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ABSTRACT

This paper explains how brain-based learning has become an area of interest to elementary school science teachers, focusing on the possible relationships between, and implications of, research on brain-based learning to the teaching of science education standards. After describing research on the brain, the paper looks at three implications from current brain research: (1) stress limits children's ability to learn, so it is important to create and maintain a safe and secure learning environment; (2) doing activities that have immediate connections to the real world increases learning and may increase the development or maintenance of dendrites in the brain, and using real problems as the basis for investigation promotes understandings that are viewed as important and skills that are viewed as useful, thus providing students with motivation for learning; and (3) to maintain learning and dendrite connections, it is important to use them. The brain needs to have concepts revisited in several different ways to encourage the active processing needed to keep connections and foster memory. Attachments include a list of relevant Web sites and National Science Education Standards excerpts. (Contains 15 references.) (SM)

Brain-Based Learning and Standards-Based Elementary Science

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2003

Brain-Based Learning and Standards-Based Elementary Science

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Brain-based learning has become an area of research interest of elementary teachers of science. Although this important research is still in its infancy, study of its implications for education have caught on as noted by the many books, articles and conferences on the subject. One such conference, *Learning and the Brain: To Use Brain Research to Leave No Child Behind* at Harvard in April, 2003 advertises topics such as:

Discover What Scientific Research Tells Us About...

- How a child's brain learns and pays attention in class
- Strategies for creating brain-based assessment and instruction
- Brain differences in reading and how to improve reading skills
- How sleep, movement, nutrition, stress, and exercise affect achievement
- Ways to use the brain-body connection and multiple intelligence in teaching
- Causes and interventions for dyslexia, ADHD, and learning disorders
- The role of emotions, gender, and the executive brain in learning
- The importance of images, the arts, and music to the brain
- Ways to improve student visual and verbal memory

Information about the conference is available on line at http://www.edupr.com/

Like others, I have found the field intriguing. Reading books and articles and talking with some of the "experts" who apply the research to education continue to stimulate my thinking. My particular focus today is on the possible relationships and implications of research on brain-based learning to the teaching of science education standards. My initial response is that of course there is a relationship. For, in order to teach and learn science, it requires cognitive aspects of the brain including thinking and memory. In addition, it demands the use of social and emotional learning processes.

Beyond the use of the brain in learning, are there relationships between brain-based learning research and science education standards? The answer appears to be both yes and no. No, there are not always immediate and direct relationships. But, yes, there are many areas within the science teaching standards that relationships can be drawn.

The first one is in the research itself. Brain research is scientific research. It uses scientific methodologies and tools. It helps expand our knowledge while simultaneously causing us to ask additional questions. It can be used as an example of research endeavors being undertaken that older children might be interested in finding out about.

For example, LeDoux and his colleagues have been exploring fear reactions using a stimulus. (See picture from his web site found below.) It involves the following idea: You are walking through the woods, and you see a coiled shape lying across your path. Instantly--before you even think "a snake!"--your brain initiates physiological responses to the potential threat.

These physiological responses are associated with the emotion of fear. Researchers are making progress in tracing the brain circuitry underlying the fear response. Attention is now focused on the amygdala, a small almond-shaped structure deep inside the brain. A portion of the amygdala known as the lateral nucleus appears to play a key role in fear.

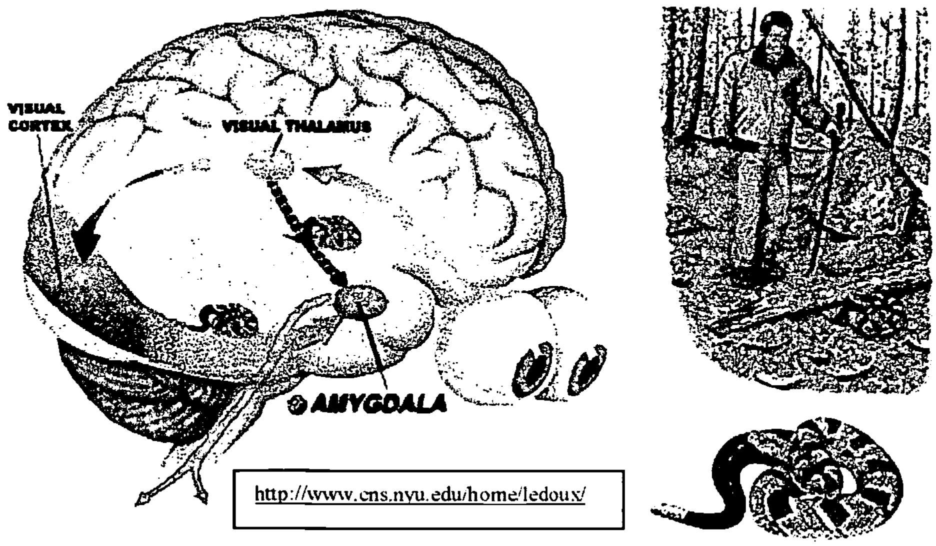


Illustration based on LeDoux JE (1994) Emotion, Memory, and the Brain. Scientific American.

Information comes in from the senses (eyes) and goes to the sensory (visual) thalamus, which monitors sensory information and sends it to the sensory (visual) cortex for processing. Simultaneously, it sends information directly to its neighbor, the amygdala, along a more direct pathway in the brain. When the amygdala receives nerve signals indicating a threat, it sends out signals that trigger defensive behavior, autonomic arousal (usually including rapid heartbeat and raised blood pressure), hypoalgesia (a diminished capacity to feel pain), somatic reflex potentiation (such as an exaggerated startle reflex), and pituitary-adrenal axis stimulation (production of stress hormones). In humans, these physical changes are accompanied by the emotion we call fear. The defensive behaviors associated with fear initiate the tendencies to fight, flee, or freeze. This research points out that all sensory information is filtered through the sensory thalamus and is sent both to the amygdala to initiate physiological processes associated with emotions at the same time it sends the information for cognitive processing. The cognitive processing determines if it actually is a dangerous snake, a snake not to be feared, or just a stick. Then, we can modify our initial responses appropriately.

Such studies provide examples of scientific research that some upper elementary students may be interested in exploring as they study the various systems of the body--particularly the brain and senses. These studies illustrate how scientific research tells us more about why we respond the way we do in various situations. .

In addition, studies of the emotional brain help inform our educational practice. Since teachers do not want to have to deal with fear responses in the classroom, it is essential that they not initiate threatening situations. For learners, a safe and secure environment is ideal. Science teaching standard D (National Science Education Standards, 1995) reinforces this when it states that teachers must ensure a safe working environment. This includes both physical and emotional safety.

When Kaufeldt (2002) interprets brain research to educators, she emphasizes three implications from current brain research. The first implication is that stress limits the ability of children to learn. Thus, it is important that we create and maintain a safe and secure learning environment. Children who are feeling threatened physically or emotionally often demonstrate defensive behaviors that interfere with or limit learning. Not only does fear limit initial learning but also it may become linked with other educational experiences such as taking tests or speaking in front of a class.

When taking a "big test", teachers are now recommending having a good night's sleep, being hydrated, and having energy food. In addition, they are trying to reduce the level of stress. One suggestion of a way to reduce stress before an important test is to tell a story, especially on yourself, before you begin the test instructions. Somehow, this type of humor tends to change the physiological and emotional responses and reduce anxiety. It helps children to release some of the stress they might have had and permits them to focus their energy on understanding and responding to the test questions.

In this time of high-stakes tests, standards-based accountability, and No Child Left Behind, elementary teachers are struggling with how to establish and maintain a positive learning environment that keeps negative stress at a minimum. Although this poster may be a good reminder, I don't think it will be sufficient. We must change our practice in classrooms.

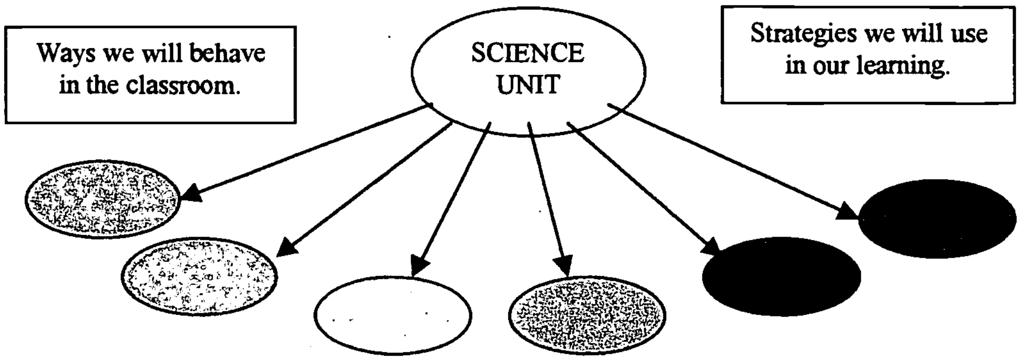
Eliminate the 4-letter "F" word---FEAR,
from our classrooms.
It fosters defensive behaviors.
Fight, Flight, and Freeze
--None of which facilitate school learning.

We need to eliminate the use of fear and threats as motivators. We need to find ways to increase children's ability to focus on learning. One way to help children focus on learning is to let them know what is to be learned.

Bloom and his colleagues who studied mastery learning over 30 years ago found that when you share the objectives of a lesson with students in advance of teaching the lesson, students they are more likely to learn what is desired (Block, 1975). This usually took the form of listing objectives on the board or putting them on overheads. Although this was helpful to a majority of students, some students continued to have difficulties mastering the desired content.

More recently, researchers at the University of Kansas, who have been exploring ways to facilitate learning for learning disabled students, found that when teachers give students a written year-long overview of a course, unit, and lesson in graphic form, that it facilitates the learning of both learning disabled and non-disabled adolescents (Bulgren & Lentz, 1996).

Although I recommend using the University of Kansas format, you can make your own format for a unit and each of its topics (see below). You can adapt some available graphic organizers from web sites such as http://www.inspiration.com Inspiration permits you to input and print out the material in both graphic and outline form, which helps you to address needs of both global and linear learners.



By knowing in advance what is expected, students' stress can be reduced. The threat of the unknown is reduced. This is helpful for many students who do not feel successful in school. Thus, it is very important to reduce any unnecessary anxiety and help students to focus on what is expected and permit them to learn more effectively.

Standard A of the national teaching standards for science supports planning and sharing goals with students, as well as making adaptations for students with special needs. It states, "Teachers of science plan an inquiry-based science program for their students. In doing this, teachers:

- Develop a framework of yearlong and short-term goals for students.
- Select science content and adapt and design curricula to meet the interests, knowledge, understanding, abilities, and experiences of students." (*National Science Education Standards*, Teaching Standards, 1995)

Providing a safe and secure environment is important to both science education and to effective teaching based on brain research. The aspects of what needs to be considered to achieve both are listed below.

Maintain a Safe and Secure Climate and Environment
- Low threat and high challenge
- Joyful and rigorous
- Inclusion and community
- Physically comfortable
- Known plans and expectations
- Time for reflection, contemplation, and expansion

From Martha Kaufeldt's web site http://www.beginwiththebrain.com/conceptsframe.html

A second implication of brain-based research suggested by Kaufeldt is that doing activities that have immediate connections to the "real world" increases learning and may increase the development or maintenance of dendrites in the brain. Brain research is not alone in recommending the use of "real world activities." This is a critical component of inquiry teaching promoted in the national science teaching standards.

Using real problems as the basis for investigation promotes understandings that are viewed as "important" and skills that are viewed as "useful." Both of these provide students with "reasons" or motivation for learning. The use of inquiry activities increases students experience base and helps them "make meaning." The ability to gain conceptual understanding through authentic experiences directly links the recommendations of standards-based science inquiry with suggestions from brain research. As noted below, having key experiences that are interactive and meaningful are crucial to fostering student understanding of science.

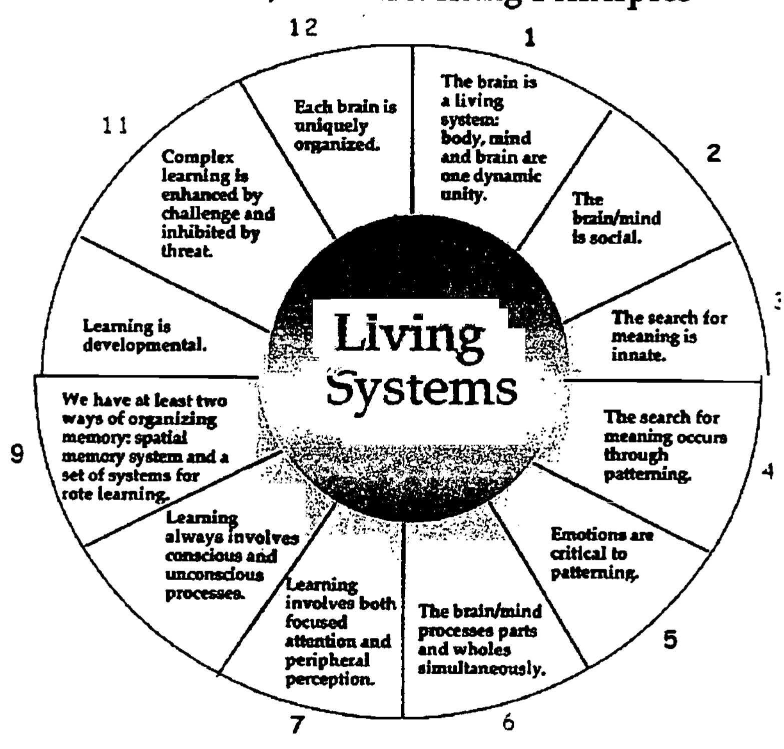
Provide Key Experiences With Content and Concepts

Complex, interactive experiences
Meaningful to the learner
Variety of input and resources
Developmentally appropriate
Sense of purpose in the real world
Builds on prior experiences
Recognizes interconnectedness
Learning environment promotes discovery and creativity
Coherent: creates a context and maintains visible connections

From Martha Kaufeldt's web site http://www.beginwiththebrain.com/conceptsframe.html

Caine and Caine reinforce these ideas in their learning wheel depicted below.

The Brain/Mind Learning Principles



Three interactive teaching elements emerging out of the principles:

Relaxed Alertness	Orchestrated Immersion in Complex Experience	Active Processing

From Caine & Caine web site: http://caineleaming.com/pwheel/

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As Caine and Caine point out, students' experiences facilitate their learning and the more authentic the experiences the more impact the experiences are likely to have.

> "Our view is that meaningful learning... requires a combination of instruction and experience, and the single biggest shift that education needs to make is (to) find ways to bring relatively authentic experience into schooling. However, that necessitates a rethinking of all the other aspects of education, from the role of the teacher to the nature of assessment." (Caine & Caine, http://cainelearning.com/research/ #3, paragraph 6.)

One of the common strategies used by science teachers in providing students with experiences that build understanding is the use of the learning cycle originally developed by Atkin and Karplus (1962) and expanded by Roger Bybee of BSCS as the basis of his constructivist 5-e model of lesson design: Engage, Explore, Explain, Elaborate, Evaluate (Trowbridge & Bybee, 1990. It is this model that we use as part of our science inquiry training for urban elementary teachers. It has been adapted by the Maryland Virtual High School of Mathematics and Science and put a 5-e model of lesson design format on line http://mvhs1.mbhs.edu/mvhsproj/learningcycle/lcmodel.html (See below.)

I. Engagement: The activities in this section capture the student's attention, stimulate their thinking and help them access prior knowledge.	• Demonstration
	  ◦ teacher and/or student
	• Reading from a
	  ◦ current media release
	  ◦ science journal or book
	  ◦ piece of literature (biography, essay, peom, etc)
	• Free write
	• Analyze a graphic organizer

II. Exploration: In this section students are given time to think, plan, investigate, and organize collected information	• Reading authentic resources to collect information
	  ◦ to answer an open-ended question
	  ◦ to make a decision
	• Solve a problem
	• Construct a model
	• Experiment
	  ◦ design and/or
	  ◦ perform

III. Explanation: Students are now involved in an analysis of their exploration. Their understanding is clarified and modified because of reflective activities	• Student analysis and explanation • Supporting ideas with evidence • Reading and discussion
IV. Extension: This section gives students the opportunity to expand and solidify their understanding of the concept and/or apply it to a real world situation	• Problem solving • Experimental inquiry • Thinking Skills Activities ◦ classifying, abstracting, error analysis, etc. • Decision-making
V. Evaluation	• Teacher and/or student generated scoring tools or rubrics

Teachers in our projects have found the 5-e model to be particularly helpful as they think about their teaching. We have not yet linked it to brain-based learning. Lyn Klosowski of Harding School in Hammond, Indiana conducted action research in her classroom on the relationship between her SCIS3 science curriculum and what she knew of brain based research and found that the ideas of the learning cycle are consistent with brain-based learning research.

In the area of active processing and having numerous experiences with a concept, we succeed best when we encourage exploration, explanation, extension of the concept into the real world, and self-evaluation of understandings and experimental results. Without the use of this learning cycle, even our best efforts to assure that our curriculum includes all of the standards, we are likely to just cover the material rather than uncover the ideas that we want students to take with them for the rest of their lives.

However, we must remember that not all students respond well to open-ended exploration. Many learning disabled students have been found to benefit from direct instruction that focuses the learning. Thus, some special educators feel that learning disabled students should not be included in classrooms that use open-ended exploration as the predominant way of learning science. Martha Kaufeldt suggested to me that the problem may be that these students have not had a sufficient time to play with the materials before they must use them for inquiry. Thus, it would be necessary to build in time for play prior to conducting an inquiry (personal communication, Feb. 13, 2003).

I have thought that maybe the inquiry activities need to be "chunked." Although I have not yet found any research to support my ideas, I believe that it may be possible to adapt the exploration process by using a graphic organizer with sections similar to those of the 5-e model. The stages would be more explicit but still would involve students in the inquiry process as depicted below. The pre-activity clarification by the teacher and student(s) might include the following:

Our Science Investigation Topic:
This is WHAT we are supposed to learn:
These are the materials we will use:
This is the first question we have:
This is what we will do to answer question 1:
I know what I am to do. _____ I know why I am doing it.________ **I know what we are to find out about. _________**

A second set of organizers can be used during the investigation or exploration phase of the inquiry. This could be set up in a laboratory report format too.

This is what we did.

This is what our experiment looked like.

This is my record of what I observed and found out.

The third phase of the investigation involves the explanation of what has been observed and how it supports a particular scientific concept. In this phase, it is essential that the teacher not only ask the students what they think, but the teacher must focus the discussion so students gain an accurate and clear understanding of the concept and how what they did relates to that concept.

This is what we think our experiment(s) might mean.

This is how my teacher, book, and others explain what they think our experiment means.

This is what I know now.

Like others, we have found that if students are to learn for understanding, they must spend about an equal amount of time in the explanation phase of the learning cycle as they did in the exploration phase. For, until students can explain what they observed and how it can be generalized into concepts or contrasted with other ideas, they don't really understand the concept in a meaningful and in-depth manner. We recommend that teachers have students explain their observations to their learning groups and to the entire class. In addition, we recommend having students depict their understandings in graphic form, in concept maps, in timelines, and in written explanations as either descriptive paragraphs, log entries, or science investigation reports.

After students can explain a new concept, it may be helpful to let the students "sleep on it." Particularly if the new concept involves the development of a perceptual skill like manipulating a microscope, give students opportunities to practice the skill in class, then let the brain "practice" the skill during sleep. Apparently, during sleep, the brain retraces the connections made while learning the skill and helps to solidify the interactive pathways by retracing them.

The elaboration or extension phase should take students beyond the confines of the classroom to apply the ideas in the "real world." This phase builds on the exploration and explanation done in the classroom to link the concepts learned with their application in situations outside classroom. I do not recommend engaging in this phase on the same day that the concept is taught unless the application is clear and not likely to be confusing. Again, when carrying out elaboration or extensions of the concept, have students keep a record of the applications.

This is where and how what I have learned applies in my life or the lives of people I might know.

In addition to applying what they have learned to other settings, students must feel that they can effectively demonstrate and evaluate their learning. All students want to be successful. By giving them both formative and summative assessment opportunities, they can demonstrate their newly acquired understandings to themselves and to others.

I know that I understand this new concept because I can--

- **Correctly answer the self-quiz questions on this topic**
- **Correctly explain the concept in my journal or investigation report.**
- **Correctly explain the investigation and its implications on a poster, in a PowerPoint presentation, or in a paper.**

Once students complete all five phases in the 5-e model, they should have command of the concept and its application.

Since science depends heavily on an extensive vocabulary, writing, reading, speaking for acquiring and transmitting knowledge, it is important that we know about and support teaching strategies that foster vocabulary development, reading and writing.

Merrow (2002) reported that poor children come to school with a vocabulary about one-fourth the size of that of middle class children. This is not revealing to many kindergarten teachers who report that they have pupils who come to school not being able to identify colors, shapes, rhymes, or letters. All of these capabilities are essential for both early literacy and for science. They are used when observing to gain information in science. Science requires that students be able to gain information through their senses. Pupils identify similarities and differences, classify the information, ask questions, and provide meaningful generalizations. To do this, students need to have the skills kindergarten teachers identify as being missing. How can we link early science activities with the development of literacy?

Two possibilities quickly come to mind. The first involves undertaking activities that can simultaneously facilitate literacy and science learning. For example, differentiating different shapes and lines is critical when identifying letters and when making basic science observations. Secondly, teachers can use science to enhance the experiential base for students to use as they make meaning from the world around them.

Research done in the 1960s when AAAS' Science: A Process Approach first came out, found that by doing science activities as the first instructional activity of the day it not only increased science understanding but also increased children's reading skills. In the schools where this happened, teachers used science vocabulary, labeled equipment, used the activities as the basis of "experience stories," read stories related to the concepts, and built on the scientific process skills and content knowledge throughout the day. The new brain research seems to support this type of learning. First, understanding and "meaning making" is facilitated when it is supported by students' experiences. Second, using the new knowledge in a number of contexts gives pupils the opportunity to practice their new knowledge. The writing of the experience stories, provides students with the opportunity to explain what they have learned.

The third implication of brain-based research (Kaufeldt, 2002), is that to maintain our learning and dendrite connections, we must "use them or lose them." The brain needs to have concepts revisited in several different ways to encourage the active processing needed to keep connections and foster memory. The use of the ideas from the morning science activity throughout the day gives children opportunities to use their new knowledge.

This idea builds on activity theory research of Leont'ev and its application in emergent literacy, which suggests that for children to really understand a concept sufficiently to make generalizations, they must have at least 3-10 experiences with the concept in its various facets. To differentiate the concept from others and avoid misconceptions, children need at least 1-3 experiences with things that could be confused with the concept. Then, the concept may be clear enough for the child to be able to make generalizations or differentiate the concept from others.

Brain research seems to support this but adds one caveat. Don't introduce the confusing concepts at the same time you are trying to have children learn the concept. It is best to have clear experiences with the concepts first. Then, after the initial generalizations are made and after a good night's sleep, you can introduce or revisit concepts that may be confused with the new concept. This permits differentiation. For, until you are sure what a concept IS. It is difficult to determine what it IS NOT.

Some of the characteristics of brain-based learning that support this include those listed below.

Facilitate Active Learning with Real Activities and Problem Solving:
Opportunities to investigate and make sense of experiences...
- Reflection
  - Time to contemplate and reflect
  - Self-observation and correction
  - Learning about ourselves as learners - metacognition
- Choices
  - Offers complex, real projects
  - Builds student's self-esteem and motivation
  - Honors multiple intelligences and individual abilities
  - Demands active processing and student engagement
- Collaboration
  - Cooperative learning opportunities
  - Uses conflict resolution strategies
  - Builds social relationships and skills
  - Builds sense of community
  - Opportunities to work with a variety of ages
  - Encourages meaningful communication and feedback

From Martha Kaufeldt's web site http://www.beginwiththebrain.com/conceptsframe.html

As science teacher educators, it becomes our job to both assure that science is taught effectively and that we, and our students, do it in a way that fosters both standards-based science learning but also takes into account what we know about learning and the brain. To do this, we must continue our own learning and continually question and alter our own practice.

At the present time, I am still playing with numerous ideas from brain research and how they inform our science teaching and the achievement of science education standards. Some of these include the following. We know that--

- Mothers who speak to their babies, even using baby talk, have children that are likely to have 300 more words in their vocabularies by age 2 than do children whose mothers have not spoken to them. (What should we do to expand students' vocabularies since science is a vocabulary rich subject?)

- Regular reading aloud to children stimulates their brain development. (How should we involve ourselves in reading aloud with and to children?)

- Growing up in a stimulating environment can increase a child's ability to learn by up to 25%. Children whose primary classrooms contain many (over 600) different books over the course of a year, are better readers that children in classrooms with fewer books. (How can we promote a stimulating learning environment while still trying to not have it overwhelming?)

- Parts of the brain of a severely abused and neglected child can be substantially smaller than that of a normal child. (What adaptations are appropriate for children with known and unknown brain injuries--physical and otherwise?)
- It is possible that smiling, laughing and tickling are used to create bonds between babies and parents. When a parent tickles a baby and the baby responds with a smile or laugh, the parent laughs and smiles too. In this way, the baby and parent get to know one another and the baby learns all about laughter by watching and responding to a parent. (How can we use humor to link with our students and promote the bonding necessary to trust the teacher and the learning environment?)
- Sleep helps reinforce memory processing of skills and doing complex cognitive tasks including logical reasoning tasks. When students are sleep deprived a short nap after lunch can help them perform better on tests. (How can we support adequate sleep for our students? How can we be sure that we don't overwhelm our students with too much new information at a time?)

I am just at the beginning of putting the puzzle together for myself and for teachers who teaching science. My observations to date suggest a positive relationship between the science teaching standards and brain research. I encourage you and your students to continue to explore ways to bring these together on behalf of our students and the science community.

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Web Sites

There are many web sites on brain research and on teaching using science standards. You can start here:

http://www.beginwiththebrain.com/ Martha Kaufeldt's web site.

http://www.beginwiththebrain.com/booksummary.html Summary of Martha Kaufeldt's book, *Begin with the Brain*

http://www.cainelearning.com/brain/ Caine & Caine web site

http://www.BrainConnection.com/ The Brain Connection

http://faculty.washington.edu/chudler/neurok.html Neuroscience for kids

http://www.nabt.org/sup/publications/nlca/nlca.htm National Association of Biology Teachers unit on neuroscience

http://www.dana.org/kids/lesson.cfm Dana Foundation lesson plans on neuroscience

http://www.explorescience.com/ Explore Science has lesson plans in science

http://www.patwolfe.com/ Pat Wolfe website on Mind Matters

http://www.pbs.org/wnet/brain/ The Secret Life of the Brain, PBS programs

http://www.dyslexic.com/kyle/kyleindex.htm My Brain is Different, a discussion of dyslexia

http://members.shaw.ca/priscillatheroux/brain.html Enhance Learning With Technology, Brain Research

http://www.student-wea.org/misc/brainrsh.htm#What are the practical messages for educators? NEA's cd

http://www.education-world.com/a_curr/curr140.shtml Growing Bigger Brains: Research Affects How Teachers Teach

http://www.einstein.graceland.edu/education/beckett/Portfolio%20Beckett/BrainPortfoilio%202.ppt Brain powerpoint

http://www.newhorizons.org/neuro/front_neuro.html News from the Neurosciences

http://linus.chem.ukans.edu/Hewlett/fivee.html Explanation of the 5-e model

http://mvhs1.mbhs.edu/mvhsproj/learningcycle/lc.html Maryland Virtual High School use of 5-e model

National Science Education Standards Excerpts

National Science Education Standards: Observe, Interact, Change, Learn. (1995). Washington, DC: National Academy Press. Available on-line http://search.nap.edu/readingroom/books/nses/html/3.html#ts

The National Science Education Standards present a vision of a scientifically literate populace. They outline what students need to know, understand, and be able to do to be scientifically literate at different grade levels. They describe an educational system in which all students demonstrate high levels of performance, in which teachers are empowered to make the decisions essential for effective learning, in which interlocking communities of teachers and students are focused on learning science, and in which supportive educational programs and systems nurture achievement. The Standards point toward a future that is challenging but attainable.

The intent of the Standards can be expressed in a single phrase: Science standards for all students. The phrase embodies both excellence and equity. The Standards apply to all students, regardless of age, gender, cultural or ethnic background, disabilities, aspirations, or interest and motivation in science. Different students will achieve understanding in different ways, and different students will achieve different degrees of depth and breadth of understanding depending on interest, ability, and context. But all students can develop the knowledge and skills described in the Standards, even as some students go well beyond these levels.

By emphasizing both excellence and equity, the Standards also highlight the need to give students the opportunity to learn science. Students cannot achieve high levels of performance without access to skilled professional teachers, adequate classroom time, a rich array of learning materials, accommodating work spaces, and the resources of the communities surrounding their schools. Responsibility for providing this support falls on all those involved with the science education system.

Science Teaching Standards Excerpts

Science teaching is a complex activity that lies at the heart of the vision of science education presented in the Standards. The teaching standards provide criteria for making judgments about progress toward the vision; they describe what teachers of science at all grade levels should understand and be able to do.

To teach science as portrayed by the Standards, teachers must have theoretical and practical knowledge and abilities about science, learning, and science teaching.

The standards for science teaching are grounded in five assumptions.

1. The vision of science education described by the Standards requires changes throughout the entire system.

2. What students learn is greatly influenced by how they are taught.

3. The actions of teachers are deeply influenced by their perceptions of science as an enterprise and as a subject to be taught and learned.

4. Student understanding is actively constructed through individual and social processes.

5. Actions of teachers are deeply influenced by their understanding of and relationships with students.

Science Teaching Standards

TEACHING STANDARD A: **Teachers of science plan an inquiry-based science program for their students.** In doing this, teachers

- Develop a framework of yearlong and short-term goals for students.
- Select science content and adapt and design curricula to meet the interests, knowledge, understanding, abilities, and experiences of students.
- Select teaching and assessment strategies that support the development of student understanding and nurture a community of science learners.
- Work together as colleagues within and across disciplines and grade levels.

TEACHING STANDARD B: **Teachers of science guide and facilitate learning.** In doing this, teachers

- Focus and support inquiries while interacting with students.
- Orchestrate discourse among students about scientific ideas.
- Challenge students to accept and share responsibility for their own learning.
- Recognize and respond to student diversity and encourage all students to participate fully in science
- learning.
- Encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.

TEACHING STANDARD C: **Teachers of science engage in ongoing assessment of their teaching and of student learning.** In doing this, teachers

- Use multiple methods and systematically gather data about student understanding and ability.
- Analyze assessment data to guide teaching.
- Guide students in self-assessment.

- Use student data, observations of teaching, and interactions with colleagues to reflect on and improve teaching practice.

- Use student data, observations of teaching, and interactions with colleagues to report student achievement and opportunities to learn to students, teachers, parents, policy makers, and the general public.

TEACHING STANDARD D: **Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science.** In doing this, teachers

- Structure the time available so that students are able to engage in extended investigations.

- Create a setting for student work that is flexible and supportive of science inquiry.

- Ensure a safe working environment.

- Make the available science tools, materials, media, and technological resources accessible to students.

- Identify and use resources outside the school.

- Engage students in designing the learning environment.

TEACHING STANDARD E: **Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning**. In doing this, teachers

- Display and demand respect for the diverse ideas, skills, and experiences of all students.

- Enable students to have a significant voice in decisions about the content and context of their work and require students to take responsibility for the learning of all members of the community.

- Nurture collaboration among students.

- Structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse.

- Model and emphasize the skills, attitudes, and values of scientific inquiry.

The National Science Education Standards envision change throughout the system. The teaching standards encompass the following changes in emphases:

LESS EMPHASIS ON	MORE EMPHASIS ON
Treating all students alike and responding to the group as a whole	Understanding and responding to individual student's interests, strengths, experiences, and needs
Rigidly following curriculum	Selecting and adapting curriculum
Focusing on student acquisition of information	Focusing on student understanding and use of scientific knowledge, ideas, and inquiry processes
Presenting scientific knowledge through lecture, text, and demonstration	Guiding students in active and extended scientific inquiry
Asking for recitation of acquired knowledge	Providing opportunities for scientific discussion and debate among students
Testing students for factual information at the end of the unit or chapter	Continuously assessing student understanding
Maintaining responsibility and authority	Sharing responsibility for learning with students
Supporting competition	Supporting a classroom community with cooperation, shared responsibility, and respect
Working alone	Working with other teachers to enhance the science program

Brian-Based Learning Concept(s)	Science Teaching Standard(s)	Science Content/Process Standard(s) & Benchmark(s)	Inquiry Learning Activities Engage-Explore-Explain-Elaborate-Evaluate

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