

# Brain-(not) Based Education: Dangers of Misunderstanding and Misapplication of Neuroscience Research

Larry A. Alferink and Valeri Farmer-Dougan  
*Illinois State University*

Oversimplification or inappropriate interpretation of complex neuroscience research is widespread among curricula claiming that brain-based approaches are effective for improved learning and retention. We examine recent curricula claiming to be based on neuroscience research, discuss the implications of such misinterpretation for special education, how neuroscience actually supports many traditional teaching methods, and suggest ways to foster more accurate understanding of neuroscience research and its potential for application in the special education classroom.

Progress in neuroscience over the past several decades has led to a greater understanding of how the brain functions as a child learns. Thus, it is not surprising that educators have sought to incorporate neuroscience research findings into the special education classroom. Indeed, several authors have indicated these neuroscience developments represent a “new paradigm” in not only special education but regular education as well (Jensen, 2008). Unfortunately, some of these efforts may be premature, based on conclusions that go beyond existing data, or are simply not supported by current evidence. Use of emerging data on brain lateralization, emphasis on particular critical periods for brain development, and misinterpretation of synaptic changes that occur during learning have resulted in teaching strategies that are ineffective.

Neuroscience research can certainly help special educators understand brain mechanisms that may underlie similarities and differences in their students, and may provide methods for the early diagnosis of learning difficulties (Gabrieli, 2009). However, while such research is certainly important, there remains a question about how it has directly led to *new* advances in classroom practices. Thus, it is critical to understand how neuroscience may support good educational practices while at the same time temper the excitement with an understanding of

---

Correspondence should be addressed to Larry A. Alferink, Department of Psychology, Campus Box 4620, Normal, Illinois 61790-4620. E-mail: alferink@ilstu.edu; or Valeri Farmer-Dougan, Department of Psychology, Campus Box 4620, Normal, Illinois 61790-4620. E-mail: vfdouga@ilstu.edu

the limitations of neuroscience applications to special education. The current article critiques four purported neuroscience-based practices: right vs. left brain teaching, educational practices that emphasize early brain development and early critical periods, brain-based instruction, and teaching to individual multiple intelligences. Importantly, the current article also demonstrates how neuroscience may be used to support both traditional and newer instructional practices.

### “RIGHT” VS. “LEFT” BRAIN INSTRUCTION

The main hypothesis purported by proponents of right- versus left-brain teaching is that the different brain hemispheres control different academic functions (Jensen, 2008). Indeed, a wide literature clearly demonstrates lateralization of function across the two hemispheres, with language processing primarily a left-hemisphere task, while the right hemisphere controls more spatial-based tasks (Garrett, 2009). However, the leap from data on lateralization of task processing to educational approaches preferentially targeting one hemisphere is a vast one and may not be appropriate. Indeed, it is imperative to understand that the educational approaches that emerged from the lateralization literature were based on work studying individuals with a severed corpus callosum. Typically, these were individuals who experienced severe and uncontrollable seizures, and the corpus callosum was severed in order to reduce or eliminate the seizures (Gazzaniga & Sperry, 1967). That is, these individuals had non-typical brain function both prior to and following the split-brain surgery. While there is little doubt that severing of the corpus callosum in these individuals provided a unique opportunity for studying the functions of the left and right hemisphere separate from one another (Gazzaniga & Sperry, 1967; Gazzaniga, 1972), it must be remembered that the study participants most likely had brain functions that significantly differed from typical individuals. A brief description of this early research clarifies this point.

The corpus callosum is the band of tissue that connects the two cerebral hemispheres and allows cross-communication. Patients who underwent surgery to sever the corpus callosum appeared to function relatively normally following surgery but significant differences did emerge: Testing showed that subjects would name objects that they could “see” with their left hemisphere but would only point to and not name objects they could “see” with their right hemisphere (Gazzaniga, 1972). This suggested that each hemisphere had specialized functions, with the left hemisphere linked to language and the right to spatial functions. Neuroscience research has continued to support lateralization of function (Garrett, 2009; Freeberg, 2006), but it is important to note that lateralized functions are integrated and occur simultaneously in most, if not all, individuals with an intact corpus callosum (Freeberg, 2006). That is, information is processed differently but simultaneously by both hemispheres. Thus, it is neither accurate nor realistic to believe that individuals may selectively use one hemisphere of their brain at a time for separate academic functions. Instructional activities that emphasize only the left brain while ignoring the right brain are not possible.

Unfortunately, poor understanding of the lateralization literature has led to the development of left-brain/right-brain based curricula. The first attempts to link split-brain research to instruction were to teach students to read, study, and remember more effectively (Buzan, 1976) and to teach art students to draw by using exercises to engage the right hemisphere

(Edwards, 1979). According to right- versus left-brain theorists, the “left-brain” is said to be the “logical” hemisphere, concerned with language and analysis, while the “right-brain” is said to be the “intuitive” hemisphere concerned with spatial patterns and creativity (Sousa, 2001). “Left-brain” individuals are said to be verbal, analytical, and good problem solvers, while “right-brain” individuals are said to be good at art and mathematics. Thus, according to brain-based learning theorists, teachers should teach to each specific hemisphere during adapted lessons. To teach to the left hemisphere, teachers have students engage in reading and writing, while right hemisphere-oriented lessons have students create visual representations of concepts (Sousa, 2001).

The problem, however, is that language and spatial information is processed differently but *simultaneously* by the two hemispheres. It is highly improbable, then, that any given lesson, regardless of analytic or spatial type stimulates activation of only one hemisphere (Chabris & Kosslyn, 1998). More important, learners need to develop both sets of skills, and in particular, students must learn to integrate both analytic and spatial learning tasks.

The importance of understanding this distinction becomes even more critical for teachers of special education students. Teaching strategies for instructing students who may have brain impairments or sensory deficits (e.g., hearing, vision loss) must capitalize on the capabilities and strengths the students *do* have. Focusing on inappropriate lessons that ineffectively target one hemisphere over another may take away attention from instructive practices that *do* help students integrate hemispheric processing. For example, many students with learning disabilities have been shown to have differences or deficits in the cerebellum or basal ganglia (Farmer-Dougan, Wise, & Heidenreich, in press). Most individuals process visual information such as eye tracking or other motor habits via these lower brain structures, freeing the neocortical areas for higher cognitive tasks. For students with learning disabilities, differences in the cerebellum or basal ganglia result in increased load on the higher cortical brain structures, such that these students use neocortical structures for not only the higher cognitive behaviors, but also the lower motoric or visual tracking behaviors. Finding ways to increase or maximize efficient processing at the neocortical level, then, is critical if these students are to learn efficiently. Unfortunately, hemisphere-specific instruction is not a method for improving neocortical processing.

## THE BRAIN AND CRITICAL PERIODS

A large body of research has demonstrated age-related changes in the brain (Casey, Tottenham, Liston, & Durston, 2005; Courchesne et al., 2001; Green & Bavelier, 2008; Hubel & Weisel, 1979). A period of very rapid synaptic development occurs from birth to around age three, such that the brains of very young children become densely packed with neural circuits. These high-density levels continue until about age ten. After age ten, synaptic pruning occurs and density declines to adult growth levels by around age fifteen (Bruer, 1999a, 1999b). Brain volume increases until around age 14, then shrinks over the remainder of the lifespan (Courchesne et al., 2000). Chugani, Phelps, and Mazziotta (1987) found that glucose metabolism in the brain increases from about age 4 to age 10 and then declines to adult levels at around age 16. Further, evidence indicates that brains of young children use more glucose than adults, with glucose uptake levels following a similar time course as synaptic density. These developmental changes have been well documented.

Educational theorists have extrapolated this evidence to suggest a critical period for learning in general (Bruer, 1999b), suggesting that it is during the early school years, during ages of approximately 4 to 10, when children may learn material quickly and easily (Jensen, 1998; Kotulak, 1996). Based on age-related changes in synaptic density, glucose uptake, and changes in the magnitude of neurotransmitter release, Shore (1997) suggested that the brains of young children are primed for learning. Basic research evidence does support the existence of critical periods, for example in the development of vision (Bruer, 1999b) or in learning specific tasks such as language (Bruer, 1999b; Kotulak, 1996; Sousa, 2001). Unfortunately, authors such as Chugani (1998) or Sousa (1998) suggested that the early childhood period is *the* critical period when learning is *most* important, to the point that later learning is neglected. That is, data on brain development have been interpreted as suggesting that the early childhood period requires greater educational emphasis than other time periods across the lifespan.

Interestingly, there is little, if any, evidence linking either the number of synapses or glucose uptake as direct causal factors for rate of general learning, or indicating that five year olds are better at learning than older students (Bruer, 1999a). Instead, the data suggest changes in the *type* of learning across the lifespan. Younger children learn vast amounts of information, but it is not until adolescence that abilities such as critical thinking, integration, or abstract reasoning develop (Baird, Gruber, Fein, et al., 1999; Sowell, Thompson, Holmes, et al., 1999). Thus, while there is no doubt that significant changes occur in the brain during early childhood, that young children may be uniquely interested in learning, or that young children appear to learn quickly, there is little evidence to suggest that this period is *the* most critical.

Such a narrow interpretation of the learning window has critical implications for the special educator. As a matter of educational policy, this implies that resources should be shifted from funding education of older children to an emphasis on preschool and elementary education. This however, uses faulty logic. Early learning *is* important, but it is important because it *sets the basis* for later learning, not because the window of opportunity closes. Individuals who fail to gain basic knowledge or fail at acquiring fundamental basic skills at early ages will not have the critical components required to engage in higher cognitive processes. But, as special educators know, children who do not learn to read by grade three can still learn to read in adolescence, and adults can certainly learn numerical skills typically learned early in childhood (Bruer, 1999b). Further, critical thinking and analytic skills appear to have their own critical period of development in later childhood and attempts to teach such skills in early childhood have met with failure (Bosse, 1995; Schoenfeld, 2006).

For the child with cognitive or physical disabilities who may take longer to acquire basic sets of information, focus must remain across the child's entire educational career. Given that the special education student begins learning at a deficit or delay, early intervention is critical, especially in the case of autism spectrum disorders or certain learning disabilities. Identifying and intervening early for problems with phonemic awareness linked to dyslexia, critical for future skill in reading before rather than after reading difficulties have been identified, may have significant implications for future reading ability (Gabrieli, 2009). But, this is because early intervention allows proper sequencing of skill development and remediation of learning problems, which may snowball into bigger learning difficulties rather than age per se. Neuroscience may point the way to neurological tests for at-risk children indicating the need for early intervention (Gabrieli, 2009).

## BRAIN-BASED EDUCATION

Another attempt to integrate neuroscience into the classroom is brain-based (Jensen, 2008; Laster, 2008), brain-compatible (Ronis, 2007; Tate, 2003, 2004, 2005), brain-friendly (Biller, 2003; Perez, 2008), or brain-targeted (Hardiman, 2003) instructional approaches. Tate (2003) provided an example of the brain-compatible approach, suggesting that some educational practices “grow dendrites” and others do not. Obviously, a significant goal of any teacher, but particularly the teacher of students with special needs, is to help a child learn. But, “growing dendrites” should be a goal *only* if growing dendrites results in information acquisition, development of critical thinking skills, and increased ability for problem solving. This is where the applications of neuroscience may have jumped beyond the data.

According to brain compatible instruction, growing dendrites is a critical goal for educators, and proponents of this approach emphasize that only some forms of instruction are brain compatible. Indeed, these theorists suggest that teaching practices such as drill, practice, and memorization do not “grow dendrites.” They purport that instructional methods that are brain compatible must follow constructivist approaches that involve open-ended, process-based, and learner-centered activities. However, Tate (2003) provided no data indicating that the methods she disparaged do not in fact grow dendrites, or that her preferred methods do. Further, she provided no evidence that it is dendritic growth that is most critical for learning and education.

In fact, there is little if any neuroscience data indicating that students who grow more dendrites are necessarily more academically competent. “Growing dendrites” is, at best, an incomplete picture of neural changes over time and inaccurate as a description of the neural mechanism for learning. Indeed, the literature suggests that it is long-term potentiation that is critical for learning and memory formation (Freeberg, 2006; Garrett, 2008). Long-term potentiation is an increase in synaptic strength that allows for the development of neural circuits that underlie memory and cognitive processing. It is not necessarily having more dendrites that is critical but the increased number and strength of connections between neurons within the newly formed neural circuits.

Focus, then, must be two-fold. First is the focus on ensuring appropriate environmental and nutritional conditions that stimulate dendritic growth in infancy and early childhood. But second must be emphasis on improving the strength of particular neural circuits, not simply on the overall growth of dendrites. Most interestingly, instructional activities such as memorization, mastery learning, and repetition-based activities appear to best strengthen and solidify the formation and maintenance of these circuits (Garrett, 2009; Freeberg, 2006). Data strongly support the use of precision teaching, mastery learning approaches, and programs such as DISTAR or direct instruction (Kirschner, Sweller, & Clark, 2006; Mills, Cole, Jenkins, & Dale, 2002; Ryder, Burton, & Silberg, 2006; Swanson & Sachse-Lee, 2000). In addition, programs that focus on mastery, including applied behavior analysis and evidence-based approaches such as Treatment and Education of Autistic and related Communication Handicapped Children (TEACCH) (Mesibov & Shepler, 2004; Panerai, Ferrante, & Zingale, 2002), have been shown to elicit better educational growth than instructional practices, which focus on open-ended or child-guided instructional practices. Thus, given the data from neuroscience combined with evidence-based practices used in special education, special educators can be assured that they are, indeed, using brain-based educational instruction. Mastery-based programs that focus on fluency and repetition are most likely to increase both better traditional learning

outcomes and produce neural circuits critical for both educational activities and transfer to daily living skills.

### BRAIN-COMPATIBLE TEACHING, LEARNING STYLES, AND MULTIPLE INTELLIGENCES

Special educators strive to arrange their classrooms to elicit the best learning outcomes. According to authors such as Sprenger (1999), arrangements that are brain compatible should elicit the best learning. More specifically, Sprenger and others suggested that this can be accomplished by teaching to different learning styles or a child's multiple intelligences (Ronis, 2007; Sprenger, 1999; Tate, 2003, 2004, 2005). These authors suggested that students have distinct multiple forms of intelligence (Gardner, 1983), and learn best through sensory or learning-style modalities that are compatible with their individual intelligence profiles. Thus, the best way to teach is to teach to the child's preferred modality. Unfortunately, the data do not support such an approach either in general education or for children with disabilities (e.g., Dembo & Howard, 2007; Kratzig & Arbuthnott, 2006).

Teaching to a specific strength in the absence of teaching to a weakness may be a disservice to students. Students are said to be visual learners who learn best if the teacher writes things on the board and uses a high degree of visual images in their teaching, while others are said to be auditory learners who learn best if they can listen to a complex concept being explained. However, a disability may limit the type of information a child may access, and in fact, the disability may even conflict with the child's preferred modality. There is no doubt a child with low-vision perceives the world in a very different way than a child with hearing loss, such that the child develops a preference for auditory material. In contrast, a child may show a preference for auditory information, but have hearing loss that impacts how well auditory information can be processed. Thus, understanding the distinction between learning strategies versus learning preferences is even more critical when teaching children with limited physical or cognitive abilities, as these children must gain multiple learning strategies within their learning skills repertoire.

Special educators do strive to adapt instructional curriculums to the individualized needs of their students—that is the very core of special education. However, focusing on a particular “style” rather than a broad set of learning skill sets may be doing children a disservice. Indeed, it is of questionable appropriateness to only teach to a child's preference. In physical education, a child may prefer to kick the ball with the right foot rather than the left. However, if that child is to become a skilled ball handler, it is important that the child learns to kick with either foot, not just their preferred one. Developing skills with only the stronger or preferred limb would not develop the “whole child.” The same is true for cognitive tasks: A child who has multiple strategies available can be taught that when one strategy is not working to switch to another, even if he or she doesn't “like it best.” Thus, it may be more accurate to strive for learning across a variety of “learning styles and preferences.” The larger the child's inventory of learning strategies, the more likely the child is to learn across environmental settings.

A second problem with brain-based or specific intelligence-based instruction is one of measurement. While it is relatively easy to develop measures that assess a student's *preferred* style of learning, identifying and then teaching preferentially to a particular modality at the exclusion of others is difficult at best. Regardless, several testing inventories and instructional

interventions claim to do just that (Dunn, 1987; Keefe, 1982; Ronis, 2007). Thus a critical question is whether the teaching to “special modalities” is really doing what it says it is doing. Indeed, teaching to a particular “learning style” often involves presentation of information across many modalities. If anything, a child who is taught in a classroom using a learning styles approach is *more likely*, not less, to interact with a multimodal rather than single modality approach, and thus will learn to process information across several, not one, sensory modality. Brain-compatibility approaches, then, may actually be doing the opposite of their purported goal: Developing strengths across multiple modalities to ensure that children learn to use many modalities of sensory input. When framed in this way, the teaching methods begin to sound much like “traditional” special education interventions: Focus on the needs of the child by strengthening weaknesses and streamlining the strengths a child may have.

### THE PROBLEM WITH WEAK EVIDENCE AND OVER- OR MIS-INTERPRETATION

Certainly our understanding of how neurons work, the role of neurotransmitters, and data showing correlations between brain activity and academic tasks has provided distinct clues into how a child learns. The problem, then, is not with the neuroscience data themselves, but how authors of these purported brain-based approaches appear to have erroneously filled in the missing research gaps. Thus, the problem is not with what neuroscientists and educators know, but with what they think they know. This “filling-in-the-gaps” results from a variety of factors including misunderstanding of the research, misinterpretation or overinterpretation of the data, and a belief in claims that are unsubstantiated or go beyond what the evidence supports.

Consider the example of neuroscience’s knowledge regarding brain cells and synaptic transmission. Unquestionably, advances in the understanding of neurons in general and glial cells in particular have occurred in recent decades. Likewise, our understanding of neurotransmitters and synaptic transmission has also increased tremendously. Thus, it is not surprising that many of the brain-based advocates describe the role of the neuron, glial cells, the synapse, and neurotransmitters (Biller, 2003; Hardiman, 2003; Jensen, 1998, 2008; Sprenger, 1999). Yet, these authors are unable to identify a single educational practice recommended by their theories that was developed *directly* because of these advances. Even Hart (1983) admitted that the neuroscientists do not know how or whether the number of neurons is linked to the ability to learn or to intelligence. Thus, the relationship between the “quality” of the brain, as determined by the number of neurons, to the scope of what students can learn or how they should learn it remains unknown. As discussed above, recent neuroscience evidence supports traditional teaching methods such as repetition, elaborative rehearsal and mastery, and not open-ended or problem-solving approaches.

Second, many brain-based learning theorists devote at least some effort to explaining the different anatomical structures of the brain and tying these to instructional techniques. Consider the example of the amygdala, a structure within the limbic system linked to emotion. Several authors noted that when individuals experience threat the information reaches the amygdala prior to being processed by the neocortex, supposedly allowing for potential hijacking of the response (Hardiman, 2003; Hart 1983; Zull, 2002). Hart suggests that this means that the “absence of threat is essential to effective instruction.” However, note that this observation did

not originate with research about the amygdala but from direct observations of attempts to teach when students are experiencing threats. If anything, the research on the amygdala suggests that the amygdala does not act alone but in a cohesive manner with the prefrontal, or thinking, areas of the brain (Garrett, 2008). Note that in this case the physiological evidence strengthens and supports what educators have been doing rather than eliciting improved educational practices.

A third problem is in the type of data that emerge from neuroscience. Many brain-based educational theorists, in order to link the function of a brain region to a particular educational practice, have relied heavily on research involving brain scans. Such reliance may be problematic because neuroscience has not yet demonstrated the accuracy or meaning of some of these correlational measures (Logothetis, 2008; Poldrack, 2006). For example, Positron Emission Tomography (PET) scans presumably measure glucose uptake (Courchesne et al., 2000). However, glucose uptake is not measured directly, but is instead inferred by a complex series of assumptions regarding the presence of a radioactive substance such as radioactive water ( $\text{H}_2\text{O}^{15}$ ) and its relation to glucose. There is strong disagreement between neuroscientists as to whether radioactive water readily diffuses to areas of high metabolism, complicating the interpretation of PET scans (Uttal, 2001, 2005). Further, PET scans are difficult to obtain in children because of the need to inject a radioactive substance and are even more difficult to interpret. Thus, much of the data relies on special cases or cases involving rare or serious brain dysfunctions. Finally, the differences found between “typical” and “atypical” children may not be readily discernable and may be open to misinterpretation unless read by highly skilled neuroscientists. Consider the case of brain scans that appeared in *Newsweek* comparing PET scans of “normal” and “neglected” children. Since the scans looked different, these scans were picked up by child advocacy groups and others as having significant social policy implications. Unfortunately, these scans were withheld from publication in a peer-reviewed journal because they were not statistically different, even though it was “obvious” to the uncritical reader that they were (Bruer, 1999b).

Likewise, functional magnetic resonance imaging (fMRI) techniques require statistical comparison of noisy signals under control conditions when the subjects are assumed to not be engaging in the experimental task and experimental conditions when it is assumed that they are. The difference between the signals that result from this statistical analysis produces a brain scan that highlights various areas of the brain by averaging these differences across time between the two conditions and sometimes across individuals as well. It is important to understand that the difference threshold that is set by the experimenter determines how much of the brain is highlighted. If this difference threshold is set relatively low, many areas of the brain will be highlighted, indicating that many diffuse areas of the brain are working on the experimental task. If the difference threshold is set relatively high, very few areas of the brain will be highlighted, suggesting that the task is highly localized in a specific brain area. Ignoring the threshold levels when interpreting the data may result in failure to understand what the brain scan shows. Indeed, outcomes can be determined as much by this difference threshold as the experimental task (Uttal, 2001, 2005).

Finally, it is critical to understand that techniques such as PET scans and fMRI techniques simply correlate brain activity with behaviors such as solving a problem in algebra or reading a page (Epstein, 2008). Like all correlations, one *cannot* conclude that the brain activity *causes* the problem solving, or for that matter, that the reading or problem solving causes the localized brain activity, as both may be linked to other variables. The problem becomes more serious

when one compares brain scans from different categories of individuals. For example, Hardiman (2003) noted a study that compared children with ADHD and controls without this diagnosis. She noted that the study found “neuroanatomical differences that compromised the alerting and executive networks of the brain” and that “compromised automaticity” (p. 17). Drawing such causal linkages between differences in brain scans across individuals based on events that are presumably correlated requires a problematic logical leap. Her interpretation assumes that the concept of an executive network can be translated into an actual physical localized network; that ADHD children are a distinct population with distinctly different brains than typical children; that current diagnostics accurately categorize children as ADHD or typical; and that these differences translate into the need for different instructional strategies. While neuroscience research most certainly adds to the information regarding children with ADHD, neuroscientists are, at this point, unable to make definitive conclusions regarding how best to educate children with ADHD based on PET or MRI evidence.

## CONCLUSIONS

The problem with introducing untested or unsupported instructional strategies into the special education classroom is that these interventions, as shown above, may be based on misinterpretation or misunderstanding of the data. Yet, neuroscience research does, indeed, provide important information regarding how children learn and gives some important guidance towards best educational practices. However, rather than suggesting dramatic changes in instructional approaches, the data appear to support traditional practices in special education rather than significant changes in instructional approaches. For example, the research described above on the formation of memory through long-term potentiation strongly suggests that neural connections are strengthened through repetition or practice (Freeberg, 2006; Garrett, 2008; Hardiman, 2003). Note that the importance of practice and rehearsal has been known for more than a century, long before the process of long-term potentiation was identified (Ebbinghaus, 1913; Hebb, 1949; Thorndike, 1913). Likewise, the data suggest that formation of memories through neural consolidation works best if students have a number of short learning sessions separated over time, not single long sessions. Again, the advantages of spaced or distributed practice over massed practice have also been known for many decades (see Olson & Hergenbahn, 2009; Ebbinghaus, 1913). Neuroscience, in this case, reinforced these best practices by providing the data at the neural level that supported these methods.

Neuroscience research offers a means to understand how best practices may be changing and improving a child’s learning and his or her brain functioning. But, given the highly technical and sometimes confusing nature of the area, the literature can be highly confusing and difficult to navigate. Special educators must be careful to not give special status to a claim simply because the “brain” or “neuroscience” is invoked in the claim.

## REFERENCES

- Baird, A. A., Gruber, S. A., Fein, D. A., Maas, L. C., Steingard, R. J., Renshaw, P. F., Cohen, B. M., & Yurgelun-Todd, D. A. (1999). Functional magnetic resonance imaging of facial affect recognition in children and adolescents. *Journal of the American Academy of Child and Adolescent Psychiatry*, 38, 195–199.

- Billier, L. W. (2003). *Creating brain-friendly classrooms*. Lanham, MD: The Scarecrow Press.
- Bosse, M. J. (1995). The NCTM standards in light of the new math movement: A warning! *Journal of Mathematical Behavior, 14*, 171–201.
- Bruer, J. T. (1999a). In search of . . . Brain-Based Education. *Phi Delta Kappan, 80*, 646–657.
- Bruer, J. T. (1999b). *The myth of the first three years: A new understanding of early brain development and lifelong learning*. New York: The Free Press.
- Buzan T. (1976). *Use both sides of your brain*. New York: E.P. Dutton & Co.
- Casey, B. J., Tottenham, N., Liston, C., & Durston, S. (2005). Imaging the developing brain: What have we learned about cognitive development? *Trends in Cognitive Sciences, 9*, 104–110.
- Chabris, C. F., & Kosslyn, S. M. (1998). How do the cerebral hemispheres contribute to encoding spatial relations? *Current Directions in Psychological Science, 7*, 8–14.
- Chugani, H. T., Phelps, M. E., & Mazziotta, J. C. (1987). Positron emission tomography study of human brain functional development. *Annals of Neurology, 22*, 487–497.
- Chugani, H. T. (1998). Critical period of brain development: Studies of cerebral glucose utilization with PET. *Preventive Medicine, 27*, 184–188.
- Courchesne, E., Chisum, H. J., Townsend, J., Cowles, A., Covington, J., Egass, B., Harwood, M., Hinds, S., & Press, G. A. (2000). Normal brain development and aging: Quantitative analysis at in vivo MR imaging in healthy volunteers. *Radiology, 216*, 672–682.
- Dembo, M. H., & Howard, K. (2007). Advice about the use of learning styles: A major myth in education. *Journal of College Reading and Learning, 37*, 101–109.
- Dunn, R. (1987). Research on instructional environments: Implications for student achievement and attitudes. *Professional School Psychology, 2*, 43–52.
- Ebbinghaus, H. (1913). *Memory. A contribution to experimental psychology*. New York: Teachers College, Columbia University.
- Edwards, B. (1979). *Drawing on the right side of the brain: A course in enhancing creativity and artistic confidence*. Los Angeles, CA: J. P. Tarcher.
- Epstein, R. (2008). The truth about brain science. *Skeptical Inquirer, 32*(5), 32–33.
- Farmer-Dougan, V. A., Wise, L. M., & Heidenreich, B. A. (in press). Functional neuro-anatomy of structures of the hindbrain, midbrain, diencephalon and basal ganglia. In Andrew Davis (Ed.), *Handbook of pediatric neuropsychology*. New York: Springer Press.
- Freeberg, L. (2006). *Discovering biological psychology*. Belmont, CA: Wadsworth Cengage Learning.
- Gabrieli, J. D. E. (2009). Dyslexia: A new synergy between education and cognitive neuroscience. *Science, 324*, 233–356.
- Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences*. New York: Basic Books.
- Garrett, B. (2008). *Brain and behavior: An introduction to biological psychology, Second Edition*. Los Angeles, CA: Sage Publications.
- Gazzaniga, M. S., & Sperry, R. W. (1967). Language after section of the cerebral commissures. *Brain, 90*, 131–148.
- Gazzaniga, M. (1972). The split brain in man. In R. Held & W. Richards (Eds.), *Perception: Mechanism and models* (pp. 29–34). San Francisco, CA: W. H. Freeman.
- Green, C. S., & Bavelier, D. (2008). Exercising your brain: A review of human brain plasticity and training-induced learning. *Psychology and Aging, 23*, 692–701.
- Hardiman, M. M. (2003). *Connecting brain research with effective teaching: The brain-targeted teaching model*. Lanham, MD: The Scarecrow Press.
- Hart, L. A. (1983). *Human brain, human learning*. New York: Longman Press.
- Hebb, D. O. (1949). *The organization of behavior*. New York: Wiley-Interscience.
- Hubel, D. H., & Wiesel, T. N. (1979). Brain mechanisms of vision. *Scientific American, 24*, 150–62.
- Jensen, E. (1998). *Teaching with the brain in mind*. Alexandria, VA: Association for Supervision and Curriculum Development.
- Jensen, E. (2008). *Brain-based learning: The new paradigm, of teaching* (2nd ed.). Thousand Oaks, CA: Corwin Press.
- Keefe, J. W. (1982). Assessing student learning styles, an overview. In *Student learning styles and brain behavior*. Reston, VA. National Association of Secondary School Principals.
- Kirschner, P. A., Sweller, J., & Clark, R. E. (2006) Why minimal guidance during instruction does not work: an analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*, 75–86.

- Kotulak, R. (1996). *Inside the brain: Revolutionary discoveries of how the mind works*. Kansas City, MO: Andrews and McMeel.
- Kratzig, G. P., & Arbutnott, K. D. (2006). Perceptual learning style and learning proficiency: A test of the hypothesis. *Journal of Educational Psychology, 98*, 238–246.
- Laster, M. T. (2008). *Brain-based teaching for all subjects*. Lanham, MD: Rowman & Littlefield Education.
- Logothetis, N. K. (2008). What we can do and what we cannot do with fMRI. *Nature, 53*, 869–878.
- Mesibov, G. B., Shea, V., & Schopler, E. (2004). *The TEACCH approach to Autism Spectrum Disorders*. New York: Springer Press.
- Mills, P. E., Cole, K. N., Jenkins, J. R., & Dale, P. S. (2002). Early exposure to Direct Instruction and subsequent juvenile delinquency: A prospective examination. Exceptional curriculum models through age 15. *Early Childhood Research Quarterly, 1*, 15–45.
- Olson, M. H. & Hergenhahn, B. R. (2009). *An introduction to theories of learning* (8th ed.). Upper Saddle River, NJ: Prentice-Hall.
- Panerai, S., Ferrante, L., & Zingale, M. (2002). Benefits of the treatment and education of autistic and communication handicapped children (TEACCH) programme as compared with a non-specific approach. *Journal of Intellectual Disability Research, 46*, 318–27.
- Perez, K. (2008). *More than 100 brain-friendly tools and strategies for literacy instruction*. Thousand Oaks, CA: Corwin Press.
- Poldrack, R. A. (2006). Can cognitive processes be inferred from neuroimaging data? *Trends in Cognitive Science, 10*, 59–63.
- Ronis, D. L. (2007). *Brain-compatible assessments*. Thousand Oaks, CA: Corwin Press.
- Ryder, R. J., Burton, J. L., & Silberg, A. (2006). Longitudinal study of direct instruction effects from first through third grade. *Journal of Educational Research, 99*, 179–191.
- Schoenfeld, A. H. (2006). What doesn't work: The challenge and failure of the what works clearinghouse to conduct meaningful reviews of studies of mathematics curricula. *Educational Researcher, 35*, 13–21.
- Shore, R. (1997). *Rethinking the brain: New insights into early development*. New York: Families and Work Institute.
- Sowell, E. R., Thompson, P. M., & Holmes, C. J., Jernigan, T. L., & Toga, A. W. (1999). In vivo evidence for post-adolescent brain maturation in frontal and striatal regions. *Nature Neuroscience, 2*, 859–861.
- Sprenger, M. (1999). *Learning and memory: The brain in action*. Alexandria, VA: Association for Supervision and Curriculum Development.
- Sousa, D. A. (1998). Is the fuss about brain research justified? *Education Week, 18*, 52.
- Sousa, D. A. (2001). *How the brain learns: A classroom teacher's guide* (2nd ed.). Thousand Oaks, CA: Corwin Press.
- Swanson, H. L., & Sachse-Lee, C. (2000). A Meta-Analysis of Single-Subject-Design Intervention Research for Students with LD. *Journal of Learning Disabilities, 33*, 114–136.
- Tate, M. L. (2003). *Worksheets don't grow dendrites: 20 instructional strategies that engage the adult brain*. Thousand Oaks, CA: Corwin Press.
- Tate, M. L. (2004). *"Sit & get" won't grow dendrites: 20 professional learning strategies that engage the brain*. Thousand Oaks, CA: Corwin Press.
- Tate, M. L. (2005). *Reading and language arts worksheets don't grow dendrites: 20 literacy strategies that engage the brain*. Thousand Oaks, CA: Corwin Press.
- Thorndike, E. L. (1913). *Educational Psychology Volume 1: The psychology of learning*. New York: Teachers Press.
- Uttal, W. R. (2001). *The new phrenology: The limits of localizing cognitive processes in the brain*. Cambridge, MA: The MIT Press.
- Uttal, W. R. (2005). *Neural theories of mind: Why the mind-brain problem may never be solved*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Zull, J. E. (2002). *The art of changing the brain: Enriching the practice of teaching by exploring the biology of learning*. Sterling, VA: Stylus.

Copyright of Exceptionality is the property of Taylor & Francis Ltd and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.