach the Mind*. Retrieved from http://www.teachthemind.com/

Weiss, R. P. (2000). Brain-based learning. *Training and Development-Alexandria-American Society for Training and Development*, *54*(7), 20-24.

Willis, J. (2006). *Research-Based Strategies to Ignite Student Learning*. Alexandria, VA: Association for Supervision and Curriculum Development.

Willis, J. (2007). Brain-based teaching strategies for improving students' memory, learning, and test-taking success. *Childhood Education*, *83*(5), 310.

Willis, J. (2009, December). How to teach students about the brain. *Educational Leadership*. Retrieved from http://www.radteach.com/page1/page8/page44/page44.html

Wolfson, A. R., & Carskadon, M. A. (1998). Sleep schedules and daytime functioning in adolescents. *Child Development*, *69*(4), 875-87.

Appendix

The 12 Brain/Mind Learning Principles

Principle #1: All learning engages the physiology.

Better learning takes place when students use their bodies and senses to experience the learning. Using the body, senses and mind increases neural plasticity.

Principle #2: The brain/mind is social.

Better comprehension takes place when positive interpersonal relationships are supported in the classrooom.

Principle #3: The search for meaning is innate.

Learners are in search of novel and unique experiences. Individual students bring their own ideas and interests to the classroom. When these pieces are incorporated into the curriculum, students obtain better comprehension.

Principle #4: The search for meaning occurs through patterning.

Patterning refers to the brain's attempt to find and create meaning and relationships among the information that it receives. The brain organizes and categorizes information according to the patterns that it can make with old and new information. The brain resists having meaningless patterns imposed on it by others; it will not store these odd pieces of information for long. Students can take their current understanding and synthesize it with new information by patterning. The key is that the information must have meaning to the learner in order for it to stick.

Principle #5: Emotions are critical to patterning.

Strong comprehension occurs when emotions are involved. When an emotional cord is "struck," a person remembers that event long after the event has passed. Powerful learning takes place when it is enriched by emotional experiences and directed by higher order functions in the brain.

Principle #6: The brain/mind processes parts and wholes simultaneously.

Better learning takes place when the details are given and the whole or bigger picture is considered as well. Students can connect the big picture and the details when teachers use real-world examples or project-based learning.

Principle #7: Learning involves both focused attention and peripheral perception.

Learners take in not only the information that is being taught, but also the subtle cues that occur within the room and from the teacher. The brain can organize and process these pieces of information simutaneously. Teachers need to model enthusiam for the learning taking place. Students can easily pick up on the unconscious signals given off in behaviors. When the teacher shows excitement for the learning, the students will engage in the learning as well.

Principle #8: Learning is both conscious and unconscious.

Students need time to reflect upon what is learned and what the information means to them to form better understanding. This time is often missed because many teachers desire a "Bell to Bell" approach, but these metacognative activities increase student comprehension.

Principle #9: There are at least two approaches to memory.

Learners store types of information differently. The brain stores memories of isolated facts and skills one way and life experiences in another more complex manner. Education that focuses just on rote memorization is missing out on a whole other piece of dynamic memory in learners. Student comprehension can be increased when they are taught to use both systems and are engaged in activities that encourage multiple memory pathways.

Principle #10: Learning is developmental.

Mental and emotional development is different for all people. It cannot be assumed that every student is ready for the same learning event at the same time. Every brain is unique in its development and maturation. Better learning takes place when students' individualities in brain development and maturation are considered by educators.

Principle #11: Complex learning is enhanced by challenge and inhibitied by threat associated with helplessness and/or fatigue.

Learning is inhibited by stress and fear and exhibited when students are challenged, encouraged, and supported. Cognitive and emotional thinking is thwarted if a student is tired. Learning needs to take place in an environment that is highly challenging but non-threatening. Students need to be encouraged to get enough sleep, so they can engage in high executive functions while in the classroom.

Principle #12: Each brain is uniquely organized.

Just as every person is different every brain is different. People have different genetic make-up that influences them both internally and externally, and they have different experiences that influence them internally and externally. Comprehension of learning increases when teachers consider students' uniqueness, varying talents and abilities (Caine & Caine, 1990).