CHAPTER 1

THE SCIENCE OF TEACHING SCIENCE

From a kid's eye view of science, learning is about experiencing the world. And it's also true that brain research confirms this perspective—learning is the result of real physiological growth in the brain spurred by massive sensory input. Such sensory input is not possible in the classroom, especially when study is based on textbooks and worksheets. When it comes to improving science education, kids and brain researchers share overlapping perspectives.

THE QUEST

In the quest to improve science education, would you not expect to utilize the results of scientific research about how the brain learns, research that has been accumulated and validated over the past 30 years? Would you not expect the prowess of 21st-century technology to reveal inner workings of the brain that have eluded us for centuries? We think so. And although the brain is admittedly complex and stubbornly mysterious, there is much we already know. Our challenge is to begin to apply this knowledge within our classrooms and schools in ways that make the learning environment compatible with how the human brain learns rather than an extension of tradition.

Science—when taught as a direct experience of the world around us—is a highly brain-compatible subject because learning from and about the natural world is as natural for the human brain as the sun's rising and setting (due, of course, to the Earth spinning). Our very existence as a species attests to this fact.

In contrast, other areas of the elementary school curriculum are comparatively recent human constructions, such as reading, writing, and mathematics. These newcomers in the evolution of the human brain bristle with abstractions which cannot be experienced by children firsthand through their senses; thus, students must learn how to learn about them before they can learn the content.

Science, when taught as a direct experience of the natural world, is easy for students to grasp and to apply in meaningful, inventive, and often highly complex ways. It should come as no surprise, for example, that many of our early astronauts were Midwestern farm boys who grew up doing science as an unavoidable aspect of growing up on the south forty. They had hours of practice, on a daily basis, with using the scientific thinking processes,[1] solving real problems, and inventing or producing useful products—from repairing farm equipment to strategies to improve profit margins.

Doing science in such real-life settings was natural and automatic, a kinder's garden for many of the best scientist this country has ever known. And while returning to our rural roots is not an option for most of us, we certainly can commit ourselves to making science experienceable, to using science to teach science.

In so many respects, current brain research findings come as no surprise and even as a validation of our personal experience as learners. It is this fit with the brain that we seek—the power to produce learning which remains vivid for a lifetime.

MARY FROGGINS

Welcome. Meet your new guide-on-the-side, Mary Froggins.

The role of Mary Froggins in this book is to challenge and summarize by stating the obvious and not so obvious in a humorous and, hopefully, not to be forgotten way. At times she will be audacious as she attempts to make a point strongly enough to compete with our unexamined pictures of "schooling" as we have known it for the past 170 years.

So, from Mary Froggins and the authors, we wish you a healthy sense of humor as you read this book and go about the task of creating a kid's eye view of science.

FOUR PRINCIPLES FROM BRAIN RESEARCH

Although the brain is enormously complex, descriptions of how the human brain learns can be expressed in relatively simple conceptual terms. And although we may not know as much as we will, we certainly know enough to get started.

The learning principles outlined here are, we believe, fundamental to establishing a working theory of human learning for the 21st century. Corroborated by researchers studying the human brain from many different avenues, they provide a powerful template for making decisions about curriculum, instruction, and other issues needed for systemic rethinking of American education.

The four principles from brain research are as follows[2]:

PRINCIPLE A — Intelligence as a function of experience[3]

Learning is the result of real, observable physiological growth in the brain that occurs as a result of sensory input and the processing, organizing, and pruning it promotes.[4] Genetics is not the immutable determiner of intelligence it was generally believed to be; although it sets parameters, experiences with high levels of sensory input can significantly increase development of one's capacity.

PRINCIPLE B — Learning is an inseparable partnership between the brain and body.[4]

- Emotion is the gatekeeper to learning and performance.

  Much of the information processed in the brain comes from information substances produced throughout the body, many of which are the "molecules of emotion"[5] that drive attention, which in turn drives learning, memory, and virtually everything else.[6]

- Movement enhances learning.[7]

  Movement is crucial to every brain function including planning and executing those plans, memory, emotion, language, and learning.

- Aerobic exercise kick-starts the chemicals for learning.

  Aerobic exercise of at least 35 minutes at 70 percent heart rate unleashes a cascade of neurotransmitters that prepare the brain to learn (create neurons in the hippocampus) and enhances learning processes).

PRINCIPLE C — There are multiple intelligences.[8]

We have not one, generic intelligence but at least seven, each of which operates from a different part of our brain. As defined by Howard Gardner, intelligence is "a problem-solving and/or product-producing capability."[9] This applies both to learning and to demonstrating understanding of an idea/concept.

PRINCIPLE D — Learning is a two-step process.[10]

- Detecting and understanding patterns—processes through which our brain creates meaning
- Developing meaningful mental programs to use what is understood and to store it in long-term memory. Such capacity to use what's understood is developed first with assistance, then used independently and finally with near automaticity.

These four principles, their brain research sources, and their implications for curriculum and instruction are described in Chapters 9-14. Chapters 2-8 describe practical, day-to-day applications.

CURRICULUM AND THE BRAIN

All decisions about science curriculum should be made with brain research in mind, particularly the new, brain-based definition of learning and the necessity for high sensory experience in learning. Since the content has largely been established by your state standards, the most important question to solve is how to localized your state standards—how to bridge the gap between national expectations and your students' prior experiences by selecting *being there* location that will provide the best illustration of the concepts and skills you need to teach.

The Quest - 1.1
Four Principles - 1.2
The Science of Teaching Science
Curriculum - 1.3
Being There and Standards - 1.6
Integration Made Easy - 1.9

FOUR PRINCIPLES FROM BRAIN RESEARCH

Principle A: Intelligence and Experience

Principle B: Inseparable Partnership — Brain and Body

Principle C: Multiple Intelligences

Principle D: Learning as Two-Step Process

MARY FROGGINS

We have rearranged the deck chairs on the Titanic so many times, each reform era with its own special vocabulary, that we have lost sight of the common sense of it all.

The bottom line about curriculum can—and should—be boiled down to these two questions:

- WHAT DO I WANT MY STUDENTS TO ***UNDERSTAND***?
- WHAT DO I WANT MY STUDENTS TO ***DO*** WITH WHAT THEY UNDERSTAND?

And, clearly, this means **do** *in real-world applications, not on end-of-chapter questions, worksheets, or tests.*

Anchoring Curriculum in Real-Life Locations

Anchoring curriculum in real-life locations makes key tasks easy. For example, making content meaningful and mentally and physically engaging while vastly increasing the amount of sensory input over that of the traditional tools of textbooks, worksheets, lectures, and an occasional video or Internet scan. Let two pivotal questions guide your thinking:

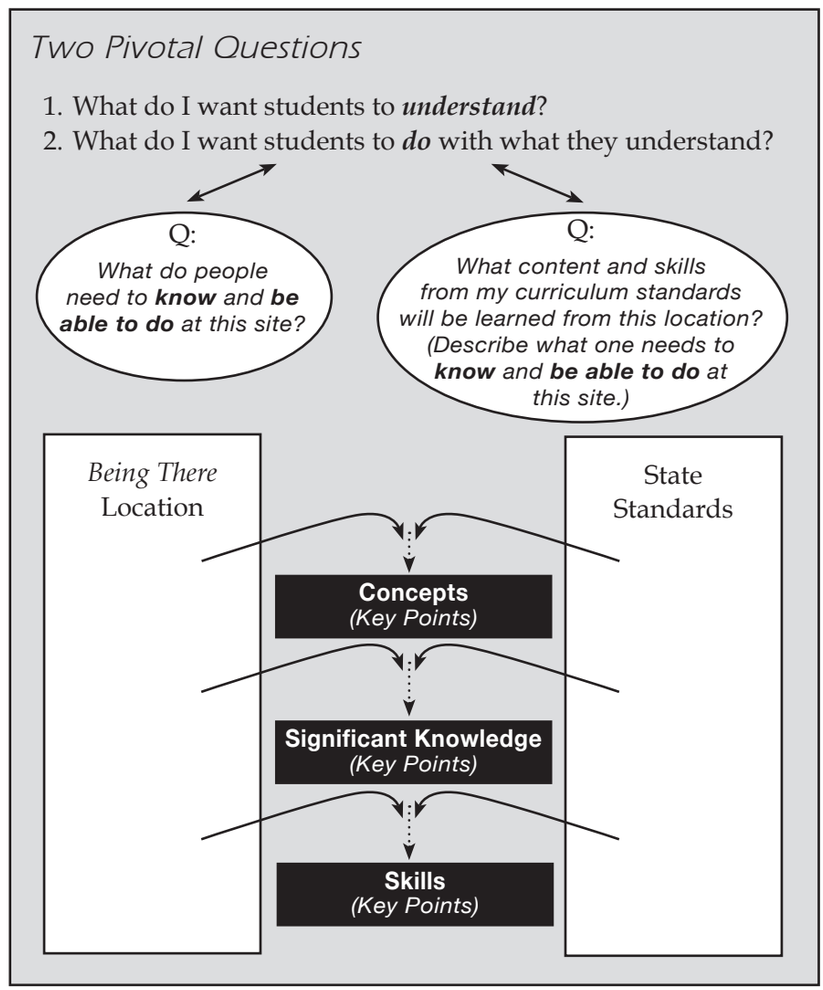


Figure 1A

Some readers may believe that their district doesn't allow money for field trips. We're not talking about field trips or end-of-year travel rewards. We are talking about study trips designed in accordance with brain research findings about how the human brain learns. Is there a difference? You bet! Is it doable? Affordable? Absolutely, if we choose

locations near the school that we and our students can revisit frequently by walking or by taking a short ride on public transportation.

Are we talking about ignoring state standards? Absolutely not. Standards adopted by the district tell us what we as teachers are expected to teach our students. We owe our students a curriculum with no gaps and no repetitions as they progress from grade to grade. Curriculum standards, be they district adopted, state driven, or school generated, are an essential foundation for good curriculum planning at the classroom level.

Are we talking about throwing away textbooks? No. But we are suggesting that textbooks be used as one of many resources, not as the curriculum and paramount instructional tool.

Anchoring curriculum in real-life locations gives students clear pictures of what we want them to understand and what we want them to do with what they understand because they can see how and when people use such knowledge and skills. The richness of these pictures also allows students to make connections both to other locations and among other content areas.

Examples of Engaging Being There *Locations*

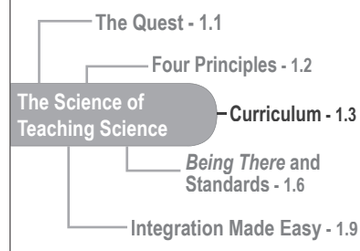
Look for sites that are immediately accessible—a walking trip of 15 minutes or less. First, look for sites on campus, such as the playground, cafeteria, bus barn, or maintenance center. Next, branch out into the neighborhoods within walking distance. Then, look for sites that can be reached by inexpensive public transportation.

Be creative. The most intriguing study trips are often the ones to locations right under our noses—locations where we have gone innumerable times but never thought to take a behind-the-scenes look, such as grocery stores, malls, our own school cafeteria or bus system.

Examples of *being there* locations[11] include:

Kindergarten — Schoolyard, backyard of a nearby home (for examples of the natural world and relevant hobbies), nearby pond, creek, or man-made pond on the school grounds, nearby park or empty lot, pet store, and animals living in or visiting the classroom and so forth.

First Grade — Any of the above locations, especially underground aspects of those locations, local habitats that are rich in animal and plant life, farms, nearby gardens (school Lifelab or nearby backyard), larger bodies of water such as lakes, rivers, ocean, and a zoo or aquarium.



MARY FROGGINS

Participation in being there *experiences activates many of our 20 senses, which in turn creates physical changes in the brain and allows for greater connections when studying the material.*

There are at least 20 senses:

- *Sight*
- *Hearing*
- *Touch*
- *Taste*
- *Smell*
- *Balance*
- *Vestibular*
- *Temperature*
- *Pain*
- *Eidetic imagery*
- *Magnetic*
- *Infrared*
- *Ultraviolet*
- *Ionic*
- *Vomeronasal*
- *Proximal*
- *Electrical*
- *Barometric*
- *Proprioception*
- *Geogravimetric*

See page 10.6 for an example of the 20 senses activated by a being there *experience.*

Second Grade — Any of the above locations plus natural history museums, taxidermy shops, construction sites and repair shops where a variety of tools are used, local businesses, and city agencies and resources such as police, fire, hospitals, and medical clinics.

Third Grade — Any of the above locations plus nearby road cuts that expose changes in landscape, before and after a flood or earthquake, recycling operations from pick up to remanufacturing to resale, and lots of neighborhood illustrations of life cycles, machines, and so forth. Also, community landmarks, businesses (grocery stores, malls, mom-and-pop stores of any kind). And don't forget observation of daily weather and the nighttime sky.

Fourth Grade — Select four or five complex ecosystems such as a nearby creek, slough, marsh, tide pool, lake, forest, or biodiverse park or backyard garden. Also have **students create and maintain as many** habitats in the classroom and schoolyard as possible, e.g., the Salmanoid project hatching salmon, a pond with all its inhabitants. What is learned in-depth there can then be extended through numerous being there experiences in varying ecosystems. Also include a state historical site or its replication that parallels your state history curriculum.

Fifth Grade — Fortunately, systems are everywhere, so start with those right under your students' noses: school transportation systems, school food systems (including where food comes from and where the leftovers go), schoolyards, local gardens and parks, telephone company, television/radio stations, a nearby creek or river, water treatment plants, car repair shops, malls, city/county bus systems, and theme parks such as Sea World, Great America, Boardwalk, Disneyworld, and Epcot. Include sites of national historical significance that illustrate concepts from your state stanards.

Sixth Grade — Any of the above observed with change and constancy of systems in mind, such as yards in the neighborhood whose growth is old and diverse, biodiverse city and state parks, waste and water treatment plants, health clinics, locations of airplane and satellite photos that illustrate change and constancy, recent cuts in hillsides due to highway building or major real estate development, agricultural fields, local manufacturing plants, local engineering firms and biotech labs, human-made systems such as a school campus or a mall with its heat/air system, water and electrical systems, and so forth, plus family homes or condos (examples of energy efficient and inefficient systems).

BRINGING TOGETHER BEING THERE LOCATIONS AND STATE/DISTRICT CURRICULUM STANDARDS

Just as a magnet attracts metal shards, a *being there* experience[12] helps attract important concepts and skills from your state standards or district-adopted curriculum and clump them into meaningful chunks. At this stage of your implementation, allow this magnetic quality of *being there* locations to do your curriculum integration and development work for you. Rather than trying to chase down various curriculum pieces, allow the intrinsically interesting aspects of the *being there* location and the most important points from your curriculum standards to simply pull together, creating a natural fit of related patterns. Make it fun. Give yourself the best chance at succeeding.

The answers to the two pivotal questions asked on the Curriculum Overview, Figure 1A, help you evaluate a potential *being there* location in relationship to your curriculum standards. Your answers also help create a basis for authentic assessment based on the real-life standards and expectations for what a capable person should understand and be able to do at this location.

Development of bodybrain-compatible curriculum requires an eye for the practical and lots of common sense; it's not a theoretical exercise.

Choosing a physical location as the anchor for curriculum is critical to creating a bodybrain-compatible learning environment for several reasons:

- The best way to ensure that students quickly grasp an accurate and comprehensive understanding of the concepts and skills of the curriculum is to allow them to experience those concepts in their real-world contexts.
- Once students understand concepts in one location, they can generalize them to other locations and use them to make predictions about events past and future. This speeds up and deepens the pace of future learning.
- Each of us must understand how our community works in order to become an informed citizen.

BRINGING TOGETHER *BEING THERE* LOCATIONS AND STATE/DISTRICT CURRICULUM STANDARDS

Guidelines for Selecting Being There *Locations*

Selecting physical locations upon which to build your curriculum is the most critical curricular decision you will make for the year. Like any builder, choose your site with care. The more solid the foundation, the more empowering your curriculum can be.

Before selecting a physical location, do your homework. Think through the following steps.

Step 1—Analyze the Potential of a Site to Teach What Your Students Need to Learn. Let the world integrate your curriculum naturally. For example, consider the common grocery store. Been there a million times? Of course. But have you ever been behind the scenes and looked at it from a business perspective? Would you be amazed to discover that the typical profit margin for grocery stores is two to three cents on the dollar? Ever wonder how many items change price? How often? And just where does this stuff come from anyway? Grown in the United States? Imported from a country with far less stringent environmental safeguards? The possibilities for study are unlimited: profits and losses, employer-employee relationships, the demographics of the clientele and producers, legal restrictions, health inspections, competition, energy costs, OSHA (Occupational Safety and Health Administration) requirements, and so forth.

After your preliminary match of state standards to the concepts best illustrated at the *being there* site, go visit the location.

Step 2—Visit the Site. Go to the location; look with new eyes. Pretend you've never been there before. Get curious! Look everything over from a fresh perspective. Look behind the scenes. Imagine what others see. What do they need to know to competently perform their roles as seller, buyer; service provider, service recipient; guide, visitor; host, guest; and employer, employee? What do visitors need to know to get the best value for their dollar, to make the wisest decisions, to avoid being taken advantage of, or to enjoy it most fully?

Be sure you take time to interview people—those who create the environment (employees and owners) and those who come to use or enjoy (clients, customers, and sightseers). Skip past the knowledge and comprehension questions of Bloom's Taxonomy. Dive right into the levels of application, analysis, evaluation, and synthesis. That's where the fun and engagement are! Ask the interviewees why they choose to work or shop here. What about this place makes them proud to work or visit here?

Always put yourself in your students' shoes. What is gripping about this location? What would bring you back again and again?

MARY FROGGINS

Many will think that basing science curriculum in being there *locations and going on study trips to visit them is a foolish idea because it's too difficult, too costly, can't be done because of insurance and liability risks, and is just too foolish to contemplate. However, I believe that the ultimate foolishness is doing what we've always done and expecting a different result.*

The United States will continue to lag behind industrial nations until it decides to commit itself to using science to teach science—until we commit to using what we now know from brain research about how the human brain learns.

The readers of this book stand at a crossroads. Which path will you choose?

Step 3—Expand Your Knowledge Base. Solid curriculum can't be developed from information off the top of one's head; also, our typical curriculum tools are limited. For example, state standards and district curriculum offer an outline and textbooks provide superficial information in summary form. Expect to become a learner. Open yourself up to the joy of discovery. Don't expect to have all the answers. Long gone is the era when what you knew by age 25 would carry you through a lifetime. Learning how to learn and learning to embrace the necessity for learning with enjoyment are the demands of our time. Model this and let your excitement and passion transfer to your students.

Pursue concepts that you believe will allow students to unlock meaning in other settings. Ask yourself several questions: What can be generalized and what can be used to predict events or happenings in other locations? From the students' point of view, what's useful? What are the most empowering concepts and skills you can help them understand?

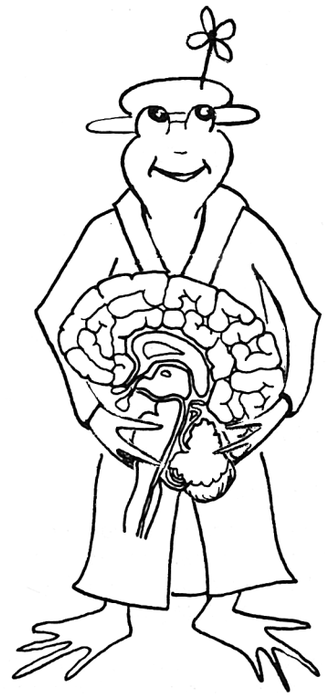
To create an immersion environment in your classroom to replicate the *being there* location, expect to have at least 50 resources in your room, such as books (e.g., Eye Witness, Usbourne series), magazines, print of all kinds written at a range of reading levels (including children's books that provide clear explanations and lots of visuals), plus multimedia options which capitalize on today's technologies (Internet, DVDs, encyclopedias, and so forth). And, very importantly, real things for hands-on exploration.

Step 4—Revisit Your Curriculum. However small or large this chunk of curriculum for the *being there* experience, is it as conceptual as you can make it? Have you prioritized the content so students will have time to understand and learn to apply the most important concepts, significant knowledge, and skills? Are your curriculum choices solid and acceptable to your supervisors? Can you explain them thoroughly to the parents? If so, you are ready to begin developing key points and inquiries.

For an in-depth discussion of how to plan, conduct, and follow up on a *being there* study trip, see Appendix A.

INTEGRATION MADE EASY

Look out the window: Science is everywhere we look, the results of history and social interaction are unavoidable, the arts are everywhere we turn, and all are going on together. Basing your curriculum in *being there* locations makes integration easy and natural; simply let your curriculum match the world we see when we look out the window, walk down the street, and window-shop in the mall.



MARY FROGGINS

This is an exciting time to be in education. The same kind of scientific endeavors that put man on the moon 50 years ago, and recently focused on how the brain operates, has rewritten our assumptions, about how the human brain learns.

It is up to us to demand that our schools use that information to transform our public schools.

Integrating Subject Content

If you're still on the fence, not yet ready to base your curriculum in *being there* locations, consider this: *Being there* locations are the great mixer—blending together subject areas and skills in natural and engaging ways. Basic skills—universally essential—can be taught using any location where they are used routinely.

Almost any mixture of natural and man–made settings will demonstrate the concepts, significant knowledge, and skills from your state standards.

History/Social Studies. Just add people to your location and you will have a window through which to view human nature past, present, or future.

Mathematics. Any location drips with numbers; all you have to do is decide what math functions and concepts you want to apply to those numbers.

Start with the obvious—how far, how long, how tall, how wide, how much, how many, what volume, what angle, which direction, how many years since, how much per square foot or per square mile, and so forth. Keep a running list of numerical data inherent in each *being there* location. Have students use data from these lists instead of those from worksheets. This allows them to create their own problems, the answers to which deepen their understanding and application of the content they are learning. Get real . . . show practical applications of geometry and algebra and more.

Reading, Writing, and Language Development. *Being there* locations offer students something real to read about and a real audience to write to. Provide the opportunity for students to communicate their discoveries and thank resource people who helped them learn. Provide a means to journal what is discovered, or compose an article to submit to the school or class newsletter or, better yet, the local newspaper.

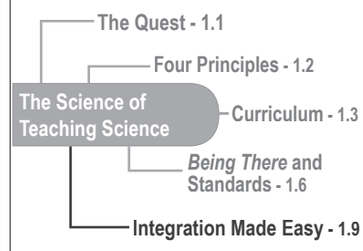
The Arts. Wherever there are people, there is art—clothing, marketing materials, interior design, architecture, paintings, cultural expressions, and more. Give students the option to sketch some of the objects they notice. Music is everywhere. Pay close attention ot rhythm and sound, both indoors and out. Analyze what is heard. What mood does it induce? Identify which instruments or objects created the sounds.

Assessment

Anchoring curriculum content in the real world also allows us to develop assessment that mirrors performance standards that students

and teachers encounter in their everyday lives. For example, we write a letter with perfect grammar and spelling because we want a real person to take our opinion seriously; we want to calculate math problems accurately when the answers have an impact on our personal lives.

For a discussion about how to make assessment bodybrain-compatible for students and meaningful and useful to teachers, see Chapter 7: Assessment.



HEADS UP

This chapter, merely a heads up for the rest of this book, provides an outline for information gathering throughout your journey through these pages. Although we have placed the discussion about how the brain learns in Chapters 9-13, the science of teaching science should be at the core of every curriculum- and instruction-related question you encounter in your teaching day. ***We strongly recommend you read Chapters 9 through 13 before you continue.***

END NOTES

1 For a discussion of the scientific thinking processes, see Chapter 5.

2 The brain research for these four principles emerged as early as the 1970s. Subsequent research, which has been extensive, has validated and expanded these summaries.

3 Marian Diamond, a professor of anatomy at Berkeley for over 30 years and pioneer brain researcher, conducted numerous lines of research into the effect of the environment and hormones on the forebrain. Her ground breaking work in the 1970s and 1980s studying the impact of enriched and impoverished environments culminated in her "enrichment theory." Enrichment theory should be read by all teachers, administrators, and parents. A layman's description can be found in *Magic Trees of the Mind: How to Nurture Your Child's Intelligence, Creativity, and Healthy Emotions from Birth Through Adolescence* by Marian Diamond and Janet Hopson (New York: A Dutton Book, 1998). Also see Diamond's most recent research project, Enrichment in Action in a Cambodian Orphanage.

4 Research in these areas has emerged from many different lines of research. When stitched together, it's indeed compelling. See the work of Carla Hannaford, Elkhonon Goldberg, John Ratey, and John Medina, among others. See the bibliography for a list of their books.

5 The most readable, and eye-popping, account of the power and omnipresent processing of emotion is Candace Pert's work; see her *Molecules of Emotion: Why You Feel the Way You Feel* (New York: Scribner, 1997), 139-140, 178.

6 Robert Sylwester has synthesized a good deal of research into a very useful and memorable phrase: "Emotion drives attention, attention drives learning/memory/problem-solving/just about everything else." See Sylwester's "The Role of The Arts in Brain Development and Maintenance," 6. Available at http://ode.state.or.us/teachlearn/subjects/arts/resources/ rolesbraindevelopment.pdf. Also see his lastest book, *A Child's Brain: The Need for Nurture* (Thousand Oaks, CA: Corwin, 2010.

7 The work of three easy-to-read authors provide compelling information about this concept: Elkhonon Goldberg, John Ratey, and Carla Hanaford. An especially good source is *Spark: The Revolutionary New Science of Exercise and the Brain* by John Ratey (New York: Little, Brown and Company, 2008), 53.

8 Howard Gardner's theory of intelligence is widely received and well ensconced; it's also our choice for the Highly Effective Education (*HET)* model. We use Gardner's work because it rings with our experiences with children and adults and because it so readily lends itself to practical applications when developing curriculum and selecting instructional strategies. See Gardner's *Frames of Mind: The Theory of Multiple Intelligences, Revised* (New York: Basic Books, Inc., 2004), xxiii-xxxiii.

9 Howard Gardner's definition of intelligence is an extremely useful alternative to the standard IQ number. See *Frames of Mind,* xxiv.

10 Leslie Hart was a man ahead of his time. From his impressive personal library of firsthand research studies, he was the first to understand that the brain is a pattern seeker that builds programs for using what it understands. With each succeeding book he wrote about how the brain learns, and how schools ignore this fact, Leslie Hart continued synthesizing his conceptualization of the two fundamental brain concepts: pattern detection and program building. His initial definition was simple and to the point:

The process of learning is the extraction, from confusion, of meaningful patterns

and

Learning is the acquisition of useful programs.

Since the late 1960s, this view of learning has become standard vocabulary. Patterns and programs is an accurate and useful description of learning. See Hart's *Human Brain and Human Learning,* 3rd ed. (Books for Educators, Black Diamond, WA, 2002), 117 and Chapters 7–10.

This conceptualization of learning is an extremely important contribution to the field of education because it's comprehensive enough to cover the wide range of practicalities that teachers, administrators, and parents face on a daily basis—from curriculum to instruction to assessment.

11 These recommended *being there* locations are excerpted from *Science Continuum of Concepts for Grades K-6,* 4th ed., by Karen D. Olsen (Black Diamond, WA: Books for Educators, 2010). Used with written permission of the author.

12 *Being there* experiences are not just activities, they are a key structure in the *HET* model. They are the base for localizing curriculum—bridging the gap between national and state standards and the prior experiences of your students. They're the key tool for delivering massive amounts of sensory input to spur learning.