

Brain-Based Learning: More Fiction than Fact

By Daniel T. Willingham

Question: It seems that great progress has been made in neuroscience over the past couple of decades—and especially over the past couple of years. Are there any findings that teachers could apply to the classroom?

Neuroscience has been moving forward in leaps and bounds, creating excitement among scientists, educators, and average citizens alike. No doubt much of the excitement is due to the images of the brain produced by fMRIs, and PET scans. Everyone seems fascinated with images that show which areas of the brain are activated by talking, reading, calculating, etc. But what do these images really tell us? For neuroscientists, they help in piecing together the puzzle of how the brain works. For the rest of us, though, the payoff is likely to come only in the distant future, not in the next five or 10 years. Consider, for example, an 8-year-old boy who can't read. A neuroscientist could give his teacher an image of his brain and explain that the wrong areas of his brain are active when he tries to read. A literacy coach or school psychologist could give the student a 45-minute assessment and then explain to his teacher that he doesn't have a good grasp of the sounds that the letters make. As a teacher, which test results would you rather have? The brain image might be interesting, but it does not provide any information about how to help the boy read. In a nutshell, that's about where neuroscience is today on most matters related to the classroom: Very exciting research is being conducted, but it is exciting to researchers trying to figure out how the brain works. Some of it is of interest to cognitive researchers who are trying to figure out how the mind works. And virtually all of it is far from being able to guide teachers.

Readers who follow the news on neuroscience may be surprised by my pessimism. It seems that some knowledge gleaned from neuroscience has already made its way to the classroom. Isn't it true that students who are left-brain thinkers (who are logical and analytical) do better in school than right-brain thinkers (who are creative and intuitive)? That schools are designed in ways that suit girls' brains? That young children's brains need lots of sensory stimulation, and that classical music is especially important? Actually, none of these ideas is quite true—they are just popular myths. In this column, I will outline the real scientific findings that led to these mistaken conclusions. I will also comment more generally on the relationship between neuroscience and education, describing why I think it's right to be skeptical of claims that neuroscientific knowledge will improve teaching in the near term, and exactly what I believe neuroscience might contribute in the long term.

Popular Myth 1: School Is Designed for Left-Brained Students

The myth that school is designed for left-brained students was born about three decades ago, when one of the hot questions in neuroscience was whether or not the left and right hemispheres of the brain process information differently. Scientists were trying to find broad categories to characterize what they then believed to be the strengths and weaknesses of each hemisphere—it wasn't long before their ideas were picked up in the popular media. Some of the left-brain versus right-brain distinctions that the scientists proposed became well known, such as analysis versus synthesis, logic versus intuition, linear processing versus parallel processing, and order versus creativity.

The scientists approached these distinctions as mere speculation—not fact—but that got lost as the research moved from the lab to the living room. The left- and right-brain distinctions held popular appeal because they seemed to capture commonly observed differences among people: Some of us are more logically minded and like math and science (left-brained types), whereas others are more artistic and creative (right-brained types). From the living room, it was a small step to the classroom. Some educators observed that when one compared the specialties of each hemisphere to what is emphasized in schooling, the right brain seemed to be getting short-changed. Reading, writing, and arithmetic seemed geared towards the logical and linear processing that was supposed to be the province of the left brain, whereas the spatial, artistic, and creative right brain had little to do during the school day. It seemed that educators were only teaching half of children's brains—and that left-brained students had a big advantage!

Today, despite efforts by neuroscientists to defuse the hype (e.g., Mike Gazzaniga's [1985] "Left brain, right brain mania: A debunking"), left brain, right brain characterizations still appear in articles and books for educators (e.g., Connell, 2002; Sousa, 2006) and there are still individualized instructional programs based on left- and right-brained learners (McCarthy, 1987; 1996), as well as numerous Web sites for teachers purporting to describe hemispheric differences. For example, under the "Best Practices" category of *Instructor* magazine's Features Library, there's an article titled "Left Brain/Right Brain: Pathways To Reach Every Learner" that offers teaching techniques for left- and right-brained students by discussing how to approach teaching the solar system (Connell, 2002). For left-brained students, the tips include, "Discuss the big concepts involved in the creation of the universe, how the solar system was formed, and so on. Left-brain students love to think about and discuss abstract concepts" and "Keep the room relatively quiet and orderly. Many students with left-brain strengths prefer not to hear

other conversations when working on a stimulating project.” In contrast, for right-brained students, suggestions include, “Have some time for group activities during the week of the solar system study. Right-brain students enjoy the company of others” and “Play music, such as the theme from *2001: A Space Odyssey*. Discuss how space might feel to an astronaut. Students with right-brain strengths are intuitive and like to get in touch with their feelings during the day.” Regarding how students are supposed to demonstrate their learning, left-brained students are to “write a research paper on the solar system that includes both detail and conceptual analysis” while right-brained students are to “create a project (such as a poster, a mobile, a diorama, or papier-mâché planets of the solar system) in lieu of writing a paper.” It’s clearly time to put this myth to rest. Let’s take a closer look at the research behind it and see how the scientists’ thinking changed over time.

Scientists have used many techniques to investigate the similarities and differences between the left and right hemispheres, but the best known and most dramatic technique is the investigation of split-brain patients. A split brain occurs when the two largest of the bundles of neurons that connect the left and right hemispheres (the corpus callosum and the anterior commissure) are severed. This surgery was developed in the 1940s and was conducted as a last resort for patients debilitated by severe epilepsy. The idea is that if an epileptic seizure begins in one hemisphere, it cannot spread to the other hemisphere. The surgery did reduce the frequency and intensity of seizures, and there seemed to be few negative effects. (Improvements in medications and the development of other surgical procedures mean that this radical surgery is rarely done today.)

It was not until the 1960s that careful testing revealed unexpected consequences of the surgery. Roger Sperry and his colleagues noted that, because of the way that the visual system is wired, in split-brain patients it is possible to present visual information selectively to one brain hemisphere. Sperry conducted a series of experiments in which visual stimuli were presented to either the left or the right hemisphere for identification (e.g., Sperry, 1974; see also Gazzaniga, 1970). Subjects responded to the stimuli in different ways: by speaking, by pointing to a picture, or by selecting from among several objects that they could feel, but not see. Sperry found that the left hemisphere did all of the speaking and could understand complex grammar, but the right hemisphere seemed unable to speak, and could understand only simple grammar. He also observed that the right hemisphere seemed to excel in appreciating locations in space. These observations lead neuroscientists to begin speculating about whether or not there really are broad differences

between how the left and right hemispheres process information, and, if so, how to characterize them.

After about a decade of trying to find a categorization scheme, scientists concluded that the left and right hemispheres could not be simply characterized. By the mid-1980s, more and better data indicated that there were not left-hemisphere tasks and right-hemisphere tasks. Rather, it seemed that both hemispheres contributed to nearly all tasks in a normal brain, and when one hemisphere was better than the other in a particular type of processing, the advantage was usually modest. (The only exception seems to be language, which does appear to be mostly localized in the left hemisphere for most people.) The broad participation of both hemispheres in most cognitive tasks became especially apparent in the 1990s when brain imaging data (e.g., from fMRIs and PET scans) of normal subjects became widely available—both hemispheres participate in virtually every task.

Why haven't these more recent findings made their way from the lab to the living room or to the classroom? I can't say, but I can reassure educators that they need not be concerned with left- versus right-brain distinctions. Barring severe brain damage or radical surgery, all of us are whole-brain thinkers. Efforts to tailor instruction should be based on a careful consideration of what the educational content calls for and on students' individual needs—not on faulty schemes for characterizing two kinds of thinkers.

Popular Myth 2: Schools Are Designed to Suit Girls' Brains

The myth that schools are a better fit for girls' brains than for boys' brains is the latest version of what seems to be a perennial debate about whether the educational system is biased toward girls or boys. In the early 1990s, educators, researchers, and policymakers directed their concern toward girls after the American Association of University Women published *How Schools Shortchange Girls*. Among other findings, the report stated that, "Research reveals a tendency, beginning at the preschool level, for educators to choose classroom activities that appeal to boys' interests and to select presentation formats in which boys excel." But recently the pendulum has swung in the other direction, and critics are drawing on neuroscience to make their case that boys are at a disadvantage in school.

A number of popular writers have pointed out that boys show substantially worse patterns of achievement over the long term than girls (e.g., boys are more likely than girls to be diagnosed with a learning disability, to be held back in elementary school, and to drop out of college) and argued that these differences can be traced to anatomic and physiological differences that are ignored by the educational system. In

short, boys are in “crisis” and the cause of the crisis is an educational system attuned to girls’ brains. Just in the past few years, these sorts of claims have appeared in popular magazines (Chiarella, 2006; Tyre, 2006; Whitmire, 2006), books (Gurian and Stevens, 2005; Saxe, 2005), and articles directed toward educators (Connell and Gunzelmann, 2004; Laster, 2004).

Teachers have been encouraged to address this crisis by making their classrooms more friendly to boys’ brains. For example, one suggestion is to use more manipulative materials, which are supposed to tap into boys’ greater spatial abilities (Connell and Gunzelmann, 2004). Although this might seem like a good idea, trying to use a cognitive strength like spatial ability to bolster an altogether different cognitive process, like reading comprehension, does not work (Willingham, 2004). Another suggestion is to allow breaks during the day, so that overactive boys have a chance to move around (Connell and Gunzelmann, 2004). That’s not a bad idea, but it won’t help schools become better attuned to boys’ brains—research shows that girls and boys benefit equally from breaks (e.g., Pellegrini, Huberty and Jones, 1995), even though they use them differently.

All told, it seems that neuroscience has brought more confusion than clarity to the debate about educating boys and girls. Why? When proponents of the boys’ crisis marshal neuroscientific findings to support their claim, they think that the neuroscience “proves” that a meaningful difference between boys and girls has been found—and then they build on that “proof” to make teaching suggestions. For example, girls have, on average, a larger hippocampus than boys do. The hippocampus is a small structure towards the middle and bottom of the brain that is known to support learning and memory (e.g., Squire, 1992). Gurian and Stevens (2004) cite the brain difference and, based on that, believe that that is the reason why girls have a better memory than boys, on average (e.g., Kramer, Delis, Kaplan, O’Donnell, and Prifetera, 1997). But this assumption that the bigger hippocampus *causes* the better memory is mistaken. It’s a common error: People often think that if the brains are different, that must be the cause of the cognitive difference. In other words, if boys have smaller hippocampi, their memory is worse because “that’s just how boys are,” and not because they are less interested in memorizing than girls are, or because society subtly encourages girls to memorize more than boys. It’s nature, not nurture. That conclusion seems to add considerable weight to the argument that our schools are biased against boys. The idea is summed up well in a quotation from a neurologist that appeared in a *Newsweek* cover story on the boy crises: “Very well-meaning people have created a biologically disrespectful model of education.”

The assumption that the bigger hippocampus causes the better memory is an oversimplification, however, because your behavior can change your brain. For example, researchers know that if you memorize a lot of material, your hippocampus will get bigger (Maguire et al., 2000). So when brain differences between boys and girls are found, we can't conclude that the brain differences *caused* the associated behavior differences. It could be that behavior differences caused the brain differences. In fact, most researchers of gender differences believe that they are due to a complex mix of biological and social forces (see Kimura, 2002, for a readable overview).

Ultimately, the neuroscience behind gender differences adds a great deal to our knowledge of how the brain works—but it doesn't add any practical knowledge that can be applied in the classroom. If we're interested in cognitive differences—such as differences in memory—then the findings from cognitive studies are decisive. After all, neuroscience is the study of the nervous system and cognitive science is the study of mental tasks and processes.

So, what have cognitive studies found? In the last 100 years, many, many researchers have studied boys' and girls' performance in controlled testing situations (e.g., performance on the Scholastic Aptitude Test or in a psychology experiment) and have, in fact, found cognitive differences between males and females—but many of these are so small (even though they are statistically “real”) that they are not worth bothering about. The larger differences include a slight edge for males in certain spatial tasks like mental rotation and mathematical reasoning, and an advantage for females in certain memory tasks and in mathematical calculation. Researchers who do this work debate whether these differences are very modest or moderate—but no researcher claims that they are large (for reviews, see Hyde and Linn, 1988; Voyer, Voyer, and Bryden, 1995; Willingham and Cole, 1997).

What's an educator to make of all this? In short, it may very well be that boys, on average, are having some difficulties in school that girls, on average, are not, and that the reverse is also true. But the surest way to pursue that issue is to investigate data that emerge from the school setting—not by looking to neuroscience. As the hippocampus example explained, neuroscientific data do not identify for us the interesting behavioral differences between boys and girls. The key finding for teachers to keep in mind is that the modest cognitive differences between boys and girls are average differences. Both boys and girls should be expected to excel in all academic subjects and helped to do so. How individuals should be helped can't be determined by their gender.

Popular Myth 3: Young Children’s Brains Must Have Lots of Sensory Stimulation—and Classical Music Is Especially Important

We have all heard of parents who diligently painted large black geometric shapes on the walls of the baby’s room, used patchwork quilts with different textured fabrics “for tactile experience,” and played Mozart every day at naptime. On the one hand we may surreptitiously roll our eyes at this subtle competitiveness. On the other hand, when confronted with an array of mobiles at the store, we may figure “Why *not* get the one that claims to provide the ‘right type’ of visual stimulation?” Well, a neuroscientist might reply, “Why not just get the mobile you like the best?” After all, the two neuroscientific findings underlying this trend in parenting—and similar trends in daycare and early childhood education—have been stretched far out of shape.

The first part of this myth, that young children’s brains need lots of sensory stimulation, is based on studies of the effects of sensory deprivation in animals. Classic work by the Nobel-prize winning physiologists Torsten Wiesel and David Hubel showed that kittens’ visual systems did not develop normally if deprived of certain types of visual stimulation. For example, in one experiment (Wiesel and Hubel, 1963), they deprived a week-old kitten of visual stimulation in one eye, but let it use the other eye. Just a few weeks of deprivation resulted in the kitten’s visual cortex not developing normally, and not recovering even after the kitten was allowed to use both eyes. The same experiment had no effect on an adult cat. Wiesel and Hubel concluded that there is a *critical period* for the development of vision. A critical period is a time in development when the organism (be it a kitten or a baby) must have some type of experience in order to develop normally; it has been a commonly accepted principle in visual development since Wiesel and Hubel’s work, and has been confirmed in studies of humans who suffered vision deprivation early in life due to a problem in their eye that was later corrected through surgery (e.g., Fine, Wade, and Brewer, 2003).

Unfortunately, those outside the research world seem to have misunderstood this research. The key to understanding—and thus properly applying—it is to keep in mind that Wiesel and Hubel compared normal development to what happens when the brain is totally deprived of a certain type of sensory stimulation. It seems that the general public took away the message that more stimulation is better. But that’s just not the case. The fact that deprivation results in a poorly developed sensory system does not mean that extra stimulation beyond what’s normal would make the sensory system any better. A baby with two mobiles will not have better vision or better processing of visual information than a baby with one mobile. So long as a baby is not being

raised in an inhumane way—deprived of interaction with others and with the world around him—his sensory system will function just as well as that of the baby with all the latest sensory-stimulating gadgets.

The second part of this myth, that classical music is an especially important form of sensory stimulation, rests on an even weaker neurological foundation. Readers who recall the hype about the “Mozart Effect” will likely be surprised to learn that it began when a scientific paper reported that college students showed a short-lived increase in spatial reasoning (e.g., ability to mentally rotate objects) after listening to a Mozart piano sonata, compared to other students who experienced silence or instructions to relax (Rauscher, Shaw, and Ky, 1993). There were many subsequent efforts to reproduce the effect. Some were successful, most were not (see Chabris, 1999, for a review), and it appears most likely that when the effect is observed, it’s not due to hearing Mozart or classical music per se, but rather to a boost in mood and arousal (Thompson, Schellenberg, and Husain, 2001).

At their best, the data on listening to Mozart supported a very short-lived boost in spatial ability for college students. Somehow, that transmogrified into the idea that playing classical music for babies would make them smarter for life. Here’s how Norman Weinberger (1998), a leading neuroscientist studying how music affects the brain, described what happened:

Although increased public interest ... [in music is] good, there is also the not-so-good in all of the public press. For example, the “Mozart Effect” has gotten so bent out of shape, one can hardly recognize it. The symptoms are clear and follow a well-trod path. A scientific paper is published. It is novel, potentially important with broad implications. Naturally, it receives attention by the media; it should. But then come the oversimplifications. Not necessarily exclusively from a careless media, but also from the fact that we all receive too much information and perhaps unconsciously boil down the complexities of reality into an easily remembered “cognitive bite”.... These findings have been encapsulated popularly as “Mozart makes you smarter”....

Once “music makes you smarter” became the popular mantra, it seemed natural to start babies and young children on a steady diet of classical music. The idea was so widely accepted that in 1998 then-Governor Zell Miller recommended that every Georgia newborn receive a CD of classical music at the state’s expense. Similarly, the Florida legislature passed a law requiring that all state-funded childcare and educational programs play classical music every day for children under the age of six.

Even folks who weren’t convinced that music makes you smarter didn’t object to these initiatives because they didn’t appear to have a

downside. Music may not make those kids in Georgia and Florida smarter, but it won't hurt them, will it? Of course, music won't do any direct damage—but there is a cost to supplying all that music and so it is appropriate to ask whether that money could have been better spent. For example, should infants be sent home with a book instead of a CD? Probably. The research indicating that being read to makes a young child smarter is much, much stronger than the “Mozart Effect” research.

Since this article is about ways that brain research has been misunderstood, I must add one word of caution with regard to this myth: The sensory development research reviewed here does not speak to overall brain development. The sensory systems do not benefit from extra stimulation—but other parts of the brain often do. For example, a baby who is spoken to a great deal will not have better hearing than a baby who is spoken to less often—but the baby who is spoken to frequently will end up with a bigger vocabulary (Hart and Risley, 1995).

So what are parents and early-childhood educators to conclude? When we think about the years zero to three, we should draw a fundamental distinction between sensory stimulation and learning. The sensory systems can and will develop normally under average home and daycare conditions—and without specially designed mobiles or Mozart. The baby's apparent enjoyment is a perfectly adequate guide to what music to play and what artwork to display. When it comes to learning, the conclusion is different in an important way. Learning at home, or in a daycare or early-childhood education setting, will bring helpful consequences. Unlike sensory development, which plateaus in early childhood, learning effects are cumulative—the more you know, the easier it is to learn more—so learning things in a rich home environment makes it easier for children to learn still more when they get to school. (For more on the cumulative effect of learning, see “How Knowledge Helps” *American Educator*, Spring 2006, www.aft.org/pubs-reports/american_educator/issues/spring06/willingham.htm.)

Will Neuroscience Inform Educational Practice in the Future?

Based on these three “well known” findings from neuroscience that turn out to be inaccurate, it might seem that the problem in applying neuroscientific data to education lies in how the data are used. Isn't the challenge to make better use of the data? To a certain extent, yes. But applying neuroscientific findings is not at all straightforward.

For neuroscience to mean something to teachers, it must provide information beyond what is available without neuroscientific methods. It's not enough to describe what's happening in the brain, and pretend that you've learned something useful. For example, some brain-based teaching books explain what's happening in the nervous system—and

thus why it is hard to learn—when the room is uncomfortably hot or cold (Jensen, 2005). But teachers are well aware that an uncomfortable room makes it hard to learn. And knowing what is happening within the nervous system does not give teachers any new solutions to the problem.

The challenge for those trying to apply neuroscientific findings to the classroom is the dramatically different levels of analysis that must be bridged as we transition from looking at a brain to looking at a child in a classroom. To understand that problem, let's set neuroscience aside for a moment, and just consider cognition. Findings from cognitive psychology can only be applied to classrooms with care and forethought because of the complexity of the mind. For example, cognitive psychologists know that practice is important to memory, but you can't conclude that students should, therefore, practice the same lesson continuously until they have mastered it; many students will get bored and attention will wander. More generally, we can say that cognitive systems interact. Laboratory experiments are carefully designed to examine one cognitive system at a time; but in the classroom, all of the systems operate simultaneously, and they affect one another. Continuous practice is good for memory, but it's bad for attention. When you apply a cognitive principle to the classroom, you have to think of the effect throughout the whole mind, not just in the system that you're targeting.

This example of interactions among cognitive processes illustrates what's meant by "a different level of analysis." Because processes of the mind interact in complicated ways, it's difficult to examine all the parts (attention, memory, motivation, and so on) and confidently predict what will happen in the system as a whole. For example, if you have a new reading program in mind, it doesn't make sense to evaluate the effect of the program on memory, attention, and so forth. It makes sense to evaluate the effect of the program on the whole system at once—that is, on the student's ability to read.

Once we start trying to use neuroscience to tell us about student learning, we have still another layer of complexity because neuroscience uses a different, more fine-grained level of analysis than cognitive psychology does. For example, "attention" is not supported by a single brain structure—it's supported by several brain structures that act together as one system. And those brain structures have their own set of complex interactions. Thus, when we examine a brain structure and try to tie it to classroom behavior (e.g., noting that girls have bigger hippocampi, and thus expecting them to remember more facts in class), we are jumping across two levels of analysis: We are looking at one structure in a larger brain system and guessing at its effect on the memory system as a whole; and then we're guessing that this effect on

the memory system will have a predictable effect on student learning in the classroom.

In general, if you are interested in describing effects at a given level of analysis, you are most likely to make progress by sticking to that level of analysis. If you're interested in describing ways that students learn best, it makes sense to study classroom situations. To the extent that neuroscience will inform good teaching practice, it seems most likely that this influence will be funneled through the cognitive level of analysis: For example, neuroscience will help us better understand memory, and this improved understanding of memory might be used to improve classroom practice. It's unlikely that leapfrogging the cognitive level analysis and going straight from the brain to the classroom will work out very often.

In a trivial sense we could say that a better understanding of the brain is bound to lead to improved classroom practice some time in the future. A deep understanding of the brain will come, hand-in-hand, with a deep understanding of the mind, and that is bound to help education. There is not, however, any prospect of a brain-based learning program of any substance in the near future. Neuroscience may, however, contribute to the diagnosis of some learning disorders in the near future (see box, pg. 33). In summary, I hope educators will approach claims that instructional techniques and strategies are "proven" because they are based on neuroscience with a healthy dose of skepticism. Cognitive and educational studies are the best sources for educators looking to improve their students' cognitive and educational outcomes.

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