CHAPTER 1

THE NEUROSCIENCE OF LEARNING

Every student can learn, just not on the same day or in the same way.

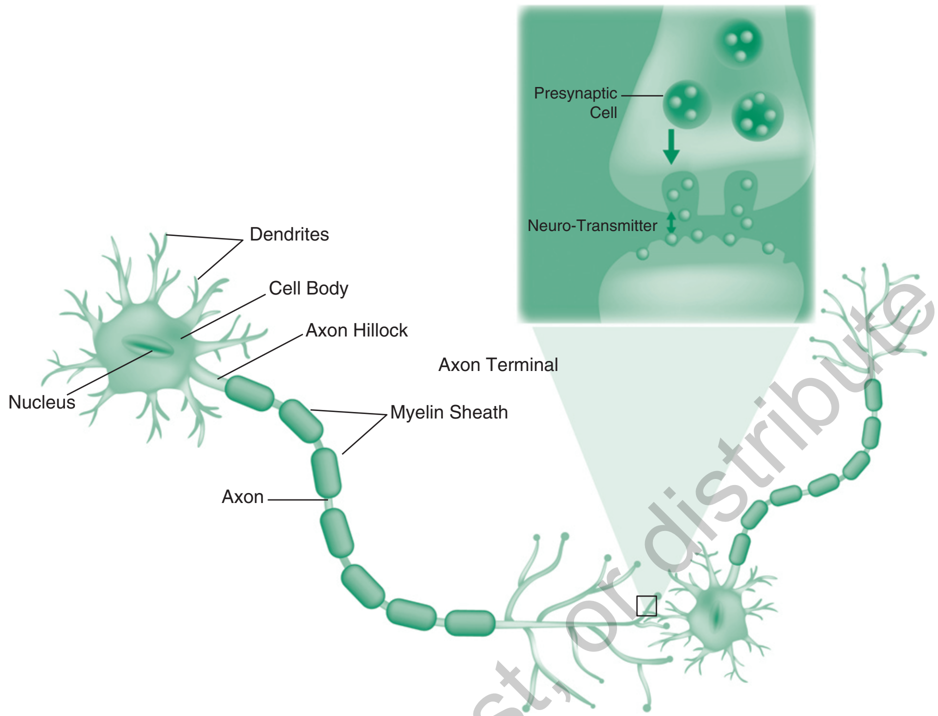
~George Evans, cartoonist and illustrator

Learning how the brain works can help us understand why some students struggle academically and emotionally – and how we can more effectively teach them. We are very literally born to learn. Babies and children are like miniature scientists, constantly observing their surroundings, identifying previously unknown objects, testing out new theories, and communicating their findings as best as they know how. Luckily, our miniature scientists come preinstalled with hardware that enables them to run their experiments and learn about their world.

BRAIN BASICS

At birth, babies have all the 86 billion or so neurons they will need as an adult, although most of these neurons are not connected to each other. As babies learn how to crawl, babble, and understand language, their neurons will make new connections with each other through electrical or chemical signals. These connections are what power the learning process. Essentially, one neuron releases a message – via a neurotransmitter – like a basketball player passing the ball to a teammate. If a nearby neuron catches the pass (the neurotransmitter), a connection has been made (Figure 1.1). The more that individual neurons communicate with each other, the easier it is for them to communicate in the future. This is the foundation of how learning happens.

FIGURE 1.1 NEURONAL COMMUNICATION



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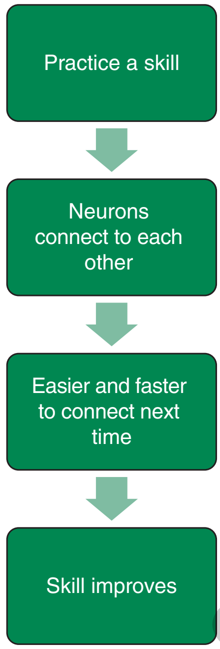
It might help to think of neurons as a microcosm of human relationships. When we meet someone for the first time, we don't know how it's going to go and if they'll like us. We might crack a joke to try to connect with them. If they smile or laugh, we know we've made a good connection, and we likely will find it easier to continue talking with them. If they ignore or rebuff us, we may be reluctant to try again. Similarly, neurons activate when they find something exciting. They release neurotransmitters to communicate that excitement and connect with other neurons that are also excited or that might get excited by the message. When two neurons connect with each other, they're more likely to connect again in the future. And over time, the communication will happen faster and faster as that neural pathway becomes more established, like a well-worn trail through a forest. An insulating layer called a myelin sheath develops around the neural pathway which allows the signal to become stronger and move faster. Then, we just multiply that process by the billions of neurons and trillions of neural connection possibilities!

As educators, we already understand how this works in the practical sense. The more that students practice a skill, the easier it gets for them to perform that skill in the future. This improvement in skill is the result of neural connections becoming stronger and quicker (Figure 1.2).

FIGURE 1.2 THE LEARNING PROCESS



But what drives us to explore our world and learn new things in the first place? Since learning is essential for survival, the brain rewards us with feel good chemicals when we learn something new or perform a new skill successfully. As Nobel Laureate and neuroscientist Eric Kandel explains: "*Our brain has an approach-avoidance system that encourages us to seek out experiences that evoke pleasurable emotions and to avoid those that evoke painful or frightening ones*" (2018). As adults, we might think of emotions as inconvenient nuisances to be controlled and managed. In reality, though, they are the driving force behind all of our actions and cannot be so easily separated from our physical body or mental processes. In Chapter 3, we'll dive deeper into the relationship between emotions and learning, but it's important to remember that we are all born with an innate drive to learn, and we derive great pleasure from succeeding.

KEY ELEMENTS OF BRAIN FUNCTION

Over the past 50 years or so, our knowledge of how learning occurs in the brain and how to meet students' needs when that learning process is disordered has skyrocketed. The advent of Magnetic Resonance Imaging (MRI) allowed us to "see" which regions of the brain are active during specific activities (like when we're reading) and better understand learning differences. Sequencing of the entire human genome (the makeup of our DNA), which was completed in 2003, provided a wealth of data enabling researchers to explore the genetic underpinnings of disabilities that impact learning. Additionally, hundreds of research studies have helped us identify effective teaching and intervention practices to meet the needs of students who struggle with learning in school.

In learning about the brain and how it functions in the learning process, there are four key elements to keep in mind:

1. **Genetic influences:** Our genes set the stage, or the parameters, for learning strengths and challenges, including disabilities. We may have a genetic predisposition that makes us more or less likely to be athletic, artistic, or autistic.
2. **Specialization and interconnectivity:** Generally speaking, each region of the brain (and even each neuron) is specialized for processing a certain type of information. For example, the reading network which is predominantly on the left side of the brain is engaged in processing the words you're reading on this page. However, it is only through the interconnectivity of large neuronal networks crisscrossing the brain that allows us to make sense of the information.
3. **Variability:** No one's brain works *exactly* the same way as someone else's brain. While the activation patterns are generally similar, there will always be some variation from one person to the next.
4. **Neuroplasticity:** The brain is constantly making new connections, rewiring itself based on environment and experiences. This neuroplasticity is what allows us to learn new things throughout our lives and adjust to new situations.

Genetic Influences

Babies are by no means born into this world as a "blank slate" upon which families and teachers can write the script for their lives. Our genes have already set the stage upon which the play will unfold. During development in utero, our genes direct our newly created neurons like a beginners' theater class, telling them where to go and what to do once they get there. Each neuron has a special part to play, and the genes give them the script to follow. As an embryo develops, each neuron, following the directions given by the genes, gradually makes its way into position and prepares for the magic.

Our genes provide the code from generations of ancestors. This code is the result of millions of years of evolution – everything our ancestors have learned along the way that will help us survive in the world, from our uncanny ability to see snakes on a hiking path (oftentimes even mistaking branches for snakes) to the development of language and the ability to read. We are the product of their learning along the way.

We may even be inheriting our ancestors' fears and traumas. Neuroscientists at Emory University (Dias & Ressler, 2014) found that they can cause mice to fear the scent of cherry blossoms even if they've never been exposed to the smell before – but their parents were. Their parents had been trained by researchers to expect a mild negative consequence when they smelled cherry blossoms, which eventually caused them to startle in response to the scent. The startle response carried over to the offspring, even to the second generation. Did the parents teach their babies to fear the scent? Or was the information passed down genetically? The researchers analyzed this by also having the parents foster baby mice that weren't their biological offspring. If the fostered babies also startled in response to cherry blossoms, then it would be reasonable to assume that the parents taught the babies to be afraid. However, the fostered babies didn't startle, while the biological babies did. Other researchers have uncovered similar findings, that fear or trauma in one lifetime can impact the biology of future generations (Curry, 2019).

While our genes are meant to provide us with an evolutionary advantage that will help us survive, the evolutionary learnings of our ancestors are sometimes maladaptive to our current environment. What is useful in one time period is not necessarily useful in the next. The cherry blossom study is a manufactured example of this from a lab. Having a fear of cherry blossoms won't be beneficial to the offspring since cherry blossoms are not actually dangerous to mice – except in a lab experiment. Release the mice into their natural environment and this would be considered an abnormal fear. If they were humans, we might diagnose them with an anxiety disorder.

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A real-life example from outside the lab is sickle cell anemia, which is a genetic disorder triggered when someone has two copies of the sickle globin gene. It affects 1 in 365 African Americans (CDC, 2020). Sickle cell disease can cause severe pain and frequent infections and significantly reduces life expectancy. So why is it so common? Why hasn't the genetic code evolved to phase it out? It turns out that while having two copies of the sickle cell trait is dangerous, individuals who have only one copy of the sickle cell trait (which is much more common – 1 out of every 13 African Americans have it) actually have a huge evolutionary advantage. People who carry this trait are resistant to malaria, a main driver of death over the past 100,000 years. Sickle cell trait essentially gives them a superpower in tropical climates where malaria-carrying mosquitos are most common. So while the sickle cell trait isn't necessarily an advantage for individuals living in regions of the world where malaria has been wiped out or is uncommon (like the United States), it has been hugely advantageous for many millennia. Had Africans not been brought to America enslaved, their descendants would have maintained a significant evolutionary advantage in countries where malaria transmission remains high.

But what does all this have to do with education? Are cognitive development and intellectual capacity genetically determined? How much does our environment impact our learning ability? Usually, it's a complex combination of genetic and environmental influences, though there are instances where the cause of learning challenges can be wholly genetic or wholly environmental. Down syndrome is a genetic disorder that causes mild to moderate intellectual disability, along with other specific characteristics, such as differences in physical appearance. The child's environment can still impact the severity of the intellectual disability, just as environment is important for any other child. But nothing in the environment can make it so that the child no longer has the traits of Down syndrome. On the opposite end, severe neglect or abuse in childhood can cause lifelong cognitive deficits. But the child's DNA still plays a role, up to a point. Two children who have grown up in the same environment – whether good or bad – may still have different outcomes depending on their genetic traits and propensities.

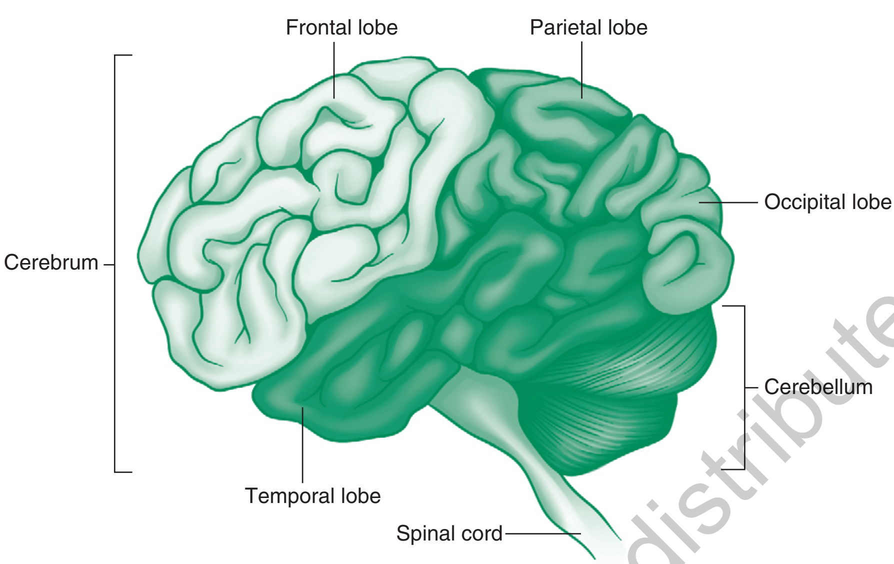
Essentially, our genes set the framework or the parameters of what is possible, like planting apple seeds in your yard. You know that the only thing you can grow with apple seeds is apples. But you rely on the environment – in the case of our apple seeds, the sun, soil, and water – to actually bring the fruit to bear. Sometimes the genetic framework is very rigid, as in the case of Down syndrome. You either have it or you don't. More often, our genetic framework is like a Magic 8 Ball giving gradients of "maybe."

SPECIALIZATION AND INTERCONNECTIVITY

Just as humans are born with a propensity for certain traits and talents, neurons are also encoded with specific preferences. Different regions of the brain specialize in processing certain types of information (Figure 1.3). The frontal lobe specializes in skills like planning and decision-making. Neurons in the temporal and parietal lobes play a role in processing language and other sensory information. Occipital neurons specialize in processing what our eyes see.

Drilling down even further, within each area of the brain are highly specialized neurons. For example, in the visual system, different neurons have preferences for different colors, orientations, and directions of movement. Research on primates has shown that certain neurons in the visual system activate when light is moving across the visual field in just the right direction and at just the right orientation. Imagine a person who has been tasked with hitting a counting clicker every time they see a fish swim by in the stream.

FIGURE 1.3 HUMAN BRAIN ANATOMY



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Fish. Click. Fish. Click. Now let's add some complexity and imagine that there are 10 people tasked with counting fish but each one is counting something different. Some are counting blue fish. Others are counting green fish or red fish. Some are counting fish swimming upstream. Others are looking for the fish going downstream. And on and on. All of this information would then get fed into a computer system to calculate the diversity of fish and their activities in the stream. That's essentially what each neuron is doing – activating every time it sees its favorite color or favorite type of movement. All of this information then feeds into higher networks of neurons that are responsible for making sense of all the data.

None of these regions is working in isolation. The left temporal lobe is highly active in processing language and reading, but to accomplish the complex task of reading, we also need the frontal lobe to help us focus on the text, the occipital lobe to process what we're actually seeing, and the limbic system (in the deeper layers of the brain) to process our emotions and memories related to what we're reading.

Throughout this book, we'll talk a lot about individual differences in the ways people learn. We all have areas of strength and areas of struggle. Some have more challenges than others. Still, we need to always remind ourselves that our similarities in the ways we learn far exceed our differences. Each person's brain works in essentially the same way, with similar patterns and neural mechanisms.

VARIABILITY

Although humans are 99.9% genetically identical, that seemingly tiny 0.1% of differences allow us each to have unique personalities, interests, and skills. While our bodies and our brains work similarly to the person next to us – following a similar pattern and using the same underlying mechanisms – they don't work exactly the same. There will always be some variability. Siblings may exhibit wildly different personalities or skill sets, despite being born to and raised by the same family. As adults, my sister and I realized that many of the teachers I loved and whose classes I excelled in were her least favorite, while her favorite teachers were the classes where I struggled. This, despite half our DNA being the same and growing up in the same home with only two years age difference between us. Of course, every individual, even siblings, will have different experiences that impact who they become as a person. However, their differences are sometimes caused or at least strongly influenced by genetic differences. Even our tendency for introversion or extroversion in adulthood can be predicted as early as four months of age, based on our reactions to things like loud noises, colorful objects, and strong smells (Cain, 2013).

All this to say, there will *always* be variance in how students respond to instructional practices. Even when using evidence-based practices that are effective for most kids, there will be kids who don't respond the way we expect. We can do everything "right," our students can do everything "right," and we still sometimes won't get the outcome we wanted. What works one day or in one class period, won't necessarily work in the next. It's not just about whether we – or our students – are trying hard enough or want it badly enough.

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Just like how when you're sick, you can help your body fight off the virus by drinking more fluids and resting, but these actions don't guarantee a quick recovery. It might be that you need a medical intervention – a medication or treatment. Or maybe your body just needs more time. But it doesn't mean you stop drinking fluids or stop resting. We can, and should, do all of the things that research tells us are most likely to be effective, and improvise and modify where we need to, but we also shouldn't be upset – at ourselves or at our students – when our efforts and their efforts don't work like a magic potion.

Variability in the learning process, while complicating our jobs as educators, is normal and actually good for society. This variability in our genetic code is what allows the human race to continue thriving. While our DNA passes along traits that were helpful to our ancestors (like we saw with the cherry blossom study and sickle cell trait), it also includes a dose of randomness so that the human species can continue to test out different ways of being. To see what works; and what we value.

Many individuals with disabilities view their differences as strengths or as aspects of themselves that make them unique. This is especially true if the adults around them have helped them identify those strengths and not see their challenges as deficits to their humanity or to society. As Kandel explains:

> *Some disruptions of typical brain circuitry can confer benefits and affirm a person's individuality. In fact, a surprising number of people who suffer from what one might see as a disorder would choose not to eradicate that aspect of themselves.*
>
> (*The Disordered Mind*, p. 9)

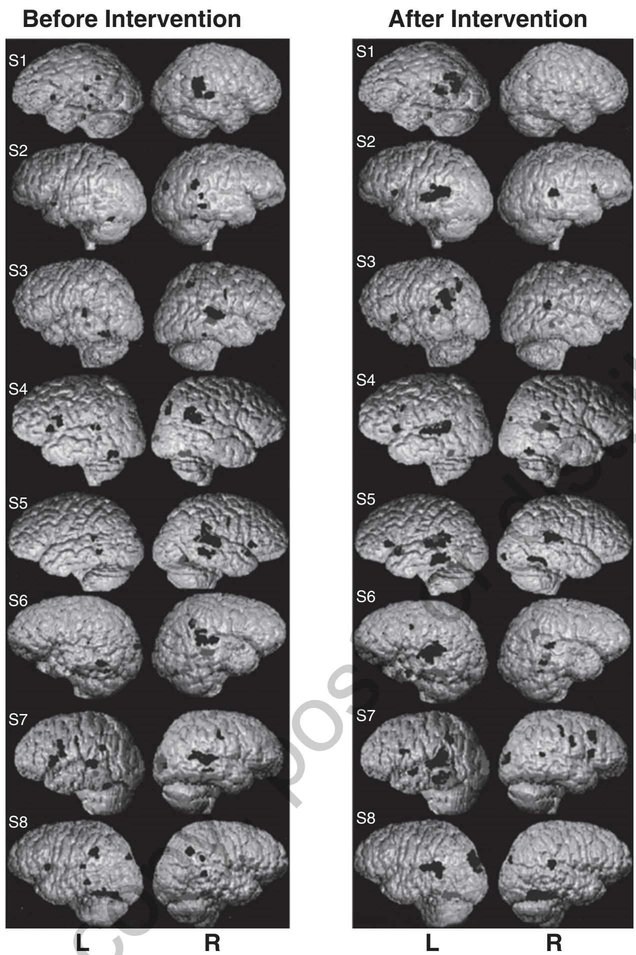
NEUROPLASTICITY

As a teacher, you are literally changing students' brains every day. The brain is constantly rewiring itself and forming new pathways based on our experiences and learning. A few fascinating examples of this:

- Cab drivers show more brain growth in the hippocampus, the brain's memory center, as they learn to navigate the quickest routes throughout a city (Maguire et al., 2006).
- Musicians activate larger portions of brain regions that are responsible for controlling finger movements (Elbert et al., 1995).
- Blind individuals who use echolocation – clicking their tongue and using the echo to navigate their surroundings – utilize the region of the brain typically devoted to visual processing (Thaler et al., 2011).

Studies using brain imaging before and after reading interventions have also given us great examples of neuroplasticity. These studies have shown that there are specific changes in the brain when students with dyslexia receive effective phonological intervention. Before intervention, there is less activation in regions of the left hemisphere of the brain that are typically active during reading. After an effective intervention, participants' brain activity looks more like that of students who are reading at grade level (see Figure 1.4).

FIGURE 1.4 CHANGES IN BRAIN ACTIVATION AFTER INTENSIVE PHONOLOGICAL INSTRUCTION



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Note: Research using magnetic source imaging (MSI) shows the differences in brain activity after students with dyslexia completed 80 hours of a phonological reading intervention. Activation within the left (L) and right (R) hemispheres of the brain are shown before and after intervention. Each row shows the individual brain activation for each student (S1-S8).

Prior to intervention, little or no activation was seen in the **left** superior temporal gyrus (STG) which is typically active during reading. More activation was seen in the right hemisphere which is typically less active during reading. After the effective intervention, all students showed more typical brain activation with a dramatic increase in activation of the left STG. Note that each student experienced neuroplasticity but each in somewhat different ways, with different activation profiles, showing the variability of brain processing.

The brain has an amazing capacity to adapt and overcome obstacles, so much so that even children who have half of their brain removed, called a hemispherectomy, as a last line of defense against severe epileptic seizures, typically experience little change to their cognitive capacity (Pulsifer et al., 2004).

The brain is able to compensate for all kinds of injuries and obstacles by rewiring networks and sometimes repurposing one region to make up for a region that has been damaged, as in the case of a hemispherectomy.

But there are limits to this neuroplasticity. Remember that each region of the brain has a specialty – something it's really good at doing. Another region of the brain might be able to fill in and help us get by, but it's like asking someone to play in the Super Bowl when they've only ever played backyard football with their friends.

Take for example an individual who has suffered a traumatic brain injury or had to undergo brain surgery. Doctors, researchers, and psychologists never know for sure how severely – or not – that injury will impact them. We can make educated guesses based on the severity of the injury, the brain region(s) impacted, and the current function we see. Some individuals may never fully recover from a brain injury and will require accommodations or new strategies to cope with the changes in their brain function. Or, with the support of their medical team, their brain might be able to rewire itself to make up for the injured area.

The key here is to remind ourselves that we can't see what cards someone else is holding. Unfortunately, when we find out someone has a disability or struggles in school, our tendency is to lower the bar. We must find the balance between meeting students where they are without lowering our expectations below what they are capable of achieving.

FROM THE CLASSROOM

Ben was a ninth grader whose family had just moved into the district. When I first met him, he avoided speaking as much as possible and when he did speak it was a whisper, almost to the point of not being heard. On top of that, he never made eye contact and hardly interacted with his classmates. We learned that in his previous school, Ben had spent nearly all his time in a self-contained classroom with students with severe intellectual disabilities.

Thankfully, our school district believed strongly in inclusion and made every effort to ensure that students received the services and supports they needed to learn. Even though Ben was many grade levels behind in reading, we made sure he was in classes that would challenge him and interest him while also providing small group instruction.

Over time, we realized that Ben wasn't avoiding eye contact or social interaction due to a disability like autism or his cultural upbringing; he seemed to have just picked up on the behavior from his former classmates. Or perhaps he was shy and anxious. With coaching, encouragement, and more peer interaction in his classes, his social skills flourished like a well-watered garden. As teachers and parents, we frequently tell kids "You are the company you keep," but then forget our own advice when it comes to deciding which school or classes kids should attend. Had Ben continued to be placed in classes where the bar was far below what he was capable of, his academic and social skills would have remained stagnant.

By the time he graduated, four years later, his reading level had jumped considerably – enough that he was able to understand higher level vocabulary in his classes, read more books independently, and text with his friends. It was a life-changing amount of progress for a student about to transition into adulthood with all its responsibilities. But his progress was most on display when he gave a 10-minute presentation that was required of all seniors. After practicing and preparing for weeks, on the day of the presentation, he spoke clearly and confidently and made eye contact with the audience. Afterward, he beamed with pride for the rest of the day, and so did we.

KEY TAKEAWAYS

- Our genes set the stage, or the parameters, for learning strengths and challenges, including disabilities. We may have a genetic predisposition that makes us more or less likely to be athletic, artistic, or autistic. Our genes plant the seeds, and our environment can either support or stifle their growth.
- The similarities in the ways we learn far exceed our differences. Each of us has a brain that works in essentially the same way, with similar activation patterns and neural mechanisms.
- Variability in the learning process is normal and is beneficial to society as a whole. Many individuals with disabilities view their differences as strengths or as aspects of themselves that make them unique.
- The brain has an amazing capacity to rewire itself to learn new things, adapt to different situations, and overcome challenges. This is called neuroplasticity. For example, when students with dyslexia receive effective phonological reading interventions, we can see changes in brain activity through brain imaging.
- As a teacher, you are literally changing students' brains every day.