Judy Willis, M.D.
Malana Willis

Research-Based Strategies to Ignite Student Learning

Insights from Neuroscience and the Classroom

Revised and Expanded Edition

RESEARCH-BASED STRATEGIES TO IGNITE STUDENT LEARNING

REVISED AND EXPANDED EDITION

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Brain-Friendly Strategies for the Inclusion Classroom

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To Paul, Alani, Sawyer, Gus, and Gretel. We love you!

RESEARCH-BASED STRATEGIES TO

IGNITE STUDENT LEARNING

Insights from Neuroscience and the Classroom

Introduction

The mind is not a vessel to be filled, but a fire to be kindled.

—Plutarch

Every class, assignment, memory, and experience shapes the brain. Understanding how the brain processes information into learning, what students' brains need in order to learn most effectively, and how and why your successful techniques work offers you keys to expanding your strategies and interventions for teaching and learning. Powerful tools of neuroscience can be applied to promote the goals of teaching and of education in general, making the classroom experience more joyful for both you and your students.

Advances in neuroimaging and mapping of pathways, connecting brain components working together, have further opened windows into the working brain. We can now see brain activity as information is being processed from the initial sensory intake to extended cross-brain conceptual networks. This ability provides us with a deeper understanding of neuro*logical* strategies that could promote students' learning, such as through personally immersive and emotionally engaging experiences. Brain scans cannot create lesson plans, but research in neuroscience has reinforced much classic educational theory and expanded our abilities to recognize the needs of individual students and provide increased opportunities for all students to develop their highest cognitive potentials.

It has been more than a decade since I wrote the first edition of *Research-Based Strategies to Ignite Student Learning*. Ongoing developments in neuroscience technology, the resulting research, and the correlations from these to classroom practices have further transformed the landscape for optimal teaching and learning. These profound research implications are the major focus of this new book. More than 80 percent of the material is new, including strategies, guided student instruction, and a planning template to further promote teaching in ways the brain learns best.

Coauthor Malana Willis is a vital presence in this book, contributing her experience and insights from the front lines of teaching and research application. And I've added new content rooted in my progression from neurologist, to 10 years as a classroom teacher in primary and secondary schools, to currently teaching educators internationally as a presenter and consultant. I continue to evaluate the most current neuroscience research and have now written more than 200 articles and 9 books connecting the science to teaching and learning practices.

As in the first edition, the major focus of this book is to help educators like you to acquire or hone strategies to guide students' brains to more effective focusing, sustained attentiveness, and active construction of understanding and memory so that they can store, connect, retrieve, and extend learning to new applications, problems, and innovations. Understanding the *why* and not just the *how to* of your most effective teaching strategies will inspire positive expectations and motivate you to use and expand these strategies and ignite these skill sets in others. By understanding the relevant aspects of brain development, attention, memory, executive functions, and development of conceptual understanding, you'll find your work becoming more effective and energizing as your students become more engaged and knowledgeable.

One foundation of the original book was the intense responsibility I felt as a neurologist, neuroscientist, and educator to increase other educators' awareness of and appreciation for the implications of *valid* neuroscience related to teaching and learning opportunities, in the face of so many "neuromyths" and "educa$h-in" products. It remains unacceptable that people without an academic background in neuroscience continue to make commercial products or become self-proclaimed pundits for personal profit, spewing forth books, presentations, or products with claims that are inadequately or not at all supported by neuroscience research.

Although educators are now much more aware of this problem, the pundits and profiteers continue to find and use invalid and self-serving interpretations of research—as well as commercially funded bad research—to promote their claims, books, and products. As a result, we need to be even more vigilant as myth busters. To that end, this book shares what I consider to be the most scientifically supported neuroscience research, background understanding, and resources you can use to distinguish illegitimate or exaggerated claims from valid conclusions. Equipped with the updated information and technology you'll learn about in this book, you'll increase your expertise at seeking the most authoritative studies and using the science to guide your own correlated strategies.

As you build your understanding, connecting the powerful discoveries of brain research to classrooms and curriculum, you'll find that you increasingly incorporate ways to help students learn more effectively and joyfully. With your increased knowledge, you'll be in the vanguard of educators better serving the needs of today's students and guiding fellow educators through inevitable transformations in how to prepare learners for the challenges and opportunities of the 21st century.

How This Book Is Organized

The sequence of chapters in this book follows the progress of sensory data through the brain as it is processed into long-term memory. In effect, the sequence charts the journey of how we process information—and thus of how we learn. Chapter 1 reviews the research, theories, and suggested strategies regarding factors that influence student attention and what triggers the brain's awareness. Chapter 2 explores how emotion affects learning and what it takes to get new information through the emotional filter. The journey continues in Chapter 3, with the construction of durable and applicable memory. Chapter 4 features the development of strong executive functions in this era of high demands on focus, self-management, goal-setting, prioritizing, organizing, judgment, reasoning, critical analysis, and innovation.

The chapters include some brief sections that supplement the primary content. Those titled Gray Matter provide scientific or technical information for readers who are interested in further exploring the topic or neuroscience that underscores the teaching strategies. Neuroscience Read-Aloud sections are practical guides for teaching students about the challenges in their developing—and still stress-reactive—

brains, and about how they can build the brain powers needed to achieve their goals with greater engagement and success. In addition, an online study guide is available for you to use as you progress through the book and for leading others in professional learning opportunities for further discussion.

Thank you for your efforts to be your very best so students can be their very best! Keep igniting!

—Judy Willis

1

How Red Wagons Capture Students' Attention

All thinking begins with wonder.

—Socrates

As I sat in the amphitheater in one of the older buildings on the Harvard University campus, attending the first day of my summer physics class, my mind was miles away from the lecture scheduled to begin momentarily. This was Physics 101–102, an intensive six-week summer alternative to the usual full-year course.

The students did not know one another, but most were taking the class for the same reason: it was a prerequisite for medical school. I sat there dreading the upcoming hours of listening, reading, and solving seemingly irrelevant problems. My thoughts shifted from these scientific endeavors to exploring the city of Cambridge after class, the cute boy in front of me wearing the tie-dyed Grateful Dead shirt, and my pile of dirty laundry that would soon walk away on its own.

Suddenly, the swinging door leading to the lecture area burst open, and a man who appeared to be in his late 50s propelled himself into the room, crouched on a little red wagon. He wore a wizard's hat and was aiming an activated fire extinguisher at the wall. This was my introduction to Professor Baez, demonstrating Newton's third law of motion—that for every action there is an equal and opposite reaction.

It was a lesson I never forgot but sadly never emulated until 30 years later, when I left my neurology career and became a teacher, trying to capture the attention of my students. I recalled how powerfully that memorable lesson engaged my attention and wondered how teachers without red wagons and fire extinguishers could focus students' attention.

My subsequent investigations of the neuroscience research about attention led me to understand why that physics lesson worked. Further, it showed me that other uses of novelty and excitement through strategies of surprise, unexpected classroom events, dressing in costumes, playing music, showing dynamic videos, displaying comic strips or optical illusions on a screen, and even telling corny jokes could capture my students' attention and promote initial connections to the lesson. I learned that if I tapped into their natural curiosity and marshaled the power of predictions, I was more likely to sustain their attention throughout a lesson or unit. I also found that I could employ activities to develop students' executive functions of focused awareness and distraction inhibition. With these strategies in place, my students were better able to attend to and engage with lessons and more successfully engage in the process of constructing understanding and durable memories.

The Brain's Gatekeeper: The Reticular Activating System

All learning begins with sensory information, but not all the sensory information available from the senses and environment is accepted for admission. For sensory input from what you hear, see, feel, smell, and taste to become memory, it must first be admitted by the brain's attention intake filter, the *reticular activating system* (RAS), shown in Figure 1.1 at the top of the brainstem (in the lower brain). This operation turns out to be very competitive. Every second, millions of bits of sensory information from the eyes, ears, nose, taste buds, internal organs, skin, muscles, and other sensors bombard the brain. Notably, though, only a tiny fraction—about 1 percent—of all that information passes up through the attention filter (see Figure 1.2).

The RAS is an attention-entry filter for incoming sensory information. It is key to arousing or "turning on" the brain's heightened level of receptivity to input. Soon you will learn how it is programmed in favor of letting in sensory information that's important for survival. Then we'll explore the development of more top-down attention focus

FIGURE 1.1

Reticular Activating System

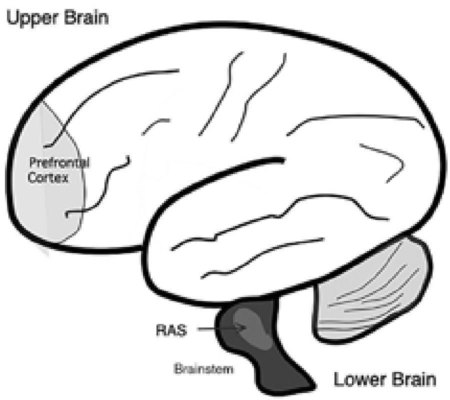
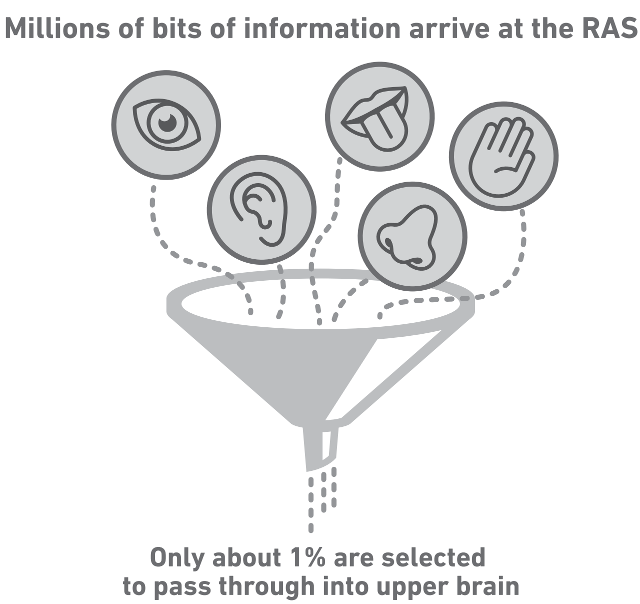


FIGURE 1.2

From Input to Output: The Selective Filter of the RAS



management as children grow. Top-down management of attention focus refers to the ability to direct attention to a particular stimulus or event in the environment (Katsuki & Constantinidis, 2014). These management circuits increase one's ability to actively dictate some of the sensory information to be accepted by the RAS.

The Priorities of the First Gatekeeper

The work of the RAS follows the survival-oriented programming of other mammals living in unpredictable, often harsh environments. Because the capacity for intake is so limited, the selection process for what gets in must be rapid and efficient. To support survival success, it makes sense that priority intake scrutinizes for potential threat or for survival resources (e.g., food, shelter, mates). This scrutiny is reflected, then, in priority going to sensory information concerning what is changed, unexpected, or different in the environment (Brudzynski, 2014).

With its programming as an alerting filter, it is understandable how the RAS responds instinctually to what is new in the environment (Garcia-Rill, D'Onofrio, & Mahaffey, 2016). Living things need to respond to changes in their environment to survive. A rapid response to novelty optimizes the chance of survival. Mammals need shelter from sudden storms, access to new sources of water when streams dry up, and places to escape to when danger is imminent, so priority attention to the unexpected or unusual is helpful in revealing new available resources for these potential future needs (Awh, Belopolsky, & Theeuwes, 2012).

What RAS Programming Means for Students

The strong reaction to novelty makes sense for this more primitive system in the human brain, but it presents a challenge when teaching information that may not evoke interest or effort. If the RAS does not select the information delivered in a lesson, little will be "learned," so we'll be looking at how to incorporate RAS intake boosters into instruction. Before describing the relationship of the RAS intake to learning in students, let's briefly consider why we adults are not as prone to paying attention only to what glitters, sparkles, moves, or pops. Simply put, adults' neural networks related to top-down attention focus are more mature. These circuits, in our highest cognitive centers located in the brain's prefrontal cortex (see Figure 1.1), develop into more efficient circuits that allow us to send messages down to the RAS to influence what information it takes in.

The RAS response to the sensory information received affects the speed, content, and type of information that gains access into the higher-thinking regions in the prefrontal cortex. These top-down attention control circuits continue to develop through the twenties. Your interventions to strengthen these circuits can boost students' influence on what information passes through their RAS filter. Further, they can learn and incorporate strategies to block intake through the RAS of input that is irrelevant to the goal or task at hand (Petersen & Posner, 2012).

By neuroscience criteria, students' brains are always "paying attention." The RAS continually filters which sensory information gets in. Often, however, what gets in will not be the information you are providing in your instruction or through students' reading and homework. Students are frequently criticized for not paying attention, but we now know that failure to focus on classroom instruction does not mean their brains are inattentive. The RAS is paying attention to (letting in) sensory input, but unfortunately it may not be related to what is being taught at the time.

Because students' environments are full of new and enticing information from the visual, auditory, and kinesthetic inputs continually surrounding them (sometimes plugged into their ears from their devices), teachers are challenged to guide students to select and focus on the intended information. It takes guidance and effort to build their abilities to resist some of the distracting input competing for attention through their intake filter systems.

Neuroscience Read-Aloud

What Gets Your Attention?

Your body has millions of nerve-cell endings that receive information from your senses—the sights, sounds, smells, tastes, touches, and movements around you and from within your own body. However, only about 1 percent of this information ever reaches your brain for further processing. Your brain can't process the millions of bits of data it receives every second, so it has a gateway, called the *attention filter,* to select what gets in. When you know the characteristics of what type of information gets through this filter and into your brain most easily, you can take control of your attention filter and decide what you want to pay attention to.

Your attention filter is programmed to give first priority to things that are new, unusual, or unexpected. That's why the focus of your attention shifts when something in your environment changes. For example, although you may start off focusing on a lecture, your attention will likely be pulled away when your senses admit something new, such as the sound of friends talking behind you, the flash of flickering lights, the breeze from the window, or smells from the cafeteria. The good news is that understanding what gets priority entry through your attention gateway will allow you to recognize the distractions and redirect your attention filter intake. You can build your skills to recognize that you have become distracted and choose to refocus your attention on whatever you choose.

Opening Attention Intake

We all come across lessons or units that don't inherently capture our students' interest. Although you've no doubt developed effective strategies to jump-start students' attention, understanding how *novelty, curiosity, surprise, the unexpected,* and *change* can influence the RAS can expand your toolkit.

There are many creative ways to infuse your subject matter or lesson with a bit of novelty and curiosity. Despite the glitter of some of the examples that follow, we're not suggesting that "edu-tainment" with bells and whistles is the simple and sole answer to holding students' attention. These examples can be altered to fit a wide range of topics and subject areas. Some require advance preparation, whereas others rely on materials that you probably have on hand or involve a simple shift in your presentation style. Here are some favorites for captivating the RAS.

Show video clips available on the internet about the upcoming topic. In college, one of Malana's professors launched his social psychology classes with a relevant clip from the television show *Seinfeld*. The human foibles portrayed on the show were an engaging way to bring social psychology principles to life while capturing the attention of students in a large lecture hall.

Play music related to the coming lesson. For example, some jazz before a discussion of *The Great Gatsby* or the theme music from the game show *Jeopardy!* before reviewing for a test would engage learners and set the tone for the activity to come.

Move in a different way. For example, if you walk backward during your normal activities while students are entering the classroom, the novelty can spark their interest as you reveal the day's topic of instruction—negative numbers, going back in history, past tense, flashbacks in literature, "backward" analysis, or hindsight about events leading up to discoveries.

Speak in a different voice or vary your cadence or volume as you read aloud, describe a scientific phenomenon, or recount a historical event.

Use suspenseful pauses before saying something important, because silence is novel.

Wear a hat or even a costume relevant to the topic. Malana and her classmates looked forward to their AP biology class because their creative teacher would frequently dress and accessorize to fit the theme. Her skeleton earrings and T-shirt accompanied her anatomy lessons, and all manner of flora and fauna were represented to pair with her lectures on botany and zoology. Despite the challenging content, her playful nod to the theme of the day captured her students' notice and lightened the mood.

Make alterations in the classroom, such as a new display on a bulletin board. A vase of flowers on the front table could draw attention to an art lesson on Georgia O'Keefe, a language arts lesson focusing on sensory details, or a discussion of pesticides or the globalization of agriculture.

Greet students at the door with a topical riddle along with a hello. For example, the following classic riddle could be written on a large sheet of poster paper next to the door for students to read as they enter the classroom: "I have streets but not pavement; I have cities but no buildings; I have forests yet no trees; I have rivers yet no water. What am I?" As students come into the classroom, they will find the answer: maps! This novel introduction can lead to a lesson on cartography, the features of maps, different types of maps, what information is included and excluded from maps, and even the creation of student maps.

Hand students note cards with a math problem (review) before they enter the room. Explain that calculating the answer will provide them with the number of the table at which they will sit that day.

Start with an unusual fact or offer a provocative quote. Invite students to consider who might have said it and why, and how it might connect to the day's theme. For example, you could post the following quote for students to ponder, initially without an attribution, before a chemistry discussion on entropy, a lesson on seasonal changes in ecosystems, or an analysis of relationships in a novel: "Nothing is absolute. Everything changes, everything moves, everything revolves, everything flies and goes away." You could pose questions such as, Who might have said this? What might this person have been referring to? How could the quote relate to the topic we are going to discuss today? Following the lesson, you could return to the quote and ask some follow-up questions: In what ways is this quote similar to what we learned today? How does it differ? What else could it connect to in chemistry, ecology, literature, and so on? This quote was said by artist Frida Kahlo. How does that information affect your reflections?

Use color to highlight something novel. We know that colored flyers in students' Friday folders tend to get more attention. Color and unusual color changes, such as a picture of a red river or a purple polka-dotted tree, do the same in class openings.

If taking attendance, have students say a response word instead of the usual "present" or "here." Your prompt can be "What was the color of your first bicycle?" Not only will color activate attention, but classmates' curiosity about their friends' bicycles may reduce the class disruption that can occur during the boring process of taking roll.

Use extremes. For example, because mammals survive in unpredictable environments, it would be reasonable for priority sensory selection to alert them to things that are more extreme than the rest of the environment, such as a huge wolf or a swarm of bees. You could use extreme numbers to add a surprising or dramatic element to a math word problem related to teaching the metric system, such as "The 3-month-old girl threw the ball 3,000 meters farther than the pitching machine did. Calculate the distance in feet that she threw it." You could also use outrageous statistics to prompt discussions at the outset of a topic. Books such as *Guinness World Records* have many real-life examples of extremes.

Start your presentations with a joke. The following pun would be a playful intro to any number of science or math activities. Q: Why didn't the sun go to college? A: It already had 27 million degrees!

Dazzle with surprising visuals. Often when students came into my math class, I had optical illusions projected, provoking their interest and conveying the message that they should always look beyond the obvious.

Start a lesson by mentioning relevant community or school events of high interest that can tie back to the lecture topic of the day. For example, if the local city council voted to build a parking lot instead of a skateboard park on available land, students could debate the pros and cons of the decision and consider the economic and political forces that led to the final vote.

Recall a personal anecdote from your own life that connects to the subject. For example, Malana's middle school Spanish teacher introduced lessons with stories about her time spent studying abroad in Spain and volunteering for the Peace Corps in Costa Rica. The tales were brief but rich with descriptive details and humor, and they helped the students focus and find meaning within the vocabulary or grammar lessons that followed.

Facilitate students' movement by speaking from different parts of the room. As they move their heads and eyes to see you, their visual sensory input changes with the shifting background.

Take students to an unexpected location to jump-start your lesson. A quick walk outside to a green space to lie down and "listen to the earth" ties in beautifully to the first chapter of the novel *Esperanza Rising,* in which the protagonist does the same. If an outdoor space is not available, a brief visit to another area on campus might work to provide novelty. Even having students sit in a different part of the classroom, switch seats, or stand up during the introduction of a lesson will alert their brains to pay attention.

Ask a question about something that students would be curious about related to the coming lesson. For example, "Why do you think monarch butterflies navigate their way about 3,000 miles (4,800 kilometers) each fall from Canada to Mexico? Each butterfly makes this journey only once in their lifetime, so how is it possible that they don't lose their way?"

Keeping Attention After the Red Wagon

Even better than using momentary novelty or change to open the RAS filter is *prompting more sustained curiosity* (Gruber, Gelman, & Ranganath, 2014). Curiosity is an intense and basic impulse critical to survival. From infancy, young brains need to make sense of the world in order to survive. Infants possess a sense of wonder, which merits preservation during school years to enhance both the memory and joyful learning. If you boost students' curiosity before or during a learning experience, the information becomes more desirable and memorable. When students are curious about something, the brain favors intake of sensory information to explain the unusual and unexpected. This curiosity motivates them to persevere in seeking information to fill the gap. Ultimately, the curiosity that triggered the initial attention becomes a source for sustained interest as the unit continues.

Advertising at the Beginning of a Lesson

Movie trailers are designed to gain the attention, curiosity, and interest of an audience. These "coming attractions" are advertisements that inspire the viewer to want more. They are usually edited to be dramatic, creating suspense by hinting at what the film is about but leaving out most of the details. The viewer, now enticed, wants to watch the entire movie to see how all the teasers resolve. Even movie posters showing a few key characters or an exciting scene spark interest.

You can advertise upcoming lessons in a similar way, using a variety of high- and low-tech tools to provoke curiosity about what's to come. You could use a poster from an existing film to spark curiosity. For example, an image from *Fantastic Beasts and Where to Find Them* could advertise a unit on the taxonomy of the animal kingdom or ecosystems and habitats. You could also create your own posters using photographs from past or present classes, or images that you create or find online. Posters could depict what people were able to do, find, or create because they had the knowledge you will be presenting.

You can tap into open-source videos and photos that come with certain computer programs. One such program is Animoto (https://animoto.com/education/classroom), which offers teachers a free Animoto Plus account to create their own promotional videos to engage curiosity and attention. Use the video at the beginning of a unit to entice your students with relevant images, video clips, music, and text. Use the following URLs to view some of the advertisements made by participants in my workshops:

- Funky Fraction Trailer at http://animoto.com/play/hJIiMYgkAHKHf7CLVhf3Kw
- Fractions: Yes We Can! at http://animoto.com/play/RZzA6MAHaGdcvsAv9FLcLA

Animoto can be a powerful tool when students use it to create videos to symbolize their new learning. This activity helps to build concept understanding and memory.

Building Curiosity Before a Lesson

Just as providing an enticing preview in the form of a poster or an Animoto video can spark interest at the start of a lesson, advertising several days *in advance of* a unit builds curiosity. For example, you can hang a series of engaging posters related to what students are about to study. Build interest by adding hints and new posters over a few days. This technique can be particularly helpful when a dull but critical and required section of curriculum is approaching.

An example was my use of *Star Wars* movie poster ads. I added a new one daily for four days, with the last one proclaiming, "24 HOURS UNTIL THE FORCE ARRIVES." The next day, the students came early and eager. I was swinging a paper cup on a string. When they were all attentive, I stopped, and a marble rolled out of the cup as I explained centrifugal force. Students' enhanced curiosity set their intake systems with a state of positive anticipation that harnessed attention. Similar "forces" for the same posters could include forceful verbs, exclamation points, forces of nature, forces that changed history, magnetic force—and no doubt others you can think of.

Another way to build curiosity is in the form of a wall puzzle. Take or make an engaging poster or picture related to the next week's unit. Cut it into five pieces, and each day add one more piece to the growing puzzle. Students will show more and more interest in what the puzzle might represent and be inspired to make predictions about what they'll soon get to learn.

A colleague described a technique used by his professor to promote medical students' curiosity before seeing the hospital patients to be evaluated the next day. The students were primed with the names of five disease processes, three of which would be revealed in the next day's patients. Their curiosity prompted them to read about all five possibilities and to really want to know which ones they could correctly identify after their reading. (This is an example of giving an authentic purpose for students' reading.)

Using Predictions to Sustain Attention and Engagement

Humans are naturally curious and want to know more about new experiences, things, or events they don't understand. This characteristic dovetails into a natural extension of the RAS priority to alert to changes in pattern, the novel, and the unexpected. After curiosity provokes RAS intake, students' receptiveness is sustained when they can make predictions about the stimulus that evoked their curiosity—the sight, sound, object, statement, picture, question, and so on—envisioning what it does, how it works, and what it has to do with the lesson.

Prediction prompts even further interest by activating the brain's instinctual need to know the *result* of our choices, decisions, actions, or answers (more on this related to dopamine in Chapter 2). When you provide opportunities for students to make predictions, such as how the curious sensory input or other novelty connects with the coming lesson, they remain more attentive to sensory input (through your instruction and their discovery) to support their ideas. Attention is sustained further as their brains seek to find out if their predictions are correct (Hunter, Abraham, Hunter, Goldberg, & Eastwood, 2016).

The following examples demonstrate ways in which you can include opportunities for making predictions into your lessons.

Discrepant events. These happenings are unexpected and puzzle the observer. Something that does not appear or turn out the way the brain expects promotes enhanced attention intake as the brain seeks an explanation (Griffiths, 2015).

Gray Matter

Patterns and Predictions

The system of storing information in related patterns (explored in Chapter 3) is a positive survival system that enhances the accuracy of prediction (and future memory) in animals. The brain makes predictions (responses to changes or choices in the environment) based on activation of memory networks constructed over time in response to the outcomes of choices or predictions made. As experiential data accumulate, these stored memories become the basis of more successful future predictions, interpretations, or responses (Peng, Zheng, Zou, & Liu, 2015).

You can capture students' attention because they want to know how to make sense of something unexpected. Place a white carnation in a vase containing blue food coloring; after a few days, it will show blue coloration in its petals. At that point, place the carnation in a clear vase with clear water, present it to your students, and invite them to figure out what happened. Or, out of students' sight, rub a balloon on a wall or your shirt. As you hold it over students' heads and their hair stands up, ask them to predict why this might be happening. In both examples, students will likely be curious to learn if their predictions accurately explained these mysterious phenomena and will sustain focus as you reveal the science behind transpiration and cohesion in plants or static electricity.

A mid-lesson discrepant event using curiosity and prediction is a great RAS rebooter. Set an orange previously dipped in liquid nitrogen on a table or counter in front of the room and "inadvertently" knock it off the surface. In its liquid nitrogen–induced frozen molecular state, the orange, which appears normal, will startlingly shatter into dozens of pieces when dropped. Ask students to predict how the surprising event might connect to the topic to come. After making their predictions, students will readily sustain their attention for topics from physics, to the breaking up of the Austro-Hungarian Empire or the polar ice caps, to the breaking down of complex problems into smaller ones, or to a famous breakup in literature (ah, poor Romeo and Juliet!).

Mystery envelopes. Creating a bit of suspense and cognitive dissonance can be as low-tech as a manila envelope! This example comes from a 4th grade social studies unit Malana taught about the California gold rush.

After the students had learned about the activities of the forty-niners who had rushed to the state to search for gold, Malana wanted them to consider the impact the miners and gold seekers had on the indigenous tribes of that region. Although they had studied Native Californians throughout the year, they had not yet considered them in the context of the gold rush.

At the start of the lesson, she held up several manila envelopes with large question marks on them and said, "Inside these envelopes are pictures of tools that people in California used in 1849. What do you predict might be in these envelopes?" Students eagerly called out tools used by gold seekers at the time: pans, picks, shovels, sluice boxes, dynamite, and so on. After their predictions, she passed out the envelopes to small groups of students and asked them to explore and discuss the contents. Inside, students found images of arrowheads, grinding stones, reed baskets, canoes, and other tools used by Native Americans.

The images caught the students by surprise and prompted them to consider anew the people already established in California before the wave of newcomers rushed into the wilderness seeking their fortune. This unexpected shift in perspective captured her students' attention and encouraged them to consider how this clash of cultures affected the well-being and way of life of the indigenous people of California.

Previewing. Before teaching a new topic, invite or assign students to preview the text (in class or at home the night before) and predict what they'll learn and what they might especially enjoy in the coming unit. Without the stress of having to "learn," students can engage simply to build curiosity.

Previewing is especially useful for things that will jump out to the RAS; students' RAS filters will be drawn to bold prints, pictures (especially of faces and animals), big empty spaces, and similar images. After a few minutes of previewing, ask students to share what they noticed. These collective observations and predictions will arouse their attention circuits as the reading and unit continue.

Unexpected objects, or the power of a radish. Like many children, you once may have objected to radishes as a garnish on your plate. Imagine students walking into your classroom and finding a radish on every desk. Instead of prompting disdainful looks, these radishes can become sources of novelty and delight.

When I first used a radish on each desk as a prediction stimulator, students were—happily—more enthusiastic than I had expected. Some even asked if they could keep theirs and eat them when we were finished. The radish was not an unfamiliar object, but having one on their school desks was a curious situation and certainly a change in the usual pattern. I told them that the radish would be linked to their upcoming unit and encouraged them to keep an open mind as to what that connection might be. Now their attention was activated to admit "clues" to the puzzle of a novel object on their desks as they remained engaged and motivated to discover explanations and make predictions.

This novelty triggered an enthusiastic and far-ranging discussion. For example, for a unit on westward expansion, I posed questions related to the radish as they progressed. One question that was carried throughout the unit was "How could your radish relate to the experiences of people during westward expansion?" Their written responses showed much more depth of understanding and compassion than those of students in previous years. Here are two examples:

- Tribes that farmed needed good soil and rain but were given the worst land when they were forced onto reservations. Their poor harvests made them bitter like radishes.
- The colonists kept the best land for their own farming and grew green, leafy crops like the radish leaves.

Making Concrete Predictions

After their curiosity has been provoked and initial predictions encouraged, students sustain greatest attention if they all make predictions, have multiple opportunities to revise or add to these predictions, and independently write them down (or otherwise respond, as with clickers). Providing multiple opportunities for conjecture creates a learning environment in which students remain focused and interested because they now want to know what you have to teach. The reason it is important that all students participate is that brains that are displaying curiosity and making predictions will be far more invested in the information that follows.

Imagine being with a group of friends who make a wager about the number of attendees at a sporting event. They are likely to be more observant to their surroundings and alert to the announcer's comments than a group member who does not get in on the wager.

For prediction to entice the brain to stay connected with information, the brain owners must remain invested in their predictions. For students to really consider the information and make enthusiastic predictions, they need sufficient time to analyze the question (or source of curiosity). When a teacher routinely asks questions and calls only on students who raise their hands, many of their classmates stop actively making their own predictions, especially when the student called on gives a correct response before the others have had time to consider their own. The brain finds no pleasure in trying to make a prediction when it expects that someone else will give away the answer. Having all students think about and write down or click in their predictions, without calling on any individual, gives everyone a chance to be an active participant. Here are some ways to do that.

Whiteboards or response cards. You can ask students to predict what a curious item might have to do with the day's class or to answer a simple question such as "Is a lizard a mammal or a reptile?" They can write their predictions on individual whiteboards or use response cards. Response cards could be preprinted with words or phrases such as yes/no, true/false, or I agree/I disagree, and students can point to their answer. Instructing them to hold their predictions close to their chest when they show you their answers relieves them of the fear of making mistakes because others won't see their responses. You also can tell if students need more time when a number of students haven't yet held up their responses. Making this observation eliminates the question that students are often too embarrassed to answer: "Who needs more time?"

Clicker systems. The digital exchange of communication in "wired" classrooms provides another way for all students to make predictions and respond to teachers' questions. This system can be expanded to show them an ongoing tabulation of class responses so they can further evaluate their predictions. Studies of undergraduates using clickers with feedback-system links have reported improved learning outcomes (Anderson, Healy, Kole, & Bourne, 2013; Deslauriers, Schelew, & Wieman, 2011). In such a clicker system, much like individual response cards or whiteboards, the teacher can ask a question, and students respond with their individual yes/no, numerical, or multiple-choice letter answers. However, with clickers, the teacher can see each individual student's response, as well as the class responses as a whole. This feedback provides immediate guidance, so teachers know if they need to revise instruction on something missed by a number of students, or if they should avoid tedious repetition of information already mastered.

Without formal clickers for tabulation, a low-tech version of getting feedback from students uses simple preset response cards with the letters *A, B, C,* and *D* in each corner. Before doing an experiment, for example, you could ask, "What will happen to the balloon's volume as it rises into space?" Students put their heads down on their desks and hold up their response card pointing to their chosen letter (or simply hold up the number of fingers that represent their responses from multiple choices listed as 1 to 4). After the various possible responses are counted and the tabulation written on the board, students lift their heads and follow up with partner or group discussions or further investigations before voting again.

Open-ended questions. Questions that do not have a single correct answer and that are student centered (connected to students' interests or experiences) can maintain interest and curiosity—and keep predictions coming—especially when students have a variety of ways and times to respond and revise. For a whole-class discussion, allow enough thinking time before calling on any respondent. Another option is to allow individual thinking time and then divide students into pairs or small groups, where it's much less stressful to make predictions and even mistakes. These opportunities promote brains engaged in the curiosity, prediction, and feedback reward experience that keeps students on track.

Embracing Teachable Moments to Sustain Interest

A migratory duck once flew through an open window in my 5th grade classroom and flapped around in a panic, bumping into walls, until I opened an outside door and it escaped. Although the event certainly triggered a huge and exciting disruption, it became a teachable moment when I was able to set aside the day's lesson plan and let students share their questions, concerns, and suggestions. From that random duck, they expanded into a student-directed discussion and inquiry about the loss of natural rest stops for migrating birds due to human encroachment on the land.

Although curiosity remains a driving force in attention and learning, we often see children gradually construe school as a job where they must follow someone else's agenda and not their own curiosity. You can recapture that curiosity and passion for learning when you take advantage of experiences they (or you) didn't expect that take place at school, triggering their attention as a powerful tool to connect with learning and wisdom in the moment and beyond.

You have probably observed students' passionate reactions to unexpected or unplanned events that ignite their emotions—perhaps after an assembly with an inspirational speaker or the announcement of a momentous news event. Teachable moments might come when you announce that a class member has unexpectedly moved away or when a butterfly flies in through the classroom window. Sometimes you don't have enough time to follow up with these potential teachable moments, but when you can, take advantage of your students' heightened state of attention and awareness.

To help the teachable moment become a focus rather than a distraction, consider the following options to sustain students' engagement and connect it to learning goals.

Prompting conversation. Older students in particular may be reluctant to open up about their personal responses or interpretations of an experience. Student-centered questions can facilitate their personalizing of the experience. Have the students discuss as a whole class, with small groups, or with partners the things that surprised, interested, or disturbed them. You can also ask what more they want to know or what they would like to do about what they just saw, experienced, or heard.

You've no doubt shared powerful assemblies with your students during which they heard speakers provide firsthand accounts of compelling personal stories, perhaps sharing the struggles of living with physical challenges, years of captivity in a POW camp, or the traumas seen as a first responder. These speakers can naturally ignite teachable moments and discussions. Sometimes your teachable extensions in the classroom will be facilitated by your previewing the topic. With your background knowledge, you'll be able to develop ways to sustain the effect of these speakers.

Journaling or written reactions. After a bit of class discussion, you can encourage reluctant participants to connect with their heightened interest and emotions through writing. This approach certainly can help all students to focus more clearly on both their feelings and the content of the information and to make connections. These writings can be mostly private, but you might invite students to share a phrase or sentence with the class. Later, their writing can serve as prompts for more formal essays or editorials about the subject. You can compile these into a class compendium posted on the bulletin board or sent home to parents, submitted to a local or school newspaper, and even forwarded to the motivational speaker who prompted the reactions.

Extending teachable moments. When teachable moments stem from highly emotional class responses, the shared compassion can strengthen the class community. A communal emotional experience, with students giving and receiving comfort and understanding from each other, builds bonds that can be recalled during times of conflict. In such times, a class community can again express the caring feelings they shared earlier. Once, when a series of arguments about handball-court rules at recess seemed to be disrupting class harmony, I said, "Remember how we were able to comfort each other after our hamster died? Can we use those caring feelings now as we work out our handball-court problems?"

Questions students raise about the events that inspired a teachable moment have future value; they are filled with the emotional importance of that powerful shared experience. You can collect a list of the questions raised by these moments and place them on a wall chart for future consideration. If the emotional moment was a terrorist act, for example, students might raise both philosophical and historical questions that could be applicable to future lessons in history, literature, or even science: Should terrorists who are arrested receive the same rights as other people accused of crimes? Was terrorism ever part of the American struggle for independence or minority rights? How are buildings designed so they implode (fall inward) instead of exploding outward when powerful detonations occur?

Referring to the questions on this list can enhance the personal significance of future lessons about related topics. The questions, originally written in response to the emotional surge of the attention-grabbing event, will rekindle some of that emotional energy, and students will respond with the heightened engagement and personal connections that propel a memorable lesson.

Powerful opportunities arise when we support students' responses to the effect of teachable moments. These opportunities can help them develop their skills of critical thinking and open-mindedness. After all, aren't those the skills we hope they will use in response to emotionally charged issues when they are adults and future leaders?

Elevating Attention Skills in Executive Function Networks

Effortful control of attention develops gradually throughout childhood and young adulthood, with a maturing and strengthening of the executive function communication networks. You can promote this development by providing opportunities for students to build top-down influence on their attention filters. Focusing and concentrating for long periods can be challenging for students—as it is for all of us. You can help them improve their abilities to stay on track longer by developing classroom opportunities that exercise those executive function networks that direct and sustain attention. Chapter 4 provides detailed discussions of the whole topic of boosting executive function; here, the focus is on some strategies for building the skill sets that promote attention focus.

Building Attention Skills Through Practiced Observation

You can help students build attention skills with guided experiences for sustained focus and observation. After considering opportunities to build their focus and observational skills, we'll look at strategies that promote students' self-awareness of their attention control capabilities.

Opportunities for younger students. With younger students, games and physical activities can be incorporated into learning to provide powerful opportunities to help build focus and extend self-regulation (Rueda, Posner, & Rothbart, 2005). The following games can be played at any time or incorporated into instruction.

- Encourage slow (but curious) observations, like following clouds moving in the wind, jet contrails spreading across the sky, or a snail slowly moving in the yard. Observations can be recorded in science journals or used to inspire artwork or creative writing.
- Toss slow-moving balloons instead of balls. While reviewing vocabulary words, students could toss balloons back and forth. A student could say a word and its definition as the balloon slowly arcs through the air or name all of the synonyms for a particular word that she can recall before the balloon is caught by another student.
- Draw a winding chalk trail with two lines students can walk between, using focused attention. The lines could follow the plot of a story, a historical time line, or geometric shapes.
- Play Follow the Leader using subtle or precise movements mixed in with broader ones. The movements could mimic those of characters in a book, behaviors of animals, or scientific principles such as the life cycle of a frog.
- Play games that require children to think or wait before acting on their first response (e.g., Simon Says or Red Light, Green Light) to build their skills of delaying immediate responses.
- Build concentration and focus by letting children find Waldo or subtle differences between two otherwise identical pictures. Students could compare and find the differences in similar maps, graphs, animal markings (patterns on the fur, feathers, scales, or skin), habitats, works of art, or photographs of natural phenomena such as sunsets, ocean waves, and waterfalls.
- Practice mindful awareness by having children intentionally use all their senses while experiencing an activity. For example, a classic introduction to mindfulness is to have students thoughtfully explore eating a single raisin as they draw their attention to all of its sensory details. This activity could carry over into a writing assignment invoking sensory details, an art lesson on textures

and shading, or a science lesson on dehydration and the evolution from grape to raisin. (Mindfulness practices in general can be a powerful way to enhance focus and attention in people of all ages. We discuss mindfulness in more depth in Chapter 2.)

An opportunity for older students. You may have heard about an experiment done in some police academies during the first few weeks of the program. A confederate of the teacher runs into the class, steals the teacher's briefcase, and runs out. The students are then asked to write down all the details they can recall describing the intruder and the intruder's actions. After they have written their reports, they are told that it was a setup, and the scene is reenacted. Predictably, they are astonished and embarrassed by how inaccurate their own eyewitness accounts were.

The experience just described dodges a high-stress individual reaction because participants see how many details were missed by *all* classmates. As such, they are receptive to the lesson to be learned: paying careful, studied attention is quite different from passively watching and listening.

You can produce a similar situation in the classroom; however, make sure that the classroom visitor's actions will not alarm students. For example, you can invite a colleague unknown to the students to come in with a basket of rose petals. (In advance, coordinate positions in the room so you cannot see her.) Have her walk to the back of the room, silently sprinkling the flower petals, and leave before you turn around. Prompt students to write a brief description of the visitor and her actions, including as many details as possible, such as hair color, clothes, and height. Did she make eye contact? Keep her eyes down? Shift them from side to side? More extended questions could invite conjecture about why the person came to the classroom. Did she seem nervous or confident? Where did she go upon leaving? Encourage students to give reasons for their interpretations. After the discussion, have the visitor return and do a reenactment so that students can notice the discrepancies between the event and their recall.

While their curiosity sustains their interest, you can explain that the observational experience reveals that their brains' attention intake is not always accurate and frequently overlooks much sensory information (e.g., descriptive details). The explanation will help them appreciate the value of attention-control focus, especially in emotionally charged situations when clear thinking is most challenged. You can certainly motivate some students' interest further by letting them know that professional detectives or investigators in science, medicine, crime labs, and archaeology have been trained and work actively to develop their observation and focused-attention skills so they can be successful in their jobs.

Transfer the insights from their observation of the unexpected classroom visitor to other experiences incorporated in your instruction. Let the students know they'll be developing those same observational skills as they observe a scenario, listen to a passage you read from a book, or watch a short video. After the experience, have them repeat the "stranger in the room" process of first writing what they recall unprompted, then adding to their observations in response to questions, and finally making interpretations that they support with evidence. They may also choose to reread or review the image, passage, or video to identify further details. Through repeated practice, they will incorporate the observation-prompting questions as part of their own independent observations, thereby increasing the quality and quantity of sensory input they can accurately perceive.

Elevating Attention Skills Through Metacognition

Attention is not just a simple process of information getting through the attention filter. Attention is a combination of self-awareness—recognizing the pulls on attention (both externally, in the environment; and internally, influenced by thoughts or worries)—and prioritizing the array of sensory information to accept the most important and block the distracting (Vossel, Geng, & Fink, 2014).

Becoming aware of the impact of distractions (distraction awareness) and learning how to avoid or minimize that impact (attention keeping) are two interventions that can strengthen students' developing executive functions of attention, concentration, and distraction-blocking control.

Distraction awareness. You can guide students' recognition of when they are less efficient at understanding or focusing on learning as a result of distractions and help them build skills and habits to inhibit the influence of distractions (Marshall, Bergmann, & Jensen, 2015). Explain to students that the ability to self-regulate what does and does not get their attention is still developing in their brains and can be strengthened by practice, similar to exercising a muscle. Plan for ways for them to recognize their progress as their attention-focus skills build. (See Chapter 2 for more about feedback on progress.)

Students will come to better understand the effect of distractions with a demonstration of how their focus and learning are reduced by distractions that you produce. For example, after explaining what you are about to do, you can provide similar types of lessons under a variety of distracting conditions (e.g., turn on a radio, repeatedly drop books, have a colleague come in several times and interrupt your lesson). Following these lessons with noncredit, self-corrected quizzes enables students to gain more insights about the impact of distractions on their learning. Class discussions after these experiences will be enlightening and provide an opening to discuss strategies.

After you moderate a class discussion about distractions and students have a chance to share strategies they use or could use to combat them, they'll be ready for the next step: advance preparation. Help students keep notes of what situations, subjects, class activities, or learning environments are most likely to stymie their attention control (e.g., an assembly, a class speaker, student presentations, recess when other students can be heard playing outside). Give them time to prepare before these situations: "We're about to go to the computer lab. If you recognize one of your attention-control thieves, which strategy will you be ready to use to keep control?"

Teaching students about their attention-keeping powers. A skilled teacher at Wichita Collegiate School in Kansas prepared a class list of attention robbers and attention-keeping strategies, some of which are presented here.

Attention Robbers

- Side talking
- People trying to be silly in class
- People making sounds at desks—clicking pens, humming, moving chairs
- Outside noises
- Too many decorations

- Teacher talking too much
- Not enough sleep
- Being hungry
- Being upset about something in your personal life

Attention Keepers

- Tell your teacher if you are having a bad attention day
- Stand at the desk
- Sit for success (move to a seat farther away from distractions or temptations)
- Employ noise-canceling headphones
- Bring a water bottle
- Get sleep and eat breakfast
- Use a cardboard privacy "office" when doing desk work or taking tests
- Prepare your mind to focus in advance when you know it will need to

When teaching students about strategies that build brainpower, their recognition of what they can get from their efforts can be motivating. Here are some examples from class discussions about what students thought they could get from building their powers of attention over distraction:

- Remembering the content of classes so I can do homework more efficiently, accurately, and in less time
- Knowing the question or topic when I'm called on in school
- Keeping track of my assignments and what materials I need when and where (e.g., things I need to bring from home for school)
- Reading a book and keeping my mind on it
- Staying focused (even during boring classes) so I remember what is taught and don't have to spend time relearning it for homework and tests
- Following all parts of directions
- Being alert to trick questions and finding my mistakes on tests
- Not being thought of or criticized as "scattered," "inconsiderate," or "irresponsible"

- Being aware of what pulls my attention off task so I can stay on task and take control of my time

Surprise students today and help them build attention-focusing skills, and you will be rewarded by their successful memory retrieval months from now. Your interventions for attention focus will empower them with the attention-intake boost they need early on. Similarly, your ongoing interventions will encourage them to build and use executive functions and higher-order thinking to sift through information, form connections and relationships, and achieve the ultimate goal of instilling new knowledge solidly into their memory storage centers.

2

How Emotions and Stress Affect Learning

No one cares how much you know until they know how much you care.

—Theodore Roosevelt

Peter was an extremely bright, dedicated student with the intellectual potential and constructive ambition to be a high academic achiever. He had moved to the United States from Southeast Asia in 4th grade. In addition to the challenge of transitioning to a new country, Peter was experiencing the struggles of divorce, illness, and death in his family.

I knew that providing opportunities for academic challenge and success would allow him more time in his comfort zone: intellectual pursuits. Knowing his situation helped me monitor his stress level and adjust the academic stretches accordingly. Not only did Peter find the school day a time of respite from stressors at home, but also, because both he and his caring mother put a great deal of value on school success, his excellent and accelerated schoolwork was a source of joy for both of them during their trying times. The following letter expresses their thoughts:

Dear Dr. Willis,

Peter is so appreciative of you and talks about you all the time to other people. The following is what Peter said about you as his 5th grade teacher.

"I think that the vocabulary and spelling tests really improved my English. I like the way Dr. Willis teaches. I also like the way she writes and gives me detailed comments, so that I can correct myself and enhance my writing and reading skills. The way she helped me in the social studies was by teaching me how to take notes, and I learned to read the pages and summarize them in notes. These helped me to understand American history.

"She is very benevolent. I will miss her very much, but I will also remember how kind she was to me. That's why I respect her very much. Her personality traits made me feel comfortable and respectable."

Sincerely,

[Peter's mom]

Ours is a stressful world in troubled times. School classrooms can be a safe haven where academic practices and classroom strategies provide children with emotional comfort and pleasure as well as knowledge. When teachers use strategies to reduce stress and build positive emotional environments, students gain emotional resilience and learn more efficiently at higher levels of cognition.

Where Did the Joy of Learning Go?

We know that most children anticipate kindergarten with awe and enthusiasm—especially when one or more older siblings are already in school. Young children may certainly be anxious about starting school, but those anxieties usually revolve around fear of leaving a parent or the security of home. The idea of being a student is exciting. Most kindergarten or 1st grade students speak passionately about what they learn and do in school.

What was actually happening in schools, though, became apparent to me indirectly in my neurology practice. As standardized test requirements constrained curricula, the need for greater emphasis on direct instruction limited curiosity-driven exploration and joyful learning. I noted increasing numbers of children and adolescents sent to my neurology office by schools and parents for evaluation of possible ADHD, oppositional-defiant syndrome, obsessive-compulsive disorder, social anxiety syndrome, petit mal epilepsy (staring spells), Tourette's syndrome, or other neurological causes for their mounting behavior difficulties.

When I evaluated these patients, I didn't find a concomitant epidemic of these conditions, so I went to observe classrooms. There, I wondered if their disruptive or unusual behaviors were most often indicative of their brains performing normally *in reaction to* the curriculum changes now mandated. Teachers were now expected to dish out facts for memorization, with less time for the interesting activities, projects, experiments, field trips, group activities, art, music, PE, and other things that made learning joyful. Classroom climate and learning experiences had shifted so that students spent an inordinate amount of time memorizing facts without being able to engage in the many interesting activities that promote more powerful learning. The problem was that the school experience had become stressful, usually because of boredom ("I already know it" or "I don't care about it") or frustration ("I don't get it, never learned it, don't know why I need to know it").

Burdened by boredom, frustration, or lack of engagement or motivation, my patients were doing what they were inherently programmed to do when their emotional monitors reached high stress levels. Their behavior displayed the limited, involuntary responses coming from the reactive lower brain as stress diverts control into the default region dedicated to survival, not thinking.

Actually, when joy and comfort are scrubbed from the classroom and replaced with homogeneity, and when spontaneity is replaced with conformity, students' brains distance themselves from effective information processing and emotional self-management.

Studies based on neuroimaging and other neuromonitoring techniques reveal that students' comfort level has a critical impact on information transmission and storage in the brain. The factors found to affect this comfort level—such as self-confidence, trust in and positive feelings for teachers, and supportive classroom and school communities—directly relate to the state of mind most compatible with successful learning, remembering, and higher-order thinking. The highest-level thinking, making of connections, and "aha" moments are more likely to occur in an atmosphere of passionate and supported learning, where students of all ages retain that kindergarten enthusiasm, embracing each day with the joy of learning (Hermans, Henckens, Joëls, & Fernández, 2014; Schwabe, Tegenthoff, Höffken, & Wolf, 2012).

The Amygdala: The Emotion-Dependent Conductor to the Higher or Lower Brain

Once sensory information enters the brain, it can be routed to one of two ultimate destinations: the *prefrontal cortex,* also known as the *higher* or *thinking* brain, which consciously processes and evaluates information; or the *lower, reactive, automatic brain,* which reacts to information through instinct rather than reflection. The prefrontal cortex accounts for less than 20 percent of the human brain; the rest consists of the lower brain (Passingham & Smaers, 2014).

Central to the brain's response to information flow is the *amygdala,* a small, almond-shaped structure deep in the brain's *limbic system,* whose functions relate to emotion and memory. As with many brain structures, we have two amygdalae, one located in each hemisphere. The cellular activity of the amygdala, at any time, directs what information passes to and from the cognitive and reflective control networks in the prefrontal cortex (see Figure 2.1).

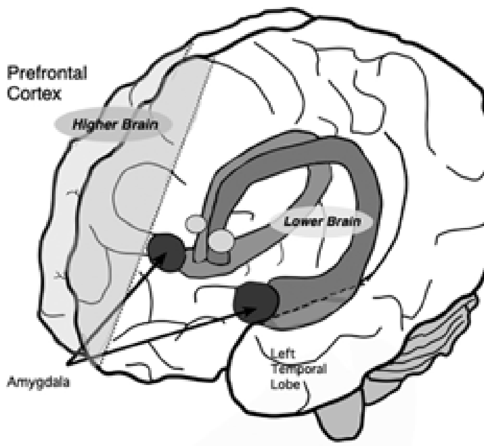
In the normal state of alertness, without high stress, the amygdala allows input from the senses to reach the prefrontal cortex for reflection by the neural networks of executive functions. There, the input can ultimately connect with prior knowledge to be constructed into developed and long-term memory (Schwabe, Joëls, Roozendaal, Wolf, & Oitzl, 2012; Seehagen, Schneider, Rudolph, Ernst, & Zmyj, 2015).

However, the amygdala reacts intensely to stress, fear, boredom, frustration, or perceived threat. These stress states increase metabolic activity in the cells of the amygdala. When this takes place, information flow through the amygdala to the prefrontal cortex is significantly limited (Motzkin, Philippi, Wolf, Baskaya, & Koenigs, 2015).

The amygdala can be considered an emotional switching station. In a high-stress state, the flow of information into the higher brain is reduced. If the new information coming through the attention intake system cannot not pass through the amygdala's filter, it may not gain

FIGURE 2.1

The Limbic System of the Brain



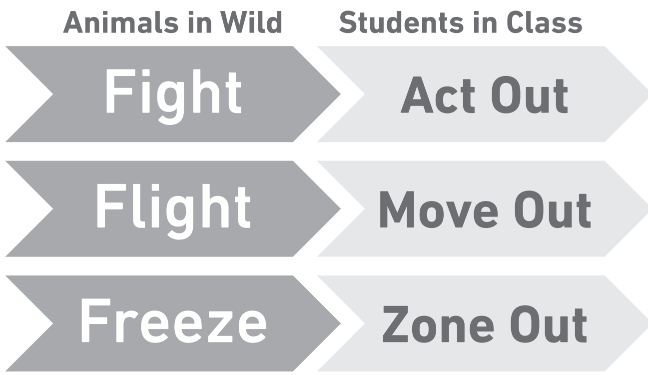
access to the prefrontal cortex. If this information flow is limited by a highly stressed amygdala, it may be conducted to the lower, reactive brain, where responses are involuntary.

When students are stressed, anxious, or confused, their lower, reactive brains have narrow sets of behavior patterns, similar to the survival-oriented lower brains of other mammals: fight/flight/freeze. As shown in Figure 2.2, students' reactive brains respond to the stress by either acting out (disruptive behavior), fleeing (frequent trips to the bathroom or the drinking fountain), or ignoring as much as they can (zoning out, switching off, or daydreaming). In these states of lower-brain control, with minimal diversion of information into the prefrontal cortex and memory-association regions, information entering the attention filter is only minimally processed into memory (Lupien, McEwen, Gunnar, & Heim, 2009; Quesada, Wiemers, Schoofs, & Wolf, 2012; Valizadeh, Farnam, & Rahkar Farshi, 2012).

In these circumstances, behavior—even though it is not voluntary—may be interpreted by teachers, coaches, parents, friends, and the students themselves as intentional misbehavior. It is important to understand that these reactions represent common misinterpretations

FIGURE 2.2

Responses When the Lower Reactive Brain Is in Control



and to share this understanding with students and parents. They need to grasp that these apparently willful actions may well be representing involuntary primitive responses.

It is also important to note that potentially stressful events do not necessarily lead to a stress response or to the same stress response in all individuals. The students' background experiences, resilience, and level of stress at the time can all influence how their brains interpret and cope with a stressor. These differing factors can explain why some students are much less affected by potentially stressful circumstances than others (Vogel & Schwabe, 2016).

The Impact of Chronic Stress

The prefrontal cortex is particularly sensitive to damage from prolonged or frequent stress. Physical changes can occur with sustained or frequent stress that decrease the neural pathways (connections among neurons) between the prefrontal cortex and the amygdala, impacting memory and emotional self-management (Arnsten, 2009; Hermans et al., 2011; Hunter & McEwen, 2013; McEwen & Morrison, 2013).

Gray Matter

How Chronic Stress Changes the Brain

One mechanism by which chronic stress changes the brain is through the excessively increased or sustained release of higher-than-normal levels of stimulating neurotransmitters (catecholamines [epinephrine, norepinephrine], implicated in the fight-or-flight response) and glucocorticoids (cortisol). These substances provide useful boosts when the stress-activated amygdala directs input to the lower, reactive brain, because they drive rapid-response behaviors that could be life-saving during suddenly dangerous situations. However, persistently high levels of these catecholamines and glucocorticoids lead to structural weakening of the communication networks that allow the prefrontal cortex to send reflective, thoughtful behavioral cues to the amygdala and the lower brain. The result can be further impairment of memory construction as well as immune-system dysfunctions.

Neuroscience Read-Aloud

What Gets Through Your Emotional Filter?

Your brain filters sensory information from the world around you entering into your brain. When you are anxious, sad, frustrated, or bored, the information may be sent into your reactive brain instead of your thinking brain. Your reactive brain does one of three things with the information: ignores it, fights against it as a negative experience (sending signals that may cause you to act inappropriately), or avoids it (causing you to daydream). If information gets routed to this reactive brain, it's unlikely your brain will truly process the information or remember it.

When your stress levels diminish and your interest is high, you can control what information gets to your thinking brain and memory. By calming your brain, you can have greater control over which sensory data from your environment your brain lets in or keeps out—and influence which information gets admitted to your thinking brain, which is called the prefrontal cortex.

Under stress, your brain may "choose" a behavior that is not very helpful because it is trying to protect you. For example, if studying for a test hasn't been very helpful in the past, your brain might discourage you from studying in the future. Or, if you felt embarrassed asking a question aloud in class, your brain might keep you from raising your hand again. These are automatic responses that happen without you "thinking" about them or "choosing" to do them.

It is normal to be frustrated when your behavior is misinterpreted and your teachers think you don't care, aren't trying, are lazy or irresponsible, or are seeking attention by being purposely disruptive. It helps to realize that you likely are not doing these things voluntarily. Your brain is receiving input into its lower, reactive regions. The problem intensifies when you start believing your behavior is your fault. When you continue to feel unsuccessful, your self-confidence and motivation drop, and the cycle only gets worse. Your brain loses confidence that effort will produce progress and so withholds it. You get further behind, and success becomes harder and harder to achieve.

The good news is that you can override the reflexive automatic behavior of your lower brain. With mental awareness and effort, you can push the decision-making process out of the involuntary default circuits and into the prefrontal cortex, where the superpowers of mind over matter known as executive functions take control with reason, judgment, and goal-directed behavior.

Preserving the Child in Every Learner: Teachers as Guardians of Classroom Climate

Back in 2007, I wrote "The Neuroscience of Joyful Education," my first article for educators about providing students with optimal learning experiences and conditions. Since then, I've focused much of my research on the factors that most critically influence how the brain learns best, and which strategies could *preserve the child in every learner.* Further, I've tried to ensure that joyful learning thrives in an educational climate filled with opportunities for students to channel their youthful information-seeking enthusiasm, a climate that avoids classrooms becoming places where interest withers due to the stifling curriculum demands. As the "guardians" of the classroom climate, teachers obviously play a critical role.

Neuroimaging and neuroelectric-recording studies of the human brain allow us to see what happens when students are stressed or affected by positive and negative emotions (Hermans et al., 2014; Schwabe, Tegenthoff, et al., 2012). So how can teachers create environments where destructive anxiety is low and still provide enough challenge for each student's brain to be suitably stimulated?

Supportive student–teacher relationships engender powerful forces for promoting a positive classroom climate and minimizing students' emotional response to negative stress. Data collected from classroom observations followed by student reports and grades have repeatedly supported the correlation of positive classroom emotional climate with student engagement and academic achievement. A key factor was teachers taking the time to make connections with their students, and at times becoming the only consistent influence in some students' tumultuous lives (Reyes, Brackett, Rivers, White, & Salovey, 2012).

Research continues to support what experienced educators have known all along about the important role that classroom-based emotional comfort plays in academic achievement. Optimal conditions develop when teachers promote an emotional climate that allows students to feel both safe and positively supported for engagement and free from perceived threats to their physical and emotional selves and their property. Eliminating all stress from students' lives is impossible, but when students feel safe, supported, and trusted, they have the comfort that enables them to return to the enthusiastic, positive curiosity they had in their early schooling. In such an environment, they can be most receptive to learning and thus channel their enthusiasm into new explorations.

Defusing High-Stress Experiences

"What is he talking about?" was my occasional plea to my med school classmate (and husband) when, during a lecture, I had lost my understanding of the professor's topic. My stress accelerated precipitously as I feared I might be missing something critical. Not only did subsequent lecture information fail to pass from my amygdala into any part of my memory, but my poor husband was dragged out of his sustained focus; eventually, he would give in to my sleeve pulling and stop listening momentarily to catch me up. In my brain, and in those of students with low tolerance for confusion or frustration, there is little room for losing understanding. The mounting stress triggers feelings of disorientation and helplessness and further impedes the ability to concentrate (Weymar, Schwabe, Löw, & Hamm, 2012).

The following are stress triggers that arise in the classroom, along with possible interventions. These triggers are not universal for all. Some students may tolerate them well; others can find them overwhelming. Review these to see if they might be unintended stressors for vulnerable students in your classes:

- **Overlooking raised hands and conveying you'll get back to their questions after you finish making your point.** This practice can be an amygdala stop sign for students who are still building their foundations and confidence in a topic's important understandings. A recommended intervention here is to let students raise hands or just make a subtle thumb wiggle if they have a question they'd like help with very soon. Just your nod of recognition or signal back, reassuring them that their questions will soon be answered, can drop their stress level so they can stay out of fight/flight/freeze mode.
- **Posting, reading, or verbally commenting on students' test or project grades in front of the whole class.** Sharing this information publicly can be a humiliating, paralyzing experience. Done correctly, sharing information about student work can reinforce and promote the positive motivation of savored successes related to progress rather than specific grades. This reinforcement can be accomplished by posting names on a "Goal Progress" list recognizing students when they make progress toward their individualized personal goals (see upcoming sections on achievable challenge and feedback). The posted list need not include what that specific progress was; moving from a *D* to a *C* can represent as much or greater progress as moving from a *B* to an *A*. It's enough to just recognize goal achievement.
- **Calling on students randomly to answer questions.** As you'll soon read, private individual-response systems decrease stress and encourage everyone to be more actively engaged. These systems can lessen the terror of being called on without volunteering, as well as soften the concept that being first to raise a hand in response to a question is a victory in a competition honoring only the student who answers first.

Getting to Know Your Students to Personalize Learning and Reduce Stress

We best serve our students by providing opportunities for them to explore and develop their own ongoing sources of motivation and resilience. *Kidwatching* is an intentional observation strategy that lets us recognize their unique strengths and interests (Owocki & Goodman, 2002). By incorporating elements of their strengths and interests into your lessons, you will be better able to keep their brains primed for successful learning.

Individualizing teaching to meet the needs of all students can seem daunting and almost impossible for a single teacher with 35 students or a secondary school teacher with 100 or more students a day. However, you *can* add elements of individualization, especially if you initially focus on a few students who seem to have the zoning- or acting-out behaviors that reflect higher stress.

Kidwatching is a dynamic undertaking, as individual students engage and interact with the learning processes. Students' actions, interactions, and responses go on whether we notice or not. We don't respond to what we don't observe, and so we miss those opportunities to gain insight into our students' strengths and challenges. So as not to lose information you can use to individually support students when needed, you can create a quick-access note card of kidwatching observations that will become motivators for each student.

I suggest starting slowly. Instead of thinking of the task as all or none, keep a pad handy on which to note down student comments or casual conversations in which students reveal special interests, pleasurable activities (with parents, friends, sports), awards or honors outside of school, and even the names of pets or their soccer teams. You can keep these notes in a general file. When you have time, every few weeks, add your pertinent insights to a file card with the student's name. As time goes on and you reflect on your kidwatching cards, you will likely find yourself making connections between students' learning strengths and interests. Your observations can lead to ways to engage students in new learning by helping them contextualize and connect the new information or experience with their positive past experiences and interests.

You could, for example, use the data you collect on students to create sample problems in a math lesson. The lesson will be of high interest to the class when they hear you enrich the problem with things you've learned about their classmates, including the names of siblings, sports they play, and organizations they're members of. Here's a specific example:

After finishing soccer practice with her team, the Falcons, Sofia had to babysit her younger brother, Felix, and their dog, Bingo. Her parents said that she would need to watch Felix and Bingo for as long as it took them to drive 10 miles each way to drop off some groceries for her grandma. If they drive an average speed of 40 miles per hour and spend 10 minutes visiting with Grandma, how long will Sofia need to keep an eye on Felix and Bingo?

You can use your kidwatching insights to support students with their social and emotional development too. Before a unit that you expect to be challenging for a particular student, it can be helpful to highlight areas in which the student excels (e.g., group work, art, computer skills) to help build the student's confidence. For example, when introducing a challenging biography unit, you can emphasize the importance that design and illustration will have in the final presentation.

If students are having difficulty making friends, use your insights from kidwatching to let them know about opportunities that could help them feel more connected to school and classmates—for example, through clubs, school or class community service projects, or lunchtime mini-productions or sing-alongs. When the activities ensure inclusion, they help students see options, not roadblocks.

You can serve students even further by documenting and passing along your observations to those who follow you as their teachers. Sharing insights about each student's most powerful sources of engagement and personal relevance can only support them on their educational journey.

Being Alert to Signs of Excessive Anxiety and Stress

Prevention is the best stress buster. Recognizing signs of an overactive amygdala will let you intervene before the "red light" reaction. When teachers take the time to make connections with their students, they become positive and consistent influences in students' lives. As you become familiar with your individual students' stress responses, you'll find yourself recognizing the signs even as they come into the room. Students who are stressed might need more frequent observation to see whether they are about to tip into their involuntary and unlearning lower brain's fight/flight/freeze reaction.

Write down and periodically review what you recognize as first and subtle signs that stress has shifted a student's brain from thinking to reacting. Clues vary among individuals, so consider a variety of ways in which students react to stress, including the following:

- Students who appear to zone out or act out may be manifesting a response to the stress of confusion, frustration, or boredom. Shortened attention focus may be their brains' way of shutting out anxiety-producing confusion about material presented in an unengaging or incomprehensible manner.
- When the number of students actively participating in a discussion or offering answers starts to dwindle, students may be confused or not interested.
- Although student questions generally indicate some confusion or students' desire for additional information, a sudden drop in the usual number of questions during a difficult lesson may signal confusion, anxiety, and fear, rather than comprehension. That signal should be a tip-off to quickly assess student understanding at that point in the lesson.
- Students may become unusually fidgety or talkative to neighbors. Such behavior might include digging around in their desks, pockets, or backpacks; passing notes; using their devices (e.g., phones, laptops); or turning around to say something to the person behind them.

When it becomes clear that students are struggling to keep up, or have disengaged due to disinterest or boredom, you can employ the following interventions and show that you acknowledge your students' feelings. Take a break, initiate syn-naps (discussed later in this chapter as a way to decrease stress), or use the individual-response system to get a read on how they are feeling or what they are remembering. If confusion seems to be the problem, students could write a few sentences about what they think was the main point of the lesson. Sharing their notes with a partner or two may resolve the confusion, provide comfort with the realization that they are not the only ones confused, or allow them to raise questions more confidently. This strategy can also be helpful if you get the sense that the majority of students have achieved mastery and are ready to move on. Their reflections may reveal their accurate understanding or demonstrate that they have misconceptions and that there is more to learn. Volunteers can read the notes for the benefit of the rest of the class.

Faculty Collaboration

Teachers can support students by looking for reasons for student behavior, especially negative changes, and having interventions at hand when needed (Hakvoort, Lindahl, & Lundström, 2018). It can be helpful to collaborate with teachers across the school to consider the stressors that may be negatively affecting a student.

Faculty meetings provide the opportunity to work together to help individual students going through stressful periods. Before a meeting, teachers who are concerned about unusual behavior or academic performance of particular students can circulate the students' names. This advance notice gives colleagues a chance to check their records and recollections for any recent changes they have noted in these students.

Here are two examples of observations and the interventions that followed:

- At the faculty meeting, it became evident that Rachael was sleepy in most classes and rarely brought in assignments on Mondays. Further inquiry revealed that she stayed at her father's apartment on weekends, went to bed late, and had no access to a computer there. Parent conference interventions and a trade to Friday nights at her father's house and Sunday nights back at her mother's house produced the desired outcome.
- As the faculty compared notes describing James's acting-out behavior, it became evident that he was particularly irritable and disruptive in his afternoon classes. The teachers on lunch recess duty recalled that he had not been playing basketball with friends as he'd done previously. The computer teacher reported that he'd been spending lunchtime alone in the computer room. Combining the information from his teachers' observations started the process of discovering how to help him reconnect with his former basketball friends and find new ones. For the next collaborative history project, his teacher placed him in a group of

classmates well-suited for potential new friendships. The music teacher successfully encouraged him to join the new synchronized drum club.

Faculty collaboration can also help increase students' emotional-academic connectedness by increasing academic relevance. These connections can be facilitated by integrating curriculum based on themes of high interest to students. For example, in upper grades, such a theme might be *corruption.* It could serve as the lens through which to view the present political climate, the carpetbaggers in the post–Civil War South, the character flaws in Dickens's *Oliver Twist,* the corrupting or corrosive effects of water rusting metal, corruption of the English language when misuse of grammar reflects negatively on an applicant during an interview, or the analysis of some critics implying modern art was a corruption of prevailing standards of beauty.

Consistency and Predictability

Before students can focus on academics, they must feel physically safe and emotionally secure. Although change is a great way to snag attention, a certain amount of predictability and consistency of rules promote a supportive climate. Alternatively, when the parameters of acceptable behavior remain unclear, materials lie in disarray, or rules are applied inconsistently, students may be distracted, confused, and unruly. You can avoid this situation when you ensure the emotional, physical, and property security of all students. It is appropriate to create challenges in the classroom, but students need to feel assured that they understand their teachers' expectations, grading systems, fairness, availability, and responsiveness. If students are confident about predictability in those areas, they have the foundation to explore and undertake creative risks. Collaboratively creating rules and expectations with your students, and reflecting on them throughout the year, enables students to build their understanding of behavior that promotes learning and a positive sense of community.

When students struggle with their behavior, you can redirect them in ways that avoid embarrassing them in front of their peers. For example, a gentle tap on the shoulder or a quiet reminder can be preferable to calling out their behavior in front of others. Establishing a place in the classroom or in a partner classroom where students can take a break or cool down can also help to defuse tension before a situation becomes disruptive. This can be a place that you ask students to go to, or they choose to go to themselves, when they are feeling upset or struggling to follow directions in class. If students' behavior has a negative effect on others, they should have the opportunity to make amends through words or actions. For issues that are difficult to resolve or require additional intervention, schoolwide programs such as *restorative justice* should be in place. Restorative justice programs support students in coming together to constructively air grievances and resolve problems (Fronius, Persson, Guckenburg, Hurley, & Petrosino, 2016).

Supportive Routines

Creating supportive classroom routines was a priority at Learning Without Limits Elementary School in Oakland, California, where Malana taught 2nd grade. Every morning, students, staff, teachers, and many parents and younger siblings gathered together in the courtyard to recite the school pledge: "We stand on the shoulders of those who came before us, as we grow into leaders who are passionate and care about making our world better. We are equipped with skills and knowledge, filled with curiosity, and we know that even when we face challenges, we will achieve!" With these words in mind, students and teachers would then head to their classrooms for a daily morning meeting.

All teachers at this elementary school had been trained in the Responsive Classroom approach to teaching and followed the program's structure for this daily ritual (Kriete & Davis, 2014). Each morning, back in the classroom, teachers would gather students into a circle and begin the meeting by having students greet one another by name. This routine would vary slightly to include clapping rhythms or salutations in various languages, but the practice of welcoming one another was always first. The teachers would then facilitate a time for group sharing. Sometimes students would share a few words about how they were feeling, or maybe name a color or an animal that represented their mood. At other times, several students who had something on their minds would take a few minutes to share their news. A brief, playful group activity or game would follow the sharing, and the meeting would conclude by reading a message that the teacher had written on the whiteboard. This daily routine took about 20 minutes. Although it was infused with academic content, the true purpose was to start the day in a comforting and predictable way and to set a tone of cooperation and inclusion. It also provided a chance for students to express their feelings and lighten their emotional load before diving into the day's lessons.

Malana and her colleagues found the morning meeting to be an invaluable investment in their daily routines. Over the course of the school year, it allowed students to feel supported by one another and secure in terms of how they would begin their day. One morning, during the sharing portion of the meeting in Malana's class, a soft-spoken student named Teo murmured that his dog had run away. After sharing a few details, he lowered his head as tears slipped onto his lap. After a brief pause, one of his classmates quietly rose from the circle and retrieved a stuffed animal from the library corner. She placed it next to Teo, who glanced sideways with the smallest hint of a smile. Soon, several other students followed suit, and after a few minutes Teo was surrounded by a mound of stuffed animals. By this point, Teo was starting to giggle. With the tension broken, his classmates joined in. The mood continued to lift as the meeting progressed with a fun game of Simon Says and a review of the morning message. Teo and his classmates went on to have a successful learning day. It is likely that Teo still felt sad and worried about his dog, but sharing his troubling news allowed his classmates the chance to offer their support and lift his spirits. Instead of carrying a secret sadness throughout the day, Teo could move on, knowing that his teacher and classmates cared about him.

The school pledge and morning meeting happened daily. Rain (when the meeting took place in the cafeteria) or shine, the first day of school to the last, students knew that no matter how their morning at home had begun, school would start with an opportunity to share school spirit and connect with their teacher and classroom peers. With this daily routine, students had many opportunities to practice the skills needed to build and show empathy, become active listeners, and share their feelings and stories with confidence. During times of low stress, they practiced these skills playfully. When times were more challenging, such as a student sharing the loss of a loved one, students were comfortable with one another and ready to express compassion.

Any routine, elaborate or simple, that provides a sense of community and consistency will help your school and classroom be a place where students want to be and feel that they belong.

Absences

Returning to school after several days or more of absence can be stressful for students. The usual teacher response is to give them information about the work they missed. Going a step further and asking if everything is all right establishes a bond with the student. Of course, this question needs to be asked in a nonthreatening way ("I missed you these past two days. What can I do to help you get caught up?") and must not appear to be an accusation to see if the absences were justified. Similarly, if a student has an excused absence for a school-approved event (such as a sports tournament or an important family occasion), recording the reason in your plan book will be a reminder to ask the student how the event went.

What a Positive Climate Looks Like

At Santa Barbara Middle School, where I taught, and at other schools where Malana taught and I've visited, student confidence is nurtured by several common factors:

- Teachers take the time to listen to students and acknowledge the value of their opinions and ideas.
- Students trust (through predictability built-upon experience) that adults who understand their mood swings and energy surges and dips will support them.
- Teachers embrace students' unique qualities and give them opportunities to be honored for their individuality.
- A school community of respect is modeled, valued, and consistently enforced.
- Thoughtfully structured academic, athletic, physical, and emotional challenges are scaffolded with the preparation and tools needed for all students to succeed to their highest potential.

- Schoolwide acknowledgments of success during class meetings or assemblies honor more than "best" athlete or academic achiever. Authentic recognition acknowledges students who reach their individual goals, help classmates, and contribute community or school service.

This student's note of gratitude to the faculty and staff, received 20 years after she went on to high school, underscores the benefit of a strong school community:

> *Our school gave me a safe place to explore and push myself academically, physically, and socially. The teachers cared and I knew they enjoyed their work. As students, we made real connections with the teachers and saw them as friends as well as mentors. That created an environment that promoted my best learning.*

Academic performance and behavior improve when there is less stress and more emotional comfort. Classrooms again become places where the imagination, spirit, and curiosity of students are encouraged, rather than being left outside on the playground as the school bell rings.

Syn-Naps: Stress Busters for All Occasions

Early in my teaching career, I was disturbed by a note left by a substitute teacher. The sub wrote that during the three days she was with my students, they were responsive during the first part of class, but many of them became inattentive, distracted, and even disruptive after about 20 minutes of her instruction. When I asked the students what had happened, they were of one voice: "She didn't give us our syn-naps."

What Are Syn-Naps?

Syn-naps are shifts in a lesson in which you have students engage with the material or each other (or both) in a way that uses a different brain network. These shifts allow the previously active regions, which could become inefficient after high-intensity work, to revitalize. Every brain needs periodic rests, during which neurotransmitters replenish and new materials process before progressing to the next topic.

I coined the word *syn-naps* as a way to embed the neuroscience of learning into our classroom language. The term provides an example of the use of word play because it implies a "nap." I would explain to students that in the brain's structure, synapses are the gaps or breaks between nerve endings that play a critical role in the construction of memory (see Chapter 3 for more about synapses).

Recall that for new information to become memory it must pass through the amygdala's emotional filter. When students' brains become anxious, highly confused, bored, or overwhelmed, the amygdala's activation surges until a stop-sign effect occurs. Syn-naps serve as restorative breaks, preventing overload of the circuits and interference with maximal conditions for memory storage; they also help maintain positive emotional states. Syn-naps provide an opportunity to maintain flow—to avoid the amygdala from limiting the flow of information moving to and from the prefrontal cortex.

Gray Matter

The Restorative Effects of Syn-Naps Brain Breaks

Even if students are unstressed by the pace or content of new learning, a point arises when the highly activated region of the brain becomes less efficient at conducting information. Syn-naps allow brain chemicals to revive in the newly depleted synapses, which are microscopic gaps between nerve cells where nerve-generated electrical information cannot pass.

These brain chemicals are neurotransmitters—such as serotonin, acetylcholine, tryptophan, and dopamine—that transport information across the synapses. At a synapse, the neurotransmitter triggers a chemical signal carried much like a passenger on a boat crossing a river.

Neurotransmitters are stored in small pouches called *vesicles* at the synaptic nerve endings. After neurotransmitters are released in response to an electrical stimulus traveling down the nerve, they float across the synaptic cleft to specifically lock onto matched receptors in the dendrite membrane across the synapse. Once the neurotransmitters hooked into the receptor have prompted the resumption of the electric signal to travel down the next nerve, two things can happen to them. A portion of the neurotransmitters floats back for reuptake by their previous homes in the axon's presynaptic storage vesicles; these neurotransmitters are ready for release the next time an electric impulse travels down that nerve. The rest are broken down and unavailable for use.

New neurotransmitter chemicals must be constructed to replace those destroyed, and that process takes time. When neurotransmitters are depleted by too much information traveling through a nerve circuit without a break, the speed of transmission along the nerve slows down to a less efficient level. When this happens, information processing takes longer or is decreased, leading to student frustration and less successful memory storage.

Planning Syn-Naps

When you do a physical workout, play hard at sports, or dance with all you've got, you work up a sweat and eventually burn out. That doesn't mean you leave the dance floor or walk off the playing field and go home to take a shower. You've learned that even a short rest or a change in which muscles you use can revitalize you and cool you off enough to return to the activity.

Syn-naps can be preplanned to restore the emotional state needed to return the amygdala from overdrive back to its optimal state for successful information flow. During these rests, the newly learned material has the opportunity to go from working or short-term memory to long-term memory (although it will not become a permanent memory until time and practice follow).

Depleted neurotransmitters rebuild within minutes if the break is taken before complete meltdown, but their rebuilding takes longer if they are severely depleted. The ideal is to prevent burnout by planning brain rests to occur before students display the first signs of fidgeting, glazed expressions, or distraction. By anticipating these overload/depletion times before they occur and scheduling syn-naps, you can avoid linking the topic just discussed with negative feelings of boredom that undermine future interest when it comes up again.

Depending on the intensity of the activity, the brain loses efficiency in about 10 to 20 minutes. Variables of age, the level of concentration, or challenges in the type of learning (e.g., intensive new learning, complex procedures, practice drills, note taking, or sustained strong efforts to maintain self-control in the face of high emotional tensions) can all accelerate the rate of depletion. Without breaks, students will eventually reach a state of neurotransmitter depletion and behave in unpredictable ways they often later regret. Learning stops.

What to Do During Syn-Naps

There is a difference between syn-naps and recess. Recess is usually unstructured free time for students. Syn-naps are planned shifts to activate different networks that have fresh supplies of neurotransmitters. This shift allows the regions that have been inputting the most intense brainpower to revitalize, allowing for optimal mood and memory.

You can stay on topic during syn-naps by varying how the information is provided or processed. Here are some suggestions for doing that:

- Read aloud from a relevant (and engaging) book about the topic.
- Have students draw a sketch or diagram related to the content.
- Employ "bodies of knowledge" activities, where students move in ways a character in literature or a person in history might have moved at a designated event, or move to imitate a biological, physical, or mathematical process.
- Tell a true anecdote about the author, historical person, or scientist when the person was the same age as your students. Personalizing the topic can boost interest and engagement, and it can be especially helpful when topics of study are necessary foundations but not of high personal relevance to students.
- Ask students to share with partners something about how the learning relates to their lives or interests; engagement can come from personal connections and relevance.
- Initiate a simple physical movement. Stretching, drinking water, or changing to an activity that stimulates another sensory system or neural network can often provide a fresh outlook.
- Take advantage of the break, and use the opportunity for students to identify and discuss similarities and differences related to the topic. The following techniques can be useful:
    - Drawing Venn diagrams
    - Generating mental images and thinking about what existing mental pictures come to mind in association with these new ones
    - Creating metaphors and analogies

During syn-naps, the newly learned material has the opportunity to pass beyond the temporary short-term and working memory while students replenish their supply of neurotransmitters and the amygdala cools down. After just a few minutes, students' brains are refreshed. They are ready to return to the next learning activity with receptive amygdalae and a full supply of neurotransmitters. Both they and you will reap the benefits of this restoration.

Emotional Self-Management

Emotions remain inseparable from students' responses to learning, engagement with school, and ultimate achievement. When students build strategies for self-management (also referred to as self-regulation), they open themselves up to more successful, motivated learning and positive school experiences (Mega, Ronconi, & De Beni, 2014).

Emotional self-control starts with emotional self-awareness, followed by emotional self-management. These abilities to control one's thoughts, feelings, and behaviors are still developing in the prefrontal cortex of students throughout the school years. As their executive function networks strengthen, you can facilitate students' emotional self-management by your modeling, imparting knowledge regarding the brain, as well as strategy-directed practice in class (Thorne, Andrews, & Nordstokke, 2013).

Increasing Receptivity to Interventions

Teaching students the neuroscience of how stress influences the brain empowers them with information that can renew their willingness to try. They understand that past failures are not predictors of their future potential. They learn that recognizing and changing their emotional state when stress builds increases acceptance of the insights and strategies you'll provide.

Neuroscience Read-Aloud

Recognizing When a Stress Response Is on the Way

There is a switching station called the *amygdala* between your higher-thinking brain control centers and your lower-brain response systems. When you feel stressed, fearful, upset, or anxious, the amygdala decreases the flow of information from the higher brain to the lower brain. This puts your lower brain, and not you, in control of your reactions—what you think, say, and do. For example, your lower brain has taken control when you do something without considering if it is the best choice—like playing a video game instead of doing difficult homework, saying hurtful things in anger to a friend, or losing track of what is happening in class because of an argument you had at lunch.

When stress inhibits the access needed for your control networks to be in charge, that does not mean you are a bad person. Remember, when you are in a high-stress state with your lower brain in control, your actions are no longer your voluntary choices. If you do or say things that you regret or that get you in trouble, those things are probably not intentional. These types of reactions are wired into your basic programming, though you do have to take responsibility for your actions.

The good news is that there are things you can do to keep the amygdala from getting into the high-stress state and to allow your highest brain centers to keep you in control. When you learn the warning signs of an emotional flare-up that can lead to stress, you can activate your brain's tools and resist the likelihood that your stress response will take control. It takes practice to build the self-awareness of your emotional state that enables you to know whether it is ramping up. As you learn what to look for, you'll soon notice how much better you are becoming at remaining in control.

The first step is to identify the emotional states that can lead to a stress reaction. To build awareness of what it feels like when your stress is about to hit the red zone, think back on a recent time when you acted out, responded without thinking, zoned out in class, or lost track of what the lesson was about and regretted it. Now think about how you felt or what was happening just before you lost emotional self-control. Did you feel butterflies in your stomach or muscles tensing in your neck and shoulders? Were your hands shaking or your thoughts jumbled, or was your vision blurred? Did you just feel angry?

As you build your ability to identify your feelings as they are starting to turn to stress, you'll be ready to activate the self-management tools that let you prevent the stress response from negatively impacting your choices and behavior.

Helping Students Build Emotional Self-Awareness

In a study in which students were prompted to identify and reappraise their own feelings of boredom, they had fewer bored episodes over time than they had experienced previously (Nett, Goetz, & Hall, 2011). Self-awareness is a skill you can help your students build with practice. Practice activates the brain to construct stronger and stronger memory networks that will be readily available to guide the learner to recognize and select a calming response to stress. This network can help students resist automatic, reactive responses; stay in the moment; settle their mind states; and reengage in learning (Berkman, Graham, & Fisher, 2012).

Here is an example of how you might guide students to build their skills at recognizing their emotional states and being aware of when their feelings are increasing in intensity. (The duration and frequency of the activities would vary depending on students' age and grade.)

An elementary school class would start with the first part of their emotional awareness training over about a week. During this week, set a timer to go off hourly to remind students to check in on their current emotional state. To help students identify their emotion and to keep the process efficient and quick, you can use a wall chart showing various emoticons of faces, each labeled with a single word describing an emotional state. The chart for younger grades will have fewer choices—for example, happy face, sad face, scared face, confused face—and the chart for older grades will have more expressions of emotions. The choices for an upper-grade class could include anger, frustration, sadness, happiness, and boredom. Prompted by the timer, students would simply look at the wall chart and either copy the face or write down the word representing their emotional state. There would be no need for any discussion, and routine activities would continue. Their responses are private.

After following this procedure for approximately one week, students move on to the next step, which lets them build awareness of the fluctuating levels of their emotional states—particularly stressful or fearful ones. The timer would still go off every hour, and students would identify their emotional state using the wall chart, with this difference: if they are experiencing the same emotion as at the previous check-in, they would make an arrow to indicate whether the intensity of that emotion has increased, decreased, or remained the same.

Near the end of each of these weeks, discussions may help students realize that they can perceive their own emotional states. This is an ability that many students do not actually recognize they possess, especially when they're feeling upset or disconnected. The second week's discussion would suggest that when they see negative emotional states increase in intensity, they can employ strategies to reverse that trend.

The intervention processes would be similar for students in secondary school, but because teachers see them for only part of each day, the timer could be set two or three times during each class until students have enough experiences to recognize their emotions and when and how they fluctuate. It can be comforting to recognize that even very negative feelings ebb and flow and rarely remain consistently heightened. It is also helpful to notice patterns of emotions getting stronger in a negative direction, which provide good opportunities for students to intervene with self-calming strategies.

Prompt students to discuss or journal about these questions: What did I notice just before my mood or behavior shifted? How do my mood and stress level influence my decisions and best choices? What can I call on to immediately feel better and get back on track? It is OK if students don't have ideas for self-calming strategies, because they will now be primed to learn from the examples that you—and their classmates—present.

Helping Students Build Self-Calming Strategies

After students gain the ability to identify their emotions and recognize growing stress, they are ready to learn self-calming strategies. Students must practice these strategies adequately to strengthen their calming neural networks so those networks can be instantly accessible when stressors appear. They can become so comfortable with a strategy that they can activate it without any noticeable change in their outward appearance.

Explain that you'll guide them and practice with them. These skills do not develop overnight, and it will take repeated practice, including some at home, for their brains to construct easily activated stress-busting tools that are entrenched in memory. Explain that, just like building muscles with exercise, the more they practice these mental exercises, the stronger these networks become.

Guided practice of any new strategy will probably have to occur daily for a week or two, and it may take even longer for habits to be firmly established. The proficiency goal is a skill strongly wired in their memory and easily retrieved when they realize they need it, and in a manner their classmates don't notice.

You might add one new strategy every couple of weeks for daily practice. Once they gain proficiency with about three strategies, they can choose which works best for them in varying stressful situations. Encourage them by reassuring them that their well-practiced calming strategies will put them in control of their choices. They can keep the flow of information running smoothly through their amygdalae to build strong memories and make good decisions.

With more heightened awareness of their emotional states and practice of stress-reducing strategies, students will better manage day-to-day stress and develop better focus and attention in the classroom. In addition to the strategies described in the following sections, many others are available, and perhaps you have personally found one that is even more useful to share with your students.

Calming breaths. Have students sit in chairs. Invite them to get comfortable, with their feet on the floor, eyes closed (if they are comfortable doing so), shoulders and neck relaxed, and hands on their laps. You can instruct them by saying something such as this:

> *With each breath, feel the restorative oxygen flowing through your lungs and spreading into your arms and legs and out to your fingers and toes. As you release the breath, imagine it expelling any stress it picked up as it traveled through your body. Continue for a few breaths, and feel your mind clearing. When you hear the chime, open your eyes, and you'll notice a pleasant calmness. Your senses are brighter. You're more aware.*

It helps to use a chime or similar gentle sound to alert them that the practice is over.

When students who are proficient in this strategy need to use it on their own, they may want to keep their eyes open to avoid notice by classmates. Although being able to use the skill without being noticed is part of proficiency, it is nevertheless a great accomplishment when students build the self-confidence, comfort, and pride to have successful self-management tools and to use their strategy without needing to hide it from classmates.

Visualizations. Calming visualizations can involve a happy event or location, an animal, or any image that provides comfort. The important thing is that a student visualizes the same scene each time, so that it becomes an automatic go-to network when needed.

Another type of visualization, called "the bubble," is helpful when students wish they were anywhere but in the classroom. That desire may be triggered by distracting sights, sounds, or smells; boredom; embarrassment after making a mistake; or hurt feelings caused by cliques or bullies. The goal is to reduce the immediate stress so learning continues and the student resists impulsive responses. Ultimately, the situation might require more direct interventions, but sometimes it suffices to just "get away" and feel safe.

To practice this strategy, students simply imagine blowing a giant bubble that only they can enter to expel stresses, worries, or distractions. No one can see the bubble, but when it's around them, they can hear and see clearly to permit the sensory input of the lesson. After they build their quick access to their safe bubble place through scheduled practices, invite volunteers to describe how it worked for them. It's great if volunteers can indicate specifically what stressor pushed them to enter the bubble while in class. When classmates realize that they had no idea the student was doing the visualization, it raises their confidence that they can also use their chosen strategy safely.

Directing and starring in your own play. A more engaging dual-role visualization provides a great transition into building awareness and control of students' emotional response in challenging learning experiences. Invite students to imagine themselves both as the director and the star of a play by giving the following prompt:

Imagine that the scene you're directing calls for the character you're portraying to act alert, clearheaded, and focused. You (the director) notice that you (the actor) are not following the script directions. As the good director you are, you meet with the actor and give instructions. Now engage in a self-conversation to help you portray the character so the audience sees a focused, alert performance, as called for in the script.

The Role of Mindfulness

Mindfulness is the state of being fully aware of the present moment without judgment. Sectors from businesses to schools have found the practice helpful for building focused awareness and observing one's sensations, thoughts, and emotions. A mindful state starts with purposefully returning one's attention to the task at hand when distracted. When practiced regularly in the school setting, mindfulness can help students to disregard extraneous emotional distractions and narrow their focus to the experiences or sensory input relevant to the desired goal (Kohn et al., 2014).

Malana found that an ideal time for regular mindfulness practice was following lunch recess, when her 2nd graders would return to class full of energy and emotion. They also often had grievances they wanted to air regarding playground interactions. The agreement was that after mindfulness practice, students could share their concerns if they were still feeling upset. With the lights dimmed, students would quietly enter the classroom and find their seat on the rug. They would close their eyes or gaze at a spot ahead of them on the floor. Malana would ring a soft bell, the students would focus on their breathing, and with gentle reminders refocus on their breath if they became distracted. After about two minutes, she would signal the end of the session and invite students to share how they felt. If anyone still had a concern to discuss regarding a lunchtime transgression, they were invited to share. However, Malana found that usually there wasn't much that students needed to discuss. The heat of the moment had passed, and they had moved on. Or, if they did still need to problem solve, they were less reactive and more reflective following the mindful breathing.

Developing the daily mindfulness routine took practice and patience. Initial giggles and discomfort gave way to a sense of calm and comfort. Over time, the routine became so secure that each day a different student would proudly lead the mindfulness session.

Mindfulness can be a powerful tool for helping students to recognize and calm their emotions while sharpening their focus for the learning they hope to accomplish. Resources for bringing mindfulness into the classroom are abundant on websites such as mindup.org and mindfulschools.org.

Stress Related to Stereotypes: Math

Mathematics is associated with powerful stereotypes, influencing some girls with the incorrect belief that they are born with lower math brainpower than boys (Ganley et al., 2013; Keller, 2002). In a study that demonstrated the power of this belief, subjects were given explanations for what was being tested. When the test was described as an evaluation of "complex math skills," girls scored lower than their male counterparts. When subjects were told that on the experimental math test they would be taking, girls and boys scored equally, girls' scores did indeed increase to approximately that of the boys (Spencer, Steele, & Quinn, 1999).

Informing students about stereotype myths can reduce the power of the stereotypes as stress boosters and motivation deflators (Blackwell, Trzesniewski, & Dweck, 2007; Crisp & Abrams, 2008). In one study, different groups of 7th grade girls were evaluated. One group was mentored by college students, who encouraged them to view intelligence as malleable. They were also taught about neuroplasticity and how learning, effort, and experience can strengthen their brains' information networks to increase their memory, understanding, and skills. They understood that, because of the power of neuroplasticity, they could choose how their brains grow and learn. The control group had no mentoring.

Compared to the control group, girls in the experimental group changed their beliefs about their control over their intelligence and success in math, turned in more homework, sought more extra help after school, and by the end of the year demonstrated acquisition of math knowledge and standardized test scores comparable to those of the boys. The findings were especially evident in students who were designated as being from low-income minority groups (Good, Aronson, & Inzlicht, 2003).

Negative Attitudes

Based on Malana's and my combined years of teaching math in grades 2, 4, and 5, and algebra in middle school, the complaint "I hate math" seems to the most frequent subject-specific woe. Even when students don't express their negativity so decisively, we hear rebuffs such as "Math is my worst subject," "Math is too hard and I'll never use it," or "Math's boring." And then there's "My parents said they were never good at math so they don't expect me to be any different."

The negativity often starts when students are young, and then, unchecked, builds up. Stress and low self-expectations related to math can come from stereotypical beliefs, parental negativity, frequent failure to understand math concepts, or fear of making mistakes. Much of early math learning is rote memorization, and students become discouraged when they mistakenly believe that speed and one right answer are the measures of their math intelligence and potential. Consequences of math negativity may include limited participation, low tolerance for challenge, falling further behind, behavior problems, and avoiding the advanced math classes needed for success in many careers after high school and college.

Moving from Negative to Positive Through Myth Busting

Among the math myths that abound are the following: You have to be very intelligent to be good at math; it is acceptable to be bad at math because most people are; and math isn't really used much outside of certain specific occupations. To help students reject these assumptions, you can help them understand how their brains work and that gender-related and other stereotypes and beliefs about special "math brains" are cultural myths not based on neuroscience. Knowing that they have authority over their own brainpower is a powerful message you can incorporate in teaching.

Here are some explanations you can offer students to bust these myths and help them boost their motivation and effort, with the new expectation that success is within their reach.

Myth 1: You either have or don't have a math brain. Many students believe that if their parents did not do well in math, their own genetic makeup will limit their potential. On the other hand—and equally challenging for students—is the belief that because parents told them that they found math "easy," their own struggles indicate their lack of a "math brain."

Parental frustrations can increase students' math stress. When parents say things like "I don't know why you're having problems. I had no trouble adding fractions with different denominators. It's so easy," students start doubting themselves. When students perceive parental frustration, they may shoulder the incorrect belief that they are letting their parents down if they struggle or ask for help, even when appropriate. The outcome can be falling further behind, not from laziness or inadequate brainpower, but because they lose confidence that their efforts will make any difference.

Reduce your students' reaction to their misperception of the genetic "good" or "bad" math brain by clarifying that, regardless of their past math experiences, all brains have the potential for success in math. Help them understand that effort and practice—even struggles—strengthen brainpower. They were born with, and will always have, the potential to achieve success in math, and with perseverance they will continually improve (see discussions of achievable challenge and feedback later in this chapter).

Myth 2: Math isn't important for everyone. "Math is not that important in most careers," "It's OK to be bad at math because most people are," or "Math isn't really used much outside of certain specific occupations in the real world" are comments that lead students to give up more quickly, especially if math feels like a hopeless struggle.

Dissuade them of their misperception of math as an isolated subject. Show them the extended values of math in ways they'll find inspiring. Find opportunities to show students how math is used in many occupations not directly focused on math, such as video game programming, aerospace engineering, architecture, animation, economics, and commercial design. Have them ask parents or people in professions they are attracted to how they use math in their work.

Guide students to see math as an accessible, valuable tool that helps them understand, describe, and exert more control over the world they live in. Offer your students experiences that inspire them to want to measure, question, and analyze things around them. Their eagerness to acquire the knowledge and mathematical tools to achieve those personally valued goals will grow from these opportunities. Stereotype-busting information about math, and math activities for all ages and skill levels, can be found on the YouCubed website (based on the work of Stanford University researcher Jo Boaler).

Boredom and Frustration

Boredom and frustration are frequent intruders that impede brain function in today's classrooms, with more than 20 percent of adolescents reporting *high* levels of boredom (Johnston, O'Malley, Miech, Bachman, & Schulenberg, 2014). Boredom can come from lessons having little personal relevance, or from instruction and drills covering information students have already mastered. The prevalence of boredom is particularly high when the required practice or tasks are overly tedious, repetitive, and monotonous, or so challenging they are excessively frustrating (Chin, Markey, Bhargava, Kassam, & Loewenstein, 2017). Boredom-triggered negative behaviors include negative behavior toward others, less productive work, withdrawal, and acting out (Bruursema, Kessler, & Spector, 2011). Frustration can be equally stressful, arising, for example, when some students don't immediately understand a lesson or feel they lack the capability to do so.

The Role of the Amygdala

Up to this point, our focus on countering stress has been through maximizing positive classroom climate, building self-management skills, teaching students about their own brains, and myth busting. These are all critical as foundational supports for reducing the excessive stress that impairs learning. We'll now go back to the amygdala and explore the reasons why sustained or frequent boredom or frustration can limit information flow, and suggest interventions for these most common school-related stressors.

As noted earlier in this chapter, when boredom and frustration persist or intensify, the amygdala reduces flow of information up to the higher brain, and memory construction can suffer (Acee et al., 2010; Hermans et al., 2014). In a stress-reactive state, with less efficient flow of reflective control networks from the prefrontal cortex through the amygdala, students have less self-management of their attention and emotions. When their amygdalae go into these hypermetabolic states (seen on scans because they are using more energy and oxygen), students are less able to access their prefrontal assets of intelligence, and their behavior output, unbridled, can be reduced to involuntary fight/flight/freeze reactions (Daschmann, Goetz, & Stupnisky, 2014).

If frustration reaches the high-stress level, the limited understanding can reduce their interest in the lesson and promote a feeling of being trapped in a hopeless or helpless learning experience. An example of this phenomenon can be seen in caged animals who lose their accustomed freedom of movement. Extended confinement can progressively raise their stress levels, shifting their brains into the involuntary reactive state. Manifestations can include uncharacteristic repetitive pacing, aggression, or even self-mutilating behaviors.

Similarly, as noted earlier, when students feel trapped by boredom and hopeless about engaging in satisfying activity or personally relevant or interesting learning, their lower brains can take control of their behavior. These involuntary behaviors, such as acting out or zoning out, might manifest as being disruptive, fidgeting, interrupting, or other problematic actions. Observers might incorrectly presume such students are cognitively incapable of doing the work. They may be mislabeled as lazy or intentionally oppositional, often with punitive consequences, when in fact their brains may be involuntarily reacting to feeling trapped by boredom and loss of freedom to choose what they do, hear, and study (Hermans et al., 2014).

From Frustration-Related Stress to Giving Up

When students are frustrated by repeated failure to achieve goals over time—whether related to oral presentations or adding fractions with differing denominators—they may stop making the effort. If the missed learning is critical, that withdrawal of effort can have enduring adverse impacts on their willingness to try other approaches. It may reduce their motivation and confidence, which can affect their choice of future courses and even careers (Young, Wu, & Menon, 2012).

Again, looking to our mammalian forebears adds a dimension of understanding. Imagine a young fox living in a den with three hills nearby. When a rodent runs by, the fox chases it to get the nourishment he needs. Things go well, and he often catches his dinner if the rodent runs up the first or second hill. He gets a nourishing meal and the bonus of intrinsic gratification from the dopamine burst that rewards his good choice (see "The Dopamine Reward System" section later in this chapter for more about the dopamine response). He ran up the hill and things worked out as hoped.

The third hill is very steep and has dense underbrush. When prey run up that hill, the young, inexperienced fox expends considerable effort to follow, but when he gets close to his prey, it always disappears into the thick underbrush. Not only are his nourishment needs unfulfilled, but he has also wastefully expended much of his energy reserve in the futile run up that steep hill. The brain's survival programming kicks in. It includes a special memory-storage system that keeps track of times when the effort to achieve a goal fails. The expenditure of the system's voluntary effort is linked to the expectation of positive outcomes, such as the pleasure reward of the dopamine response. Alternatively, the programmed response to repeated effort *without* positive outcomes prompts subsequent withholding of effort for similar endeavors in the future. This is, of course, a favorable survival system for our fox, preventing further use of his limited energy reserves for the low payoff that comes when he runs up that very steep hill.

The Fixed Mindset

Unlike the fox who saves energy and promotes survival by avoiding challenges likely to be unsuccessful, students who withhold effort after repeated failure can suffer negative consequences for their learning and long-term life opportunities. Further, when the repeated failures and withdrawal of effort revolve around critical understanding and foundational requirements, big gaps can exist in their knowledge.

Suffering repeated failures to understand, making frequent mistakes (even striking out in baseball repeatedly), or achieving low grades despite increased effort in hard subjects can promote learners to develop a *fixed mindset.* Mired in this state, students can lose belief in their capacity to succeed and believe that no amount of effort will overcome their limitations.

As students advance in grade level, their negativity can grow progressively year after year, with repeated failures or frequent or sustained boredom or frustration. Their stress reactions accelerate, and their efforts are likely to diminish. Their brains become less likely to expend the energy necessary to persevere, and their acquisition of knowledge further suffers. Without the needed foundation of knowledge to understand subsequent instruction, the gap between background understanding and the foundation needed for future learning widens, and they become even more susceptible to the onset of the stress-related amygdala response related to learning (Blackwell et al., 2007; Yeager & Dweck, 2012).

The Growth Mindset

Rather than feeling helpless about their abilities, students with *growth mindsets* feel more confident in their capacity to learn and change their brains. They tend to continue despite difficulty, select more challenging classes, be open to trying new strategies, and sustain effort and interest even through setbacks (Yeager & Dweck, 2012). The growth mindset in students has been correlated to more successful learning in a given year, compared to the absence of this mindset in other students (Claro & Loeb, 2017).

Neuroelectric studies of subjects with growth mindsets and fixed mindsets revealed differences in their brains' responses to making mistakes. Those with growth mindsets had significantly more brain activity in regions of attention and memory, and they rebounded well from their mistakes, including gaining accuracy compared to those with fixed mindsets (Moser, Schroder, Heeter, Moran, & Lee, 2011).

Teaching Students About Mindset

Many students become skeptical and doubt the possibility of improvement when they face challenge. Burdened by the negative baggage from criticisms, myths, and labels, they remain reluctant to put in further effort. They need to understand that these negative comments promote untrue assessments of their potential. This realization, and other interventions, will at least help motivate them to try again, and with your guidance, to succeed where they've failed before. Here are some examples of criticisms that are not valid for most students:

- If you are not succeeding in school, you are not smart.
- If you have trouble paying attention, something is wrong with your brain.
- Goofing off is willful disobedience, and if you'd just try harder, you would do better.
- You have to make do with the brain you were born with.
- You need a "math brain" to do math.

Students need to understand that their challenges do not arise from abnormalities in their brains or limitations in their intelligence. Further, their futures need not be restricted or limited by past failures.

With that understanding, students can get back on track and regain positive expectations to fulfill their potential for future successes.

What Learning Without Negativity Sounds Like in Class

Students who have been able to shift from a fixed to a growth mindset have been able to articulate this process. Here are quotes from students who recaptured their confidence and competence:

> *One thing that's really neat about math now is I'm not afraid to try new ways to solve problems or say what I think in a class discussion, even if I'm not sure. I'm not so panicked, so I actually can focus on what my classmates say in the discussion, and that gives me more ideas. I remember times I asked the teacher for help but was so nervous about the teacher or other kids thinking I was dumb that I didn't even remember the explanation. Now I'm calm enough to listen and really hear what I need to not be confused. —Jos, Grade 7*

> *I found out that with effort I could build more nerve cell connections, which means I have stronger memory. I can snag information I stored in one category, like learning about decimals, and apply it to something I need to do, like figure out money. I never believed in myself, and now that I know about my brain, neuroplasticity, and how the brain makes corrections in networks that make wrong predictions, I'm not surprised when I do well and I am excited to keep working, even when I make mistakes, because I don't think there are limits to the goals I can reach. —Kami, Grade 5*

Later in the chapter, in the discussion of interventions, you'll see how correlations from neuroscience research offer guidance in boosting emotional positivity and perseverance, as well as helping students relinquish a fixed mindset and adopt a growth mindset. First, however, let's look at a neurotransmitter that is one of the keys to promoting perseverance and engagement in the classroom and beyond: dopamine.

Opening Doors with Dopamine

Dopamine is one of more than 200 different chemical neurotransmitters carrying messages to and between neurons. Dopamine is made in the brainstem, a narrow column of critical pathways that sits between the base of the brain and the spinal column and has connections to the rest of the nervous system.

Dopamine is the neurotransmitter most closely associated with pleasure and intrinsic motivation. When dopamine levels increase, so does our sense of satisfaction and pleasure, and desire to persevere. Chances are that when you are immersed in one of your most rewarding activities, you experience these positive feelings that sustain your desire to continue participating in the activity and to repeat it when possible. Dopamine feedback guides the brain regarding the value of expending its limited internal resources, such as energy, attention, or time. As a bonus, other mental processes, including memory storage, comprehension, higher-level thinking, and creativity, can be enhanced with the increased dopamine (Anderson et al., 2016; Berke, 2018; Boot, Baas, van Gaal, Cools, & De Dreu, 2017; Cerasoli, Nicklin, & Ford, 2014; Robinson et al., 2012).

The Dopamine Reward System

The dopamine reward system correlates with the brain's programming to seek pleasure or experiences predicted to result in pleasure. All mammals have the drive to seek and experience reward, and motivation for the dopamine reward drives adaptive behaviors (Bergey, Phillips-Conroy, Disotell, & Jolly, 2016).

All animals must make predictions in order to survive. They must predict, for example, where to find the safest place to sleep, the best source of food, or the most abundant supply of water. To ensure that they will repeat the actions related to accurate predictions (e.g., the successful selection of the fork in the trail to reach a stream for water), the dopamine reward system sends out an encouraging dopamine boost when they choose the correct option (e.g., a path that leads to a stream). The pleasure derived from experiencing the dopamine boost will lead the animal to repeat the choice, behavior, action, decision, or response to a new stimulus in the environment.

Let's examine the dopamine reward system in terms of our fox, who learned to stop running up the hill where he never caught the prey. Because his brain is now focused on the two lower hills, where there are not too many places to hide, the fox frequently achieves his goal and catches his dinner. He certainly gets the immediate reward of the tasty meal, but more important in terms of directing his future decisions, he gets a dopamine boost and pleasure that are quite separate from actually eating the tasty meal. His brain experiences that deep dopamine reward and satisfaction as a result of having made a correct prediction. The successful prediction's release of dopamine, and the accompanying pleasure that his brain receives as feedback, will promote making this same prediction in the future.

So the fox will get a boost of dopamine by just looking at prey on the hill where he has been successful. This dopamine will also help enhance attention. As a result, the fox will be engaged in behaviors that are more geared to his successful survival and will avoid the choice of the steep, energy-expensive, and failure-prone hill that reduces his survival potential.

In humans, the dopamine reward system follows the same brain programming to seek pleasure or experiences that, based on previous experiences, are predicted to result in pleasure. This reward system facilitates subsequent motivated learning and enduring memory (Ferenczi et al., 2016).

The pleasure derived from achieving challenges is what we'll focus on to activate the dopamine reward system for positive emotional states, motivation, and growth mindsets. We'll look through the lens of the video-game model to find opportunities to engage learners, considering specific components that researchers have found to be the most compelling to avid gamers (Miller, Shankar, Knutson, & McClure, 2014). The essence of these components, rather than actual video games, can be used to inform instruction that compels our students to persevere through challenges.

After this next section, we'll explore how achieving challenges promotes students' dopamine release to facilitate the responses of pleasure, motivation, memory, and perseverance. First, though, let's consider other experiences that may trigger dopamine release. You've probably already discovered many of these by recognizing their positive and successful influences on your students. They include prediction, choice, music, optimism, movement, positive interactions with peers, being read to, acting kindly, expressing gratitude, and humor.

Some specific dopamine-boosting activities follow.

Prediction. Making predictions activates the dopamine reward cycle. In young children, this relationship is just beginning to develop. During those very early years, even actions we would not label as predictions can release dopamine, much as clear predictions do in older children and adults. For example, when young children request the same bedtime book each night and proudly proclaim what picture they "predict" will come up next, we know their proclamation is not really a prediction, because each night they repeat the same pronouncements about what's next. They've seen the same pages many times and have memorized their order. These proclamations about things they already know certainly do not qualify as actual predictions and would likely be an inadequate stimulus to release dopamine for school-age children. We might conjecture that the benefit of the generous dopamine reward in young children is what incentivizes their brains to be primed for predictions, feedback, and accuracy as they progress toward becoming more advanced learners.

In older children and adults, a dopamine reward for a correct prediction requires some degree of uncertainty as to the accuracy of the choice, answer, or decision. The attention boost from curiosity described in Chapter 1 is further enhanced by the prediction-making dopamine release. Because the brain seeks the pleasure associated with this dopamine release, it even prereleases dopamine that can promote success with the expectation of an upcoming prediction opportunity (Eshel, Tian, & Uchida, 2013).

Although educators may be concerned that the repeated failure of incorrect predictions will stifle the predictive process, there are ways to mitigate this unease. For example, using an individual response device system, such as small personal whiteboards, allows students to avoid the embarrassment of making mistakes in front of classmates. Plus, using the suggestions in Chapter 1 about providing opportunities for students to revise their predictions will keep interest high. Indeed, the dopamine reward system generates pleasurable feelings even when learners do not initially make correct predictions but start thinking that they are getting closer to being correct. With directed feedback, ongoing instruction, and continued effort, they gradually achieve correct predictions, maintaining sustained motivation (Eshel et al., 2013).

As learners continue to experience the pleasurable feelings generated by developing correct predictions, they increasingly experience positive expectations from corrective feedback. With these experiences, they increase their tolerance for mistakes and build the habits of a growth mindset (Robinson et al., 2012). As they experience success from perseverance, they become more resilient in terms of pushing themselves through boredom, frustration, and challenges. Their tolerance expands as they become more successful at pushing through setbacks and expanding their comfort zones of creativity and exploration.

Choice. In early research, providing the opportunity for choice improved test scores in a study in which two groups of students were given a battery of tests to take. The experimental group was given the option to select which tests to take, and in what order. That group reported less anxiety, and scores were higher (Stotland & Blumenthal, 1964). Giving students some freedom in how they demonstrate their achievement or progress toward learning goals for an assignment leads to a dopamine boost generated by choice (Parker et al., 2016).

Adding choice also helps diminish the paralyzing powerlessness some students develop as a result of their boredom or frustration. With choice, they benefit from a sense of empowerment that comes from finding personal relevance in their studies and a sense of ownership over their learning goals (Aelterman et al., 2019).

Choice provides an opportunity to use your kidwatching cards. At the start of particularly challenging units, tell students how some of the learning choices will connect to their interests, and remind them of specific past successes they have had in related topics or assignments.

Opportunities for choice can be incorporated throughout the school day, from selecting independent reading books to choosing which part of a long-term project to work on during class. You can also provide a variety of options for homework that students can choose from. With the learning goal in mind, you can provide choices (or invite students to suggest their own alternatives) that will show evidence they're achieving that goal. For example, if the goal of an assignment is to summarize a book chapter, they could create a video using Animoto.com, a graphic organizer or flowchart of the information, a picture or visual image, a PowerPoint presentation, a web page, a skit, or a book for younger students.

Music. There is evidence that dopamine activity in the brain's reward areas increases with the pleasure of listening to music (Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011). As students enter the classroom, you could play music that relates to the upcoming topic (e.g., a Strauss waltz as they are about to study Austria). During creative writing or art, enjoyable music can be used to promote focus and creativity.

Optimism. It is logical that optimism would counter stress and anxiety. Consider promoting student optimism before embarking on a challenge. In two studies (elementary and secondary level) assessing the influence of optimism, subjects were randomly assigned to a positive-mood induction group in which they were prompted to think about the happiest day of their lives. A control group received no such prompt. Both groups completed questionnaires evaluating self-efficacy for math and were then given five minutes to do 50 math problems. In both studies, students in the optimism-activated, positive-mood condition completed significantly more problems accurately than children in the no-intervention control condition (Bryan & Bryan, 1991).

Movement. Movement and physical activity are associated with increased release of dopamine. Incorporating movement into learning yields benefits from the associated increase in memory, attention, and perseverance associated with the dopamine boost (Best & Miller, 2010; Erickson, Hillman, & Kramer, 2015; Esteban-Cornejo, Tejero-Gonzalez, Sallis, & Veiga, 2015; Tivadar, 2017).

The following strategies involving movement may increase dopamine levels, bringing mood and motivation benefits for students:

- **Pantomime.** Vocabulary pantomime is a memorable, dopamine-boosting way for students to use movement to memorize and understand the meaning of vocabulary words and content-specific words. They can start with partners or small groups and use their notes as they build confidence. Eventually, volunteers can review the words with pantomime for the whole class.
- **Word gallery.** Prepared with a list of vocabulary words, students walk around the room and make a note each time they find a

numbered poster that has a verbal or pictorial representation of a word on the list. Students then add their own sentences or drawings to the wall charts. Playing music that students enjoy as they move through the activity can make it even more dopamine enriching.

- **Ball-toss review.** Students toss a ball to one another, and on catching the ball, they state one thing they remember from a lesson.
- **Snowball toss.** Students each write a key point of a lesson on a piece of paper without their names. The students then stand in a circle, crumple up their pieces of paper, and toss them into the middle of the circle. Students take turns selecting a "snowball" to read aloud to the class.
- **Stand and spell.** Students spell new words in the air using a body part of their choice—for example, an elbow or a knee.
- **Four corners.** Each corner of the room is marked with one letter: *A, B, C,* or *D.* Students answer multiple-choice questions by moving to the corner of the choice they believe is the correct answer. They can discuss their reasons as a group and try to convince other groups to join them. If these discussions change their opinions, students can change groups.

Neuroscience Read-Aloud

Dopamine

Your brain has more than 200 specialized chemicals called *neurotransmitters,* and there is one that particularly contributes to good feelings. When this brain chemical *dopamine* is released in higher amounts, you experience increased pleasure and drive. You are also likely to be more attentive, motivated, and creative, and to create stronger memories.

Dopamine levels increase in response to a number of experiences. Some of the strongest increases occur when you achieve a challenge, accomplish a task, or reach a goal you've worked toward. The more often your brain experiences the dopamine pleasure from challenges achieved, the more effort your brain puts into related activities that might be even more challenging.

We'll be working in class to help you apply your own brain's great dopamine system so that your learning experiences are more enjoyable and memorable, and your efforts result in success.

Gaming and the Dopamine Reward System

As the previous sections have shown, teacher-constructed interventions can reduce stress and help students develop a positive mindset through the dopamine reward system (Arsenault, Nelissen, Jarraya, & Vanduffel, 2013; Nakahara, 2014). Now let's focus on one particular example of the power of this system—video gaming—and explore how it can inform classroom practice.

Consider attributes typically found in avid video gamers. They persevere despite repeated failure, setbacks, and increasingly challenging work. These players can get to the point of such intense satisfaction that they continue the game even when tired or hungry. They display considerable creative energy. Studies of avid video gamers provide key insights reflecting the process of promoting dopamine release to fuel positive mood and sustained perseverance. The elements of the video game model that so compel these gamers have been deconstructed, providing principles whose application to classroom instruction can be implemented without the presence of actual games (Gee, 2003).

A number of factors seem to drive dedicated video gamers, promoting motivation and perseverance from the dopamine reward system. These factors include goal clarity, achievable challenges, predictions, and feedback on progress toward the ultimate goal.

Goal clarity. Consider the example of a dedicated video game player who is playing a game with levels 1 to 10. Dedicated players are clear on what the goal is for the game (e.g., saving the Earth from a devastating asteroid collision) and are motivated to achieve that goal, even though it is merely fantasy. These dedicated players also recognize clear goals and skills that are required for mastery at each progressive level of the game. They are clear about what they need to do.

Achievable challenges. Achieving challenges is one of the most prominent ways to release the dopamine reward. Gamers in the most popular games are almost always playing at their individualized level of achievable challenge—that is, the level that the brain recognizes as being both achievable and challenging (Takahashi et al., 2011). Dedicated players playing the most compelling games avoid the high stressors of boredom or frustration because the games continue to push them to their individual levels of achievable challenge as they develop mastery.

As an example, a 10-level game, for independent play, would start all new players at Level 1, but if the players already have mastery of the task required at that level, they will, within a few moves, automatically be advanced to Level 2. There is no waiting for other game players (in a room or across the country) to master Level 1. It is simply the player's individual mastery that results in the immediate progression to Level 2. The player then attempts mastery of Level 2, and later Level 3. Players who take an unusual amount of time to master Level 1 face no adverse feedback comparing their time to that of another player. The stress of "keeping up" dissipates.

In successful video games, each progressive level presents more challenge than the ones before. The player's brain becomes desirous of sustaining play to further seek the dopamine reward from achieving more challenges (Ripollés et al., 2018). That means the new level must not only offer a new challenge not yet mastered, but also furnish one that the players believe is achievable through practice, learning from mistakes through feedback, and sustained effort.

Predictions. We've recognized the association between making, or anticipating the confirmation of, predictions and sustained interest, curiosity, and dopamine release (Parker et al., 2016). While working to acquire basic mastery, players have frequent opportunities to make predictions (e.g., trial-and-error responses with immediate feedback as to whether their choices were successful).

As each new level escalates in difficulty, the player will likely fail (make incorrect predictions/moves/choices) an increasing number of times before attaining mastery, but perseverance remains high through the recall of prior repeated experiences with these games and pleasurable response to them via the dopamine reward system. In compelling games, mastery goals of each level are clearly understood and believed to be achievable by experienced players who have developed confidence in their abilities to recognize challenges and evaluate them for potential success. In addition, dedicated gamers have learned from previous gameplay that the initial, seemingly insurmountable difficulty of each new task is achievable with effort, response to feedback, and practice (Ripollés et al., 2018). These players can make errors up to 80 percent of the time when they are moving through a new level, but they persevere and use the error feedback to adjust their play.

Their brains, conditioned by positive response to tasks previously associated with reward, do well (Green et al., 2012).

One explanation for this perseverance despite mistakes, rather than frustration and abandonment, is the knowledge and assurance that they will immediately have the opportunity to make another, progressively better prediction. Through experience, they have found that despite frequent errors, they do eventually improve and make incremental progress toward their goals (Krebs, Boehler, Roberts, Song, & Woldorff, 2012). Rather than interpreting error as inability to achieve mastery, they use the immediate feedback to adjust and alter their next move. We can see how this benefit of perseverance through repeated "failures" in gamers can link with teaching goals, particularly with helping students change from fixed to growth mindsets.

Feedback on progress. Getting frequent feedback en route to a goal, and not just upon reaching the final goal, is an important component for sustained effort as the game's challenge (and learning in general) increases. At least two of the activators of the dopamine reward system are dominant in the most compelling video games: prediction and awareness of achieving challenges. Both require that players receive ongoing feedback. An aspect of the dopamine reward surfaces when players receive feedback about their ongoing predictions as they improve with practice. In addition, success in reaching a goal triggers dopamine reward through the intrinsic satisfaction players experience with feedback that indicates they've achieved mastery of their current level and advancement to the next level. What the brain—and therefore the player—then seeks is greater challenge at the next level, providing another opportunity to achieve further mastery and enjoy the dopamine boost of success.

When the player begins a new level, the actual task—even if it includes intriguing novelty in music, graphics, avatars, or background—needs to be recognized as a challenge. Even before the sense of boredom becomes a conscious thought, if the brain senses that the new task has not increased the challenge (it's too easy or already mastered), expectation for the dopamine pleasure drops, effort is withdrawn, and game play stops.

Let's look more closely at elements of the video game model—goal buy-in and achievable challenge (with ongoing feedback)—as applied to your classroom.

Goal Buy-In

Goal buy-in constructively strengthens all learning by pushing the brain further through its limited resources of energy. For self-preservation, the brain is programmed to expend valuable resources when it recognizes that the effort will result in a desired goal. Desired goals in the video game model offer the intrinsic satisfaction of dopamine reward pleasure. Let's consider how you can modify the presentation of topics that students are unlikely to find appealing.

When students buy in to a goal, they demonstrate greater motivation to put forth effort and attentive focus (Mahatmya, Lohman, Matjasko, & Farb, 2018). Even choosing whether to pursue a challenging achievement task (at the expense of having fun) or having fun (over the opportunity to achieve a challenge) relates to the individual's level of general motivation. This raised level of motivation and sustained recognition of their effort leading to their progress can be harnessed to increase their positive expectations and effort regarding other challenges. To promote the brain's commitment, sustained attention, and effort, goal buy-in (as recognized in the dedicated video gamers) serves as a motivating start (Hart & Albarracin, 2009).

Strategies for Developing Goal Buy-In

Motivating the brain to expend its limited resources of oxygen, nutrients, and required mental effort is a necessary task. To achieve motivation, students' brains need an expectation of worthwhile satisfaction (including, but not limited to, personal relevance, curiosity, and positive expectations of things they'll do with their learning). And, incorporated in your hooks and lures, students need clarity at the beginning of a new unit regarding goals and what it will take to achieve them, including the different assessment opportunities they'll have to demonstrate their learning.

After telling students about the new unit's learning goals, consider how you can help connect those stated goals to their own personal learning aims. When students create personal mastery goals related to the unit goals that they consider worthy and achievable, they approach a unit with more positive expectations. Here are three strategies to try.

1. Sell it for buy-in. When previewing a topic, rather than simply plunging in, start by emphasizing how students will find it useful. For example, if the topic covers percentages in math, show them two advertisements relevant to their interests displaying a different price and different percentage discount. Ask them which is the better bargain. Then, they will want to know what you have to teach: how to calculate percentages. For sustaining interest and learning, they can engage in performance tasks throughout the unit. In the case of percentages and interest, they can search the internet or newspapers to compare bank, credit union, or savings and loan interest rates to determine which is the best.

When a lesson or block of lessons is full of facts to memorize, consider how you can help your students look forward to appealing activities incorporated into the unit. For example, for foreign language vocabulary they must memorize, explain that one homework assignment will be to select a recipe to translate from a cookbook in that language and bring the recipe into class. Students can buy the dish, or better yet, make it themselves.

2. Essential questions. Essential questions (EQs) as described by McTighe and Wiggins (2014) reflect the heart of the subject (or curriculum). They promote different plausible responses rather than yielding a single answer. These questions can help you target your learning goals and mesh your goals with student goals. They are opportunities to stimulate student discussions at the start of a unit and sustain higher-level thinking and deeper understanding as the unit continues.

You can also select some of a text's more thought-provoking, open-ended questions that prompt connections to students' previous knowledge. Instead of formal note taking for each reading, start units with students reading or even skimming the chapter to seek connections to their own lives or current events. They can represent these by writing, through graphic organizers, or via sketches and diagrams.

3. KWL (Know-Want-Learn) charts. Encourage students by asking, "What do you *think* you know about ______?" (mention a big, interesting part of the topic to come). You'll engage their buy-in through predictions (which, expressed as thoughts, can't be wrong), activate prior knowledge, and engage sustained curiosity because of an additional built-in peer interest: "What will my friends say?"

After putting their "Think I Know" items in the chart's *K* column (*Know or Think I Know*), they sustain buy-in with the choice and opportunity to pursue their curiosities and interests in the *W* column: what they *want* to know. Students are then setting their own motivating and "owned" goals for learning.

After each lesson—during a syn-naps or when otherwise appropriate—students can meet in small groups to discuss what they have learned. Groups can then have representatives share the lists they collaborated on. This component allows students (in groups or as a whole class) to reconsider, clarify, or amplify information that they "thought" they knew in the *K* column. Doing so shows that one's understanding of a topic naturally develops upon learning new information. Additionally, if students create their own individual KWL charts with the following components, they can expand their personal charts in class or as homework:

- K—What do you *think* you **know** about the coming unit of study?
- W—What do you personally **want** to know about to the topic?
- L—What did you personally **learn**?

You open doors by introducing new unit goals in ways that enable students to feel some ownership of their destiny. The creation of a KWL chart at the beginning of a unit increases student ownership, because students ask questions and identify aspects of a subject they are curious about. When they see that they already know (individually or as a class) a good deal of information related to the new topic, stress recedes and optimism rises.

Expectations for Application

When students recognize instruction as meaningful and relevant, buy-in thrives. It will blossom when students are engaged in applications of the learning, evaluations, innovations, interpretations, constructions, analysis, or drawing conclusions from a unit's work

(Hassinger-Das et al., 2016). Relevant projects could be something they create, such as a new environmental plan to reduce erosion, a competition to build a catapult that shoots a beanbag the farthest, or a "homework machine" consisting of math strategies (a box of formulas, strategies, procedures) they can access as a future resource when solving problems. Here are other ideas, organized according to subject areas.

Language arts.

- Based on a novel students read for class, have them write about or draw important parts to create a time line on butcher paper that winds around the classroom walls. They could then take students from another class on a "tour" of the novel by explaining the text and images as they escort them around the classroom.
- Engage interest and humor as you build students' understanding of how to use and not to use thesaurus-prompted vocabulary words. Using a paragraph they have written or taken from a text and a hard-copy thesaurus or computer link, students switch out words in the same paragraph twice. The first time, they select synonyms they believe are improvements to substitute for their original words. The second time, they select synonyms they find silliest and write these as substitutions. Students typically enjoy sharing these with partners or the whole class and do get the message about caution and opportunities related to using a thesaurus. They could share their examples with students from a younger class who are just learning about synonyms and reference materials.
- Before handing out a new book, make a photocopy of two consecutive paragraphs from the first chapter students will read; choose paragraphs that are particularly engaging or curious. Without telling them where the text came from, just start reading the first of your paragraphs. Stop after reading the one paragraph, and if you chose well, you'll soon hear them calling out for you to read more. Then you can say, "OK, but just one more paragraph." After the second paragraph, if students again ask you to read one more, you'll get to boost their interest (even in yet another work by Shakespeare or Dickens) when you reveal that they will indeed get to read more in their new book. For

homework they could select a paragraph or two that they find most compelling to read aloud to a family member, with the goal of trying to get that person to read the book too!

- Promote buy-in for punctuation by rewriting sections from books they like and removing the punctuation marks they are studying. The task of restoring punctuation provides an engaging challenge even when the text is familiar.

Here is an example from my classroom of how I implemented the last suggestion:

Lesson scope: *Introduction to a unit on rules of punctuation*
Grade: *5 (could be applied to upper-elementary through high school)*
Goal: *To promote student interest in* wanting to learn *about proper use of punctuation*

Lesson description: *To promote curiosity and engage students through an area of high personal interest, I told them I had an advance copy of the first pages of a new Harry Potter book by J. K. Rowling. I explained that although Rowling had not planned to write any more books, she was inspired to do a follow-up to her last book, and a friend had slipped me a sneak preview.*

After the students had asked questions (I kept answering, "You'll see") and class curiosity rose, I distributed a page of print. I had actually taken random paragraphs from an earlier Harry Potter book and typed them into the computer as a single paragraph without any punctuation or capitalization.

When I distributed the page, students protested that they could not read it. They were truly frustrated. I listened to their complaints and nodded agreement with most of them. The class was so engaged that they essentially led the discussion I had hoped for when I asked them what could resolve their frustrating dilemma. Here are a few of their initial comments:

- *I want you to put in commas or periods or quotes so I know who says what.*
- *I can't read this because it's not separated into sentences and paragraphs. I need you to put things together that go together.*

I offered them the challenge of working together in groups to figure out what punctuation was needed to make the page readable and to write it down specifically. I suggested tips, like reading aloud in small groups to hear the natural pauses where periods and commas were needed. The students took control of finding solutions to a problem they wanted to solve. Their subsequent comments included these:

- *I need to know where to put periods so I can separate the sentences.*
- *I want to learn how to pick words that should have capital letters and make those changes in this page.*
- *I think there are people talking. I see Harry's name and words that don't look like regular words but that people use when they speak. I think those things are clues to where quotation marks go. I want to know if I'm right and how else to figure out where to put quotes so I know who says what.*

Social studies or geography. A fantasy-based application of learning can help to stimulate interest for periods in history or places in geography. For example, before a unit on expeditions of Antarctica, explain that students will get to keep track of who were the most successful explorers and what strategies they used to ensure their success. Confirm that they'll collaborate in groups to keep these records. Have them select what they consider to be the most effective leadership characteristics and positive strategies, and also note what they think are poor judgment choices. After weighing all these factors, students decide who they would choose to lead as they embark on an exploration of Mars.

Math.

- For subtraction, counting by multiples, prime-number identification, negative numbers, and similar functions, have students create a number line with tape around the room. They'll be able to use dopamine boosters of choice—movement, prediction, and achievable challenge—as they work with well-matched partners to give each other problems to "walk out" and solve.
- Using Monopoly or other play money or checkbook registers, begin by giving each student $1,000. They can look at different

interest rates (e.g., for savings accounts, money market funds, treasury bonds) and choose the vehicle they think will grow their money (the value of their invested money) the most during the next several weeks. They'll be motivated to check the changes in interest rates or fund/bond values throughout the weeks and will soon realize that a dollar-amount increase is not the same as a percentage increase. Suddenly, percentage calculation using proportional equations becomes valuable information they want to know so they can predict how much their investment might be worth by the end of the unit.

A unit I called "The Grapes of Math" brought together the elements of the last example.

My middle school math students would usually groan in response to revisiting the same topics year after year when introduced to ratio, proportion, rate of change, and the metric system. As a buy-in for these, as well a bit of science, I dedicated several weeks to the Grapes of Math, for which students got to make wine in class. (Living in a winemaking region and having been a home winemaker, I knew that the students would ultimately have no interest in actually sampling their unappetizing fermented creations. However, I never actually said that tasting was out of the question when they began, leaving students to wonder if they might actually be taking a sip of wine in math class!).

For the first class, I brought in a quart of unpasteurized grape juice and a hygrometer. I poured the juice into a tall, rather thin glass vase as I explained the chemistry of fermentation. The students knew there was natural sugar in fruit juice, and I began to explain the process of conversion of that sugar into wine. A bit of questioning prompted discussions of how they could get that fermentation going. They learned that mold in the air, which turns our old food "moldy" green or fuzzy, is a living organism that could do the job on their grape juice.

I began:

So we have this sugar in the grape juice and mold in the air that settles on the grape juice, just like it does on bread we leave out. This mold is a living thing called yeast, and it gets nourishment from the sugar in *your grape juice. Just like you produce waste products from what you eat, so does the yeast. The yeast eats the sugar, which is then released as two different waste products—alcohol and carbon dioxide. The carbon dioxide will just float off into the air, but the alcohol stays in the juice as it turns into wine.*

As students desperately wanted to know when their grape juice would be wine, I started the math part of the explanation. I explained that in every molecule of sugar in the grape juice the yeast cells eat, they will release half of it as alcohol and half as carbon dioxide.

I showed them the hygrometer, a tool they would use as soon as they entered class during the next few weeks as the fermentation progressed. A hygrometer looks like a giant thermometer; it is buoyant and floats in liquid. It measures the density of molecules (specific gravity). The first measurement was a specific gravity of 24, and they then had to figure out what it would be when the wine was finished. (Ultimately the sugar drops to zero in dry wine, and the alcohol that remains, measurable as the remaining specific gravity, is roughly half the initial hygrometer measure.)

Their interest in the topics of ratio, proportion, and rate of change was activated along with the yeast in their grape juice. Each day, they went right to the jar of grape juice, measured the molecular density (specific gravity) on the hygrometer, and then used their math to calculate what percent of the way it had progressed to the ultimate end point. They soon saw that the rate of change was not a simple matter of arithmetic subtraction, because the number dropped by increasing amounts as the days went on. Thus, to predict the day fermentation would be complete, they had to grapple with variable rates of change.

And what about the metric system? Along with their daily measurements of their fermentation and new predictions, they became virtual "wine growers." They discovered the variables involving the metric measurements they needed to plan for their vineyard crops. They were invited to read about different wine varietals and select the one they would grow on their one hectare (a metric area they got to figure out equals 10,000 square meters) to produce the greatest amount of wine.

I provided empty 750-millimeter wine bottles (with the numbers blacked out) and measuring cups with metric measurements. The students figured out that they could analyze the amount of liquid each bottle held by filling it from the measuring cup and keeping track. Ah, but the result was still in metric units, which required them to convert if they wanted to know what that meant in standard numbers.

They wanted to know how many grapes it would take to make a bottle of wine. I then showed them some grapes from the market to demonstrate different sizes and gave them time to research the size of grapes produced by different wine varietals. Next, they needed to know how many plants of their chosen varietal could be planted in the single hectare. They discovered that some of the varietals producing the biggest grapes needed more room for the vines or that the vines did not produce as many grapes as varietals that produced smaller grapes, some of which could be packed densely into a vineyard. Decisions and predictions were made, compared, and revised as they hit the internet and found a variety of answers. Their insights included the following:

> *My website said with chardonnay grapes it takes 600 to 800 grapes per bottle, which may be about eight bunches of grapes per bottle. They said that there could be 45 bunches on a healthy grapevine so I figured about five bottles from a healthy vine. Now I have to find out how many chardonnay grapevines can be grown in a hectare of land. Then I can figure out how many kg of grapes I'll get from my hectare of chardonnay vines.*

> *I checked out the pinot noir, which said that an average wine grape weighs about 2 grams, and it takes 15 grams of juice from the grapes to make a ml of wine. My partner and I did the math and figured out that means 590 grapes in a bottle. There are about 75 grapes in a cluster or bunch and a production of about 100 grams per cluster. Each of our varietals' vines produces about 20 clusters. Now we can figure out how many vines our vineyard could support.*

> *My varietal was cabernet sauvignon, and they weighed an average of 1.8 grams with an average of 68 grapes per cluster last year, which works out to about 860 grapes in a bottle of cabernet sauvignon. Now we have to find out about how many of those grapevines can grow on our hectare.*

Wine making is probably not an option for most classes, but if you can find something students really want to do or know that pertains to your geographic area, and the information you need to teach is something they would want to know to reach that goal, you've got the ingredients for buy-in!

Personal Relevance

Let's now look at ways to promote positive emotions for engagement, motivation, and memory by integrating personal relevance into instruction. Recall that one of the more prevalent causes of high-stress boredom is low personal relevance. Relevance increases when students recognize instruction as information to help them acquire information or skills they find meaningful or useful (Hulleman, Thoman, Dicke, & Harackiewicz, 2017).

Studies assessing the positive influence of finding personal relevance, forming connections, and personally valuing the information being taught consistently support the benefit of incorporating personal relevance in teaching. In one study, students in the same classroom were randomly assigned to two groups every three or four weeks throughout the semester. Those in Group 1 were to write a summary of the material they were studying. Group 2 students were to write essays about the usefulness of the course material in their own lives.

The intervention was surprisingly minor relative to the outcomes. Group 2 showed both an immediate and ongoing improvement in science course grades, sustained increased interest in science, and pursuit of more science-related courses and careers in the future. The influence was especially noteworthy in students who had held low expectations of success (Hulleman & Harackiewicz, 2009; Hulleman et al., 2017).

Following Student Interests

A talented ballet dancer in my 7th grade advanced algebra class was excellent in math problem solving, concepts, graphing, and number manipulation, but stymied by the technology of the graphing calculators the students periodically used. To increase her comfort and interest in working with a graphing calculator, I connected the calculator to a CRV ranger—a handheld device used to measure the speed and distance of moving objects, similar to a highway patrol officer's speed gun. I showed her how she could use the device to record a graph of a few simple dance moves she had choreographed. I demonstrated this by using the CRV to record the "dance" of simple movements forward, back, left, and right across the room. When she saw that her "dance" was now in graph form that people could learn to read and follow, she shed her fear of operating a graphing calculator, because it was now integral to her choreography-graphing goal. Once her original reluctance was eliminated by her interest and project success, she was less stressed and more optimistic about learning the other graphing-calculator skills she needed.

As you start using the information you've accumulated about your students to link their learning and their interests, it makes sense to start with only a few students at a time and to gradually increase this personalized relevance. If you try to include each student's individual interests and backgrounds in each unit introduction, you'll deplete your own dopamine motivation. If you proceed in stages, the dopamine reward from your achieved challenges will encourage your efforts to further incorporate all your students.

You'll have "aha" moments of insight as you see the many ways their interests in superheroes, wild mustangs, science fiction, the ocean, space exploration, insects, music, sports, art, people from other lands and times, or game heroes connect to the upcoming topic. You'll be rewarded and the class climate will improve when students, previously bored to the point of acting out or zoning out, connect with their work and grow less disruptive.

Ways to Incorporate Personal Relevance

You can weave personal relevance through your lessons in a variety of ways. Some work to hook students at the launch of a unit, and others can be incorporated throughout daily instruction. Here are some suggestions.

Note taking/note making. Make listening to a lecture and taking reading notes more enjoyable, memorable, and personally relevant with note taking/note making. This form of brain motivation includes both prediction and connection with interests and goals (Towey et al., 2016).

Students fold a sheet of paper vertically. On the left side, they write the information they would usually write about the topic while taking notes on a lecture. This might include summaries, vocabulary, and important facts. The right-side column is for their personal note making; they can write comments (or even draw sketches), questions, what surprised them, how the information connects with one of their interests or applies to their lives, what they want to know more about, what it reminds them of, or what they predict will come next. Each note they make allows personal interactions with the material and the concomitant brain boosts related to attention, interest, and memory. Figure 2.3 provides two examples.

FIGURE 2.3

Examples of Note *Taking* and Note *Making*

Note Taking (Based on What Teacher Has Said)	Student's Note Making
The direct object is the receiver of an action. For example, "He mailed a *letter*."	I received great *news*. School is closed because of snow!
The chapter you read has several examples of foreshadowing.	I predict one will be when Sam said, "I thought the day would be just like every other, but I could not have imagined how wrong I was."

Personally relevant photographs. Encourage both topic and peer interest by taking and posting photographs of the students in previous years' classes engaged in some activity that will be part of the learning in the upcoming unit. Your students will be excited to recognize students who are a year ahead of them engaged in the activity they will do. This response demonstrates the positive peer influence of the "older kids" doing something they'll be doing.

Personally or culturally relevant topic choice. When possible, personalize students' inquiries, projects, or reports. Have them think about and even ask family members about what might be a particularly meaningful topic, especially in relation to family heritage, culture, places where family members have lived, jobs they've had, or the impact of historical events (Aceves & Orosco, 2014). Students can also just think about which topic options might dovetail with their interests, such as a country for a history project that is the originator of their favorite foods, is hosting the Olympic games, or developed their favorite dog breed. If they love sports, how can they use math to make predictions for which teams will succeed based on evolving statistical data? If mechanical creation is their "thing," how could the science of machines, levers, friction, and so on help them build something new and challenging (Aceves & Orosco, 2014)?

Guiding Students to Find Their Own Relevance

Ideally, at any point in a lesson, you should be able to ask your students, "Why are you learning about this?" and get valid responses, but it is not always possible to explain the immediate relevance of every lesson. It is always high-yield planning, though, when you can help students see the relevance or future importance of any lesson—and it is even better when you can build their independence in finding satisfying connections to their own personal interests, goals, or heritage (Takahashi et al., 2011).

Students appreciate empathy, so it may help to ask a question that expresses that feeling. For example, you could say, "I know this seems pretty dry and not really important to your own life, but can you think of any way this information could sometime be useful or meaningful to you now or in the future?"

You can incentivize students to make their own connections by telling them they'll be getting a break from regular homework. All they need to do is use their notes, text, lecture, or class discussions to make a list (you decide the minimum number of items) of how the information/learning could possibly connect with their interests, out-of-school activities, or goals. Tell them to select one item they will read in class the next day. These items could be written onto an evolving, posted list where other students might relate through that same connection. Here are some examples of how students expressed their thoughts on personal relevance:

- Batting averages are calculated to the thousandth, so that helps increase relevance and therefore my interest about decimal place values.
- The vocabulary I'm learning in Spanish is letting me figure out more and more of the street and building names in our town.

- I can use physics to see if my soccer kicks are better when they arch high or travel more level to the ground.
- I thought this art class would be boring and I'd be terrible, but now I see that we'll be using things I like, like clay, wood, and even food in our art. I can get into that!
- I love everything about boats, so I'm hoping that in this lesson about explorers, I'll get to do a project that has something to do with navigation. Maybe the changes in their ships during the decades of exploration.
- Things started out promising when we saw those old photos from the Civil War that the teacher said were primary sources from the government archives. I'd be into evaluating different photos.

The Goldilocks Zone of Achievable Challenge

An 11-year-old student who had heard my explanations about how brains respond to different situations, including dopamine reward, described her favorite video games:

> *The games are challenging, but not so hard, so I know if I work at a task I can make it. I use the feedback from my mistakes, and when I figure out how to get to the next level—wow, do I feel great. It is called intrinsic satisfaction and comes from my own brain's chemical, dopamine, each time the game shows me that I've moved a step closer to my goal.*

To promote positive emotion, memory, and perseverance, you can apply the video game principle of *achievable* challenge to the classroom—without video games. An achievable challenge is one in which a student has the capacity (or skills to develop the capacity) to meet an ambitious goal. As Goldilocks might say, the challenge is "not too hard, not too easy, but just right!" Child-development theorist Lev Vygotsky used the phrase "zone of proximal development" to describe an achievable challenge (Tudge, 1992).

A challenge that is too easy leads to boredom, and sustained boredom leads to stress and ultimately disengagement from learning. A challenge that's too difficult triggers frustration and hopelessness.

Likewise, goal failures, if sustained or frequent, also lead to excessive stress and fixed mindset. However, when facing an achievable challenge that is just within their reach, students skirt the detrimental stress, and the amygdala remains open to the prefrontal cortex.

Consider these examples of challenges that are either inadequate or perceived as unachievable:

- You are dropped off at the top of a ski resort's steepest run when you've had experience only on the beginner slopes.
- You have to spend your day on the bunny hill when you're an expert skier.
- You play a game of darts with the target 2 feet away.
- You play a game of darts with the target 200 feet away.
- You are in high school and drilled daily in class on single-digit addition.
- You are a sophomore in high school assigned to do graduate school–level work.

Putting effort into these situations has no appeal to a brain innately programmed to withhold and preserve its limited resources if the mental enterprise is inessential for survival or doesn't involve a potential source of pleasure (e.g., dopamine reward).

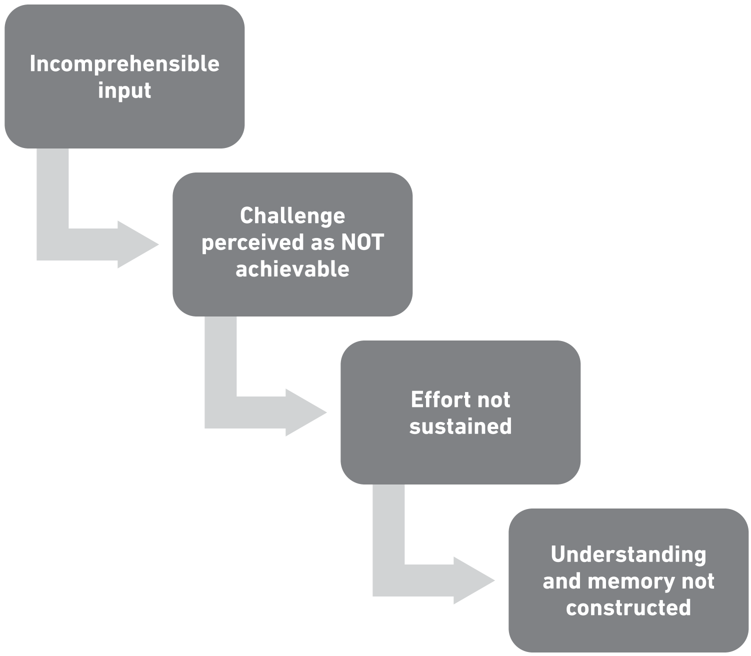
These limited options would promote either boredom or frustration, prompting the stress response and, eventually, negativity (see Figure 2.4). One way to think about individualized achievable challenge for students is as an opportunity for them to recognize their capability for success at an ambitious goal level.

Positive Expectations for Success

To counter the inertia produced by repeated failure or by boredom as a result of mastery, students need opportunities to progress at their individual levels of achievable challenge. One way to create these opportunities is to provide choice and a variety of pathways (see next section). First, let's focus on the ways students can progress at their individual levels of achievable challenge, as in those compelling video games discussed earlier.

FIGURE 2.4

Consequences of Instruction That Doesn't Meet Students' Levels of Achievable Challenge



As noted, progressive-level video games influence motivation by engaging players at their appropriate ability level and then taking them through increasingly challenging levels as they became more and more skillful. As proficiency improves, the next challenge stimulates efforts to obtain the new mastery because the player can reach that level with practice and persistence.

Students are most motivated by the expectation of a dopamine reward when they learn at their individualized levels of achievable challenge. When one of these two elements—either the achievability or the challenge—is inappropriate, motivation lags. This outcome applies whether students are still working to reach a basic level of mastery or have already mastered a topic and need increasing challenge and complexity to sustain their motivation (Green et al., 2012).

What we've learned from the compelling response of avid video gamers relates to learning goals for all students in terms of learning and progressing within their personal zones of achievable challenge levels, enhanced by ongoing assessments for feedback on progress. In addition, frequent formative assessments can guide teachers in appropriately adjusting the level of challenges or individual supports, as needed.

Paving the Way for Achievable Challenge

Success in promoting progressive achievable challenge starts by setting and acknowledging high expectations for all students, while ensuring access to the appropriate tools to reach these goals. Pre-assessments can reveal students' background regarding the mastery goals. Formal or informal pre-assessments are guideposts to support learning at students' achievable challenge levels. Class discussions and pretests are examples of pre-assessments that can reveal the content knowledge, beliefs, and skills students have before the start of a unit. If you use pretests, make sure students understand that they are not expected to know most of the information, as it has not yet been taught and will be the substance of the upcoming unit. They need to know that these tests will not be used for any grading purposes and that the results on the unit pre-evaluation will not wedge them into a permanent level or group. All can change as they acquire knowledge and skills.

These pre-assessments provide guides for you to use to shepherd students into achievable challenge pathways that correspond with their level of mastery. Further, they allow you to intervene when content knowledge is inaccurate or insufficient, skills are inadequately developed, mistaken understandings limit knowledge growth, or enrichment opportunities need to be provided.

In addition to pre-assessment tests, you can adjust individual lessons to the best level of students' comfort and challenge even before you determine a final lesson plan. To do this, have students respond to homework reading *before* class by completing and submitting very brief responses to questions posed about the information most pertinent to the upcoming instruction. They can e-mail you these brief responses or big takeaway understandings they got from the readings, as well as note points in the reading that were very confusing.

This assignment serves several purposes. It keeps students accountable for doing the reading, so they are best prepared for the instruction, and it informs you about the knowledge gaps and strengths available to guide your instruction and differentiation planning. This feedback process highlights the points to explicitly review in class. It avoids the attention-loss pitfalls of lessons that students either do not understand—to the point of frustration—or that they already understand so well that the lesson offers no challenge or engagement.

It may seem as if this reading-response communication would extend an already long workday and prep time. However, as you continue to use the process and fine-tune your instruction in response to student feedback, the positive changes you observe will demonstrate the payoff for your efforts. We know how difficult it is for some students to admit in class that they can't follow the lesson or the text. With this communication system, students come to class without the stress of expecting more frustration or boredom. They know you now recognize their confusion, and they arrive in class trusting that if they *pay attention,* you will address it. Similarly, those with existing mastery trust that they will have opportunities to apply their knowledge to new challenges instead of tedious repetition.

Priming for Success Through Scaffolding

Relating goal buy-in and personal relevance to the unit, as described earlier, will prime students to sustain effort within their range of achievable challenge. Further, being reminded of past successes will support their undertaking of new challenges and reactivate their dopamine reward response in anticipation of the positive feelings they experienced earlier (Green et al., 2012; Ripollés et al., 2018). Now let's look at the role of scaffolding as another important element of priming students for success.

Scaffolding, an educational term coined by Vygotsky, refers to support provided to students to help them achieve greater levels of success, and ultimately independence, while working toward a learning goal. It provides another tool to maintain achievable challenge levels in the "Goldilocks zone." You can provide scaffolding of varying degrees by using models, rubrics, demonstrations, examples, partner work, brainstorming, and tools to boost reading comprehension and subject area skills. The following example illustrates how scaffolding can work.

I had a student who became rapidly frustrated as soon as he didn't understand even the opening overview of a math topic. Unless I stopped the class and explained the information to him one on one, he went into fight mode and called out angry remarks like "You never pay attention to me" or "You're a terrible teacher and I hate math."

I knew that when we worked one on one, he easily grasped the information. His need for instant control and low frustration for incomplete understanding had developed over the years as a result of his failure to define and reach goals, which left him with fixed mindset feelings of helplessness and hopelessness. My goal was for him to believe that I understood his concerns and would work with him to build his confidence, knowing that strategies were available to help him. I explained, as I did to all students, that his stress was impeding his intake of information so that he shut down before he could reach understanding.

The plan I suggested allowed him to do two fewer homework problems each night in return for previewing the next day's lesson at home by just skimming the pages that would be the topics of instruction. The preview was not intended for him to learn the material, but to increase his familiarity with the information and new terms when they came up in class so he did not fall into the fight/flight/freeze mode.

The plan worked. During the lessons, he followed along with much more resilience because he had the comfort of recognizing the information from his preview and the confidence that there would be class time for us to work together on things he didn't understand.

Scaffolding Reading Comprehension

The "achievable" part of achievable challenge is more available to learners who have a strong background or scaffolding in reading comprehension. Here are some ways to promote that skill.

"Talking to the text" with sticky notes. This technique compels students to use the general principles that we know increase reading comprehension: prediction, activating prior background knowledge, making personal connections with reading, prioritizing importance, and evaluating pictures and diagrams. Without a way to monitor their actual use of those strategies, students are unlikely to use them. The "talking to the text" technique provides this accountability. When using it, teachers provide a variety of prompts that students will respond to when they do their assigned reading. In class, before reading, students write the beginnings of the prompts on sticky notes; for example, "I didn't know that information before and I find it interesting because . . . ." When students come across a point they find interesting, they complete the prompt on the sticky note. Students using this technique are motivated because the assignment has personal relevance, has no wrong answers, and requires very little writing. In short, this is a low-stress but high-reward activity because it promotes the general principles of reading comprehension.

These prompts can be designed to suit any subject and grade level. After posting a list of 10 or so prompts in the room, assign the numbers of the phrases students are to copy onto sticky notes to complete and affix into their book at the appropriate point as they read. To use this technique to support the strategies of making predictions and activating prior knowledge before reading, students would briefly preview the text and transcribe and complete these predictive prompts on their sticky notes:

- I think you'll be telling me . . .
- I already know things about you, so I predict . . .

To engage the strategies of making personal connections, prioritizing importance, and evaluating pictures and diagrams *while* reading, students could complete several of the following prompts on the sticky notes that they prepared in class:

- You are similar to what I have learned before, because you remind me of . . .
- I would have preferred a picture of . . . (Students can sketch/download their own image instead.)
- I didn't know that, and I find it interesting because . . .
- I disagree because . . .
- This is not what I expected. What I expected was . . .
- This gives me an idea for . . .

- I want to know more about this than you have to offer. I'll find out by . . .
- I have a different way of interpreting this information, which is . . .
- I won't let you get away with this statement, so I'll check your source by . . .
- This could be a clue to help me answer the "Big Question" because . . .
- I think this will be on the test because . . .

Self-questioning. Students can improve their independent reading comprehension by self-questioning. You can begin by modeling examples of self-questioning in class as you read a passage together. To form their own questions, students can look at chapter questions or create their own after previewing the chapter. As they read, they look at their questions to see if they have reached an understanding that allows an answer. For example, if one of their questions was about types of rocks, and they have finished the subsection dealing with that topic, they should have an answer. Because they are able to check the accuracy of their answers by going back to the sections, they can recognize what they didn't know and reread to revise their understanding.

Verbalizing thoughts during reading. Sometimes we read without processing. To make the process of reading comprehension obvious to students, help them verbalize as they read. You can model this process by reading aloud from the text or literature book the students have. As you read, pause to describe or summarize what you've just read. You can also include predictions or particular things you are interested in finding out as you continue to read.

Scaffolded note taking. Students who need to take notes on independent reading can be scaffolded as they build their understanding of what information they should include. You can easily provide such scaffolding by using good-quality notes that a previous year's student took on the same section. Make several copies of each set of exemplar notes. To provide differentiated levels of scaffolding based on students' developing mastery of note taking, white-out varying amounts of the exemplar notes. For students needing a great deal of guidance, you would white-out just a small portion of the exemplar, leaving them to fill in more obvious pieces. For example, for a chapter about the three causes of air pollution, you could omit one cause from the notes. Looking at the section that describes three causes of air pollution, students might recognize that the first two have been included in the notes and there is a space for them to write the third one, which they can easily find in their textbook. As students need less scaffolding, you would supply copies of the exemplar notes with more lines redacted, so the advancing students have more opportunities to fill in the data.

Scaffolding Math Through Estimation

Estimation, with feedback and revision, builds students' number sense and understanding of math concepts. When students have opportunities to estimate, they tend to be more successful at future symbolic arithmetic problems (De Smedt, Noël, Gilmore, & Ansari, 2013; Hyde, Khanum, & Spelke, 2014).

When we adults provide estimates, it is with the understanding that our estimates will not be precise. This imprecision is particularly troubling for students who are anxious about making mistakes. You can help learners understand that errors are part of the estimating process by modeling how you estimate and demonstrating how to use feedback to provide clues to improve their next estimations. I did this with a backpack weight estimation.

A teachable moment for estimation came when my students got a heavy new textbook that added significant weight to their backpacks. I sympathized and then said, "Let's see how well you can predict how heavy your backpacks are." Students volunteered to have their backpacks be the ones the class would evaluate. As these were passed around the room, each student wrote down an estimate of its weight. After each backpack was weighed, I invited students to consider how they might adjust their next estimation based on their predicted weight and the actual weight of the previous backpack. I heard reactions like this: "I'm an overestimator, so I'll need to drop my estimations." As they continued to predict the weight of subsequent backpacks, most students found that they were getting closer to the accurate weights. It was time, then, for some discussion about how they could use estimation as they approached solving their math problems.

"More than/less than." This strategy, particularly good for younger students, builds number sense and a positive attitude about the value of estimating. Bring in cans of food that weigh approximately 8 ounces and 16 ounces; these will be the standards for comparison. Students then evaluate other cans of food that weigh between 8 and 16 ounces and predict which of the two standard cans the others are more like.

Anchoring. Anchoring is a way to promote the use of estimation without the stress of making big over- or underestimates. Try this yourself:

- Cover the rest of this page so you don't see the answer.
- Write down your estimate for how many ways there are to make change from one dollar.
- Now, use anchoring to revise your estimate. "Between 50 and 400, estimate the number of ways to make change from one dollar."
- Estimate again. Did your estimate change?

The answer is 293. Anchored estimates are usually more accurate because boundaries guide accuracy. Experiences with anchoring will increase students' confidence in their abilities to estimate—or at least to try.

Estimation homework. Students often don't take the time to estimate during homework because their goal is to finish quickly and get the single correct answer. When I gave an assignment to first estimate and then solve, my sense was that students didn't do the estimation first but just solved the problem and then entered something in the estimation box.

Having students estimate before solving offers a valuable opportunity to assess their understanding of the concept. You can interest them by saying, "Today you'll get to start your homework in class." However, when it comes time to do that, tell them they'll get to do the estimating part of the problems in class and the solutions at home.

If you find students with estimates that are way off, reflecting poor understanding of the concept, and time permits, you can do quick deskside instruction. If time is insufficient, you can revise their homework assignment to one that promotes review of the concept rather than have them go on without that understanding. Similarly, if you see students with very good estimations, you can adjust their homework to a more challenging and engaging opportunity using learning rather than repetitive drilling of something already mastered.

Why I Stopped Carrying Pencils in Class

When providing scaffolding, it is important not to overdo it. Have you ever experienced the frustration or confusion of asking someone to show you how to do a new process or use a new app on your phone or computer? The person takes the phone or sits down at your desk. Her fingers not only block your view of what she is tapping but also move so quickly that you can't even follow the sequence. When you tell her you didn't understand what she did, her response is often to do the same thing again, perhaps a bit slower. Still, you're not really seeing or understanding each step she is doing. What I learned is to ask for the "demonstrator" to let me be in charge of the keyboard as she talks me through the motions and the process.

This experience is why I stopped carrying pencils in class—to avoid writing on students' work when they asked for help. I realized that while writing on their papers and blocking their view, I didn't give them the chance to construct their own understanding. Without pencils, I was better able to be their guide on the side, allowing them to do the writing and or to work out solutions to problems themselves more actively, with their own pencils and brains. Further, students take much more pride and ownership over work they do themselves. Malana still remembers a well-meaning art teacher in 7th grade who "fixed" a small section of a still life she was working on. Although his manner was kind and helpful, and the section that he drew was pristine, she felt disappointed about the finished work, because the most proficient part of it wasn't hers.

Breaking It Down

As a means of scaffolding, we often suggest that students take a complex problem or assignment and reduce it into smaller, familiar parts. The following activity, done once, can put muscle into the meaning of "breaking it down" for understanding.

Give each table group an irreparably broken clock, watch, safe appliance (unplugged and not sharp), or mechanical toy (e.g., a talking stuffed animal or a jack-in-the-box). Your instructions will guide students to the awareness that they really can find things they understand when they "break down" something complex. Here is an example of the instructions you can give:

1. Look at your object for a full minute or more and think about how it works. If your group has some predictions, discuss them.
2. Now take it apart and look at things that make it work. As you take it apart, discuss parts you recognize, such as springs, screws, coils, wheels with teeth, gears, batteries, or electrical wiring.
3. Now, again, discuss how these components may work together to serve the function the object is intended for.

After the groups finish, you can say, "You just experienced your ability to break down something that seemed beyond your understanding into parts you did understand. Now maybe you can do this with other things, such as difficult math problems, term papers, unraveling a poem, or just about anything that seems overwhelming at first."

Personalized Routes to Mastery

Personalized learning opportunities allow students to choose from a variety of ways to build mastery and to progress at their own pace. They become more engaged learners, moving ahead at comfortable levels by being in charge of choosing their routes and having them modified in response to their increasing levels of achievable challenge. Although individualization is not possible for all students all the time, options for providing variable levels of challenge and self-pacing within each path include Khan Academy, flexible groups, flipped classrooms, and a variety of challenge approaches in books and website resources (Parker et al., 2016).

The following strategies can be useful in building mastery:

- Start by explaining to students that regardless of the tools or the pace they choose, they are all capable of progress toward mastery.

- When using a variety of sources for building mastery, label the levels 1 to 5 or 1 to 3. Students can choose to start at any level, moving sequentially or even skipping levels as they feel ready for greater challenges. Numbered levels, when available as individual private information for learners, can provide feedback on progress toward their mastery goals. When using a leveled system, it is important to develop a classroom climate in which a diversity of learning styles and strengths are valued. The purpose of having students note their level is for them to recognize personal growth and progress, not as comparison for competition. The goal is to create a labeling system that is clear but also subtle enough to not be overtly obvious to others which level a classmate is using.
- Use varied-level materials on the same topic (e.g., for students with different reading levels, including ELLs and those with transitional reading abilities). You can use materials available online or in regular texts. Students can choose tools, read-aloud texts, links to challenging vocabulary words, and more.
- Take advantage of self-paced online learning and tutorials, including websites that provide videos or demonstrations describing the topic at stratified levels of complexity. Khan Academy (www.khanacademy.org) provides an opportunity not only for individualized progression of learning but also for flipped lessons. Students watch online instructional videos about the topics they will be studying further in class. They can play or replay these videos as needed to answer questions generated throughout the instruction. In the flipped-classroom experience, students prepare by reaching the specified mastery on the Khan lesson and then, in class, ask questions, discuss, and apply the learning in meaningful ways.
- Flexible groups are great additions to self-directed paths to mastery. In these sessions, you meet with small groups to address a topic, providing extra guidance or teaching advanced skills. Students can select a group based on your description of what the group will be doing and the students' understanding of their current mastery. These groups accommodate students of different skill levels who would be lost in the whole-class environment.

Because the groups are flexible, students can move in and out of them as their mastery increases or ebbs.

- Work stations for younger students can also provide flexible paths to mastery. For example, you can label the tasks for each station with numbers 1 through 3, and students can choose the level to start at each station. If they choose Level 3 and find it too hard, no problem; they go back to Level 1 or 2 and work their way up.

Learners' emotional states have a profound impact on their ability to learn successfully. In a neutral or positive state, when students are interested and engaged in the learning, information can pass through their attention filters and be directed via the amygdala up to the prefrontal cortex, where advanced levels of cognition and memory formation can take place.

Alternatively, a brain in a stressed state will be limited in its ability to direct information to the prefrontal cortex and less able to access higher-order thinking and problem-solving skills. Instead, information selected by the reticular activating system may be diverted by the amygdala to the lower brain, where the automatic responses of fight/flight/freeze will be triggered. In the classroom, students might express these responses by acting out or disengaging from learning.

In school, stress can be caused by challenges including physical discomfort, social or emotional struggles, and academic frustration. When academics are too easy or repetitive, stress can be caused by boredom. If a lesson far exceeds students' skill levels, or they have repeatedly failed to achieve a similar goal in the past, the fear of failure can trigger a stress response. Although the lower brain responses of fight/flight/freeze are triggered automatically, teachers and students can take action to reduce the stress response.

Teachers can foster a climate of emotional support by connecting with students and helping them to feel safe, secure, and understood. This can be done through informal positive interactions or structured activities, such as comforting class meetings. Students who gain emotional self-awareness and learn about their feelings are better able to respond to stressful situations. Learning about false stereotypes can also help students overcome resistance to trying something they find daunting. Teachers can provide lessons in emotional self-management strategies, such as mindfulness, guided relaxation, and visualization to help students mitigate emotional discomfort. Further, students who learn some basic neuroscience can become aware of the infinite potential for their brains to learn and grow through neuroplasticity. This understanding can help students transition from a fixed mindset to a growth mindset, and therefore be more likely to see a challenge as an opportunity rather than a barrier.

All brains experience the stress of fatigue when overworked. Infusing lessons with strategically timed learning shifts, or "syn-naps," will allow taxed neurotransmitters to be replenished and learners to refocus with renewed engagement.

Teachers and students can also reduce stress and promote positivity and perseverance by tapping into the power of the dopamine reward cycle. Incorporating dopamine boosters such as choice, music, optimism, movement, positive interactions with peers, being read to, acting kindly, expressing gratitude, and humor can keep brains engaged and receptive to learning.

Making correct predictions and achieving challenges are two of the most powerful dopamine boosters. These elements, which are two of the reasons that video games are so compelling, can be used in the classroom to promote student engagement and success. Tapping into the video game model, teachers can help diminish the stressors of boredom or frustration by (1) supporting students in identifying and working toward their goals, (2) providing instruction that is meaningful and relevant to their students' interests, (3) guiding students to work at a level that is appropriately challenging, and (4) providing frequent, ongoing feedback that allows students to recognize progress toward their goals. With these elements in place, students feel the excitement of personal growth and academic achievement and can better meet the stressors of the school day with confidence.

3

The Journey from Sensory Intake to Memory

Education is what survives when what has been learned has been forgotten.

—B. F. Skinner

During recent decades, neuroscience research has provided extraordinary insights for our understanding of the nature of learning. Never before have neuroscience and classroom instruction been so closely linked. Advances in technology as well as the sciences enable us to have more insights into the workings of the brain as it learns to help guide us to potentially more effective ways to teach.

Linking the New to the Known

Establishing long-term memory requires a daunting journey that begins with a most basic awareness of our environment. That awareness must then pass through brain filters (the RAS and the amygdala) to reach the hippocampus, where it is either forgotten or connected with preexisting memories and encoded as *short-term* memory. Ultimately, some—but not all—of these short-term memories progress to *long-term* memory.

Patterns: Paths for Memories to Follow

Patterning is a process whereby the brain perceives, interprets, generates, and expands memory connections of related information, broadened by time and experience. Education is all about augmenting the patterns that students recognize, construct, and expand. As their ability to see and work with patterns grows, and new material is presented in a way that enhances these relationships, students can generate more efficient short-term memory, extensively linking the new with the known. Linking and encoding new sensory input into a short-term memory requires activating prior knowledge related to the new input. Let's see how prediction and activation of prior knowledge can light the paths for new memory to follow.

Prediction Requires Patterning

Not unexpectedly, the brain has a system linking new learning to things already known, which provides the mental maps required to process new memory (Bransford, Brown, & Cocking, 2000). This relational memory system of linking the new with the known is another critical mammalian brain system that promotes survival in unpredictable environments.

To survive successfully in the wild, animals need to understand their environments by making meaning of what they see, hear, smell, and touch. The brain supports this need by connecting sensory input with similar stored memories of related experiences. By storing information in neural networks based on similar or related patterns, the brain can activate those memory patterns in response to new, but similar, sensory information. This process guides it to understand or interpret the new information and predict more successful responses—decisions, choices, and so on (Davachi & Wagner, 2002).

An example would be a fawn making the connection or conditioned response to the raised tails of the adults in the herd as a danger signal. The fawn's brain recognizes that signal as the probable approach of a predator, and guided by prediction, it runs for shelter even before it sees, hears, or smells the threat.

Predictability based on pattern recognition is also a powerful component of successful learning for students. Their brains work to make sense of new things and experiences based on prior related experiences. This predictive ability is the basis for successful reading, calculating, goal setting, and appropriate social behavior. Successful prediction is one of the brain's best problem-solving strategies.

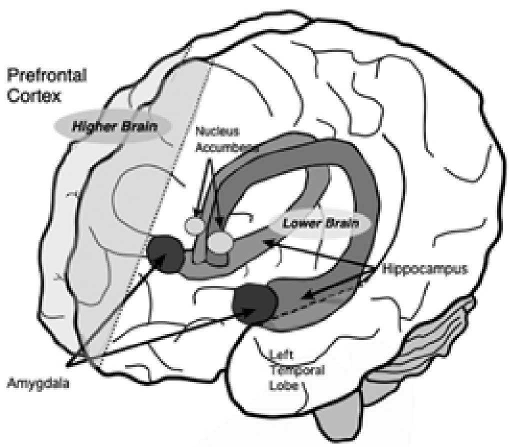
Consider how literacy is built as memories are stored in related patterns (schema). These memory networks of relational patterns become expanding foundations that subsequent related knowledge connects to as literacy develops. When a word has an element recognized as familiar—such as prefixes, suffixes, rhyming words, or word roots—and fits with an existing related memory circuit, the patterns guide the understanding of the new word (Hassevoort, Khan, Hillman, & Cohen, 2016; Hofstetter, Tavor, Tzur Moryosef, & Assaf, 2013).

Meet the Hippocampus

As we continue to follow the process of acquiring memory, it's time to acquaint ourselves with the hippocampus—the place where the new physically hooks up to the known (see Figure 3.1). The hippocampi, one on each side of the brain, are small, seahorse-shaped structures with connections to the amygdala, the prefrontal cortex, and other structures involved in memory (Zeithamova, Dominick, & Preston, 2012).

FIGURE 3.1

Hippocampus



In the hippocampus, new sensory input links to related information now activated and summoned from memory storage networks in the cerebral cortex. As we see how this linkage takes place, keep in mind that the hippocampus does more than encode new information into short-term memory. It also stores the associations and connections made among newly and previously connected memories, and it works with the prefrontal cortex to remember (retrieve) information from long-term memory storage in the cerebral cortex (Ison, Quiroga, & Fried, 2015; Wenger & Lövdén, 2016).

Activating Prior Knowledge in the Hippocampus

A teacher's task, then, is to promote short-term memory pattern matching in the hippocampus, so new input can link with what is known. Helping students activate the relevant prior knowledge (previously formed and stored related memory) propels them toward this goal.

This prior knowledge exists in stored networks of brain cell connections based on relationships—for example, things experienced together, such as farm animals; words ending in *-ing;* or types of rocks. Effective teaching uses strategies to help students recognize patterns and then make the connections required to link the new input to the related known memory (Wimmer & Shohamy, 2012). The more relational patterns students construct in long-term memory, the more efficiently their brains can recognize new information and activate appropriate neural networks from storage to link up with the new learning in the hippocampus (Ison et al., 2015; Squire, Genzel, Wixted, & Morris, 2015). In addition, the more experiences students have making connections and understanding how information and memories are related, the greater will be their ability to seek out and access these prior-knowledge networks to encode with the new learning (Zeithamova et al., 2012). This capacity is why students benefit from pattern-recognition opportunities that boost abilities to know when something new fits into a pattern previously seen. These skills can be enhanced by activities such as matching patterns, playing games such as tangrams, predicting what comes next in a repeated sequence, and always giving their reasons for these predictions.

Students can form their own patterns for new learning by relating information to mental categories they create based on a commonality, such as pleasure. Because all students have stores of prior knowledge about things that have been pleasurable, pleasure can be a tool to use as a criterion for establishing a memory pattern. When students need to recall a list of words or phrases in any order, such as elements of impressionism, categories of things that reduce carbon emissions, or names of shapes, they can categorize them by using a personal interpretation of "pleasantness." Invite students to arrange a list of words they need to know based on how "pleasant" they find the words, from most to least. To show the value of this approach, you can first do a demonstration. Have half the students just copy a list of words you write on the board, and have the other half copy the words in order of "pleasantness." Have them hide their lists and then write down as many words as they recall. The majority of students who remember more words will have written them in order of "pleasantness." Students can also choose their own criteria for sorting their list, such as most to least "tall" letters or numbers of letters in the words.

Activation Strategies

The brain's ability to recognize related stored memory in response to new information is an automatic process for most adults, because we understand the context of the book we are reading or the lecture we are hearing (Shing & Brod, 2016). However, students don't have our plan books. In between days or classes, a lot goes on that captures their attention. Remembering what topic was the focus of each class over the past few days easily slips into the background. You can help students activate their prior knowledge by starting a class with the assumption that they have likely forgotten where they left off and how the new information fits in with what has happened over the past week.

Using strategies that help students relate new information to existing memories enables them to detect the patterns and make connections. Consider these ways to present information so students can connect to their prior knowledge:

- Show videos or images that remind students of prior experience.
- Display items on bulletin boards. For example, when studying shapes, as you explore circles, put up circles. As you explore squares, add them to the board along with the circles. Adding to the board with the "shape of the day" builds the recognition that these are all within the relational context of "shapes."

- Practice number sequences, such as counting by threes, so when students see the number sequence 3, 6, 9, 12 . . . , they are most likely to recognize the number 15 as belonging to that sequence.
- Invite students to take new words and place them in multiple categories. For example, students can link the word *metamorphosis* to intrinsic patterns, such as these:
  - Words with the same ending—for example, *photosynthesis, synthesis, analysis, phagocytosis, mitosis*
  - Words with similar meanings—for example, *change, transformation, alteration*
  - Words with similar roots—for example, *morph, morphology, amorphous, morpheme*
  - Words with the same prefix—for example, *metaphor*, *metaphysical*
- Use further word analysis of context-specific words. This analysis can be more successful if it activates patterns in prior knowledge—and it can also help engage students who know more than one language. For example, to introduce the new word *infirm,* invite students with knowledge of Spanish to see if this word sounds like any word in Spanish. When they suggest *enfermo* and know it refers to being sick, connections are made through language patterns.
- Present analogies, metaphors, and similes as effective ways for students to connect what they know with the new information, much as graphic organizers of similarities or differences connect the new to the known. For example, "Adverbs often end in 'ly' and give more *meaning* to verbs, like acting kind*ly* gives more meaning to a friendship."

Narratives as Memory Enhancers

If you've had the pleasure of reading bedtime books to young children, you've probably observed one of the reasons narratives are so compelling. I saw this phenomenon during my daughters' childhoods, when they wanted the same book, *Goodnight Moon,* to be read over and over. Not only did they want the same book, but even after dozens of readings, they continued to excitedly "predict" what would be on the next page and to take great pleasure in being "right."

That childhood desire, of wanting to hear the same books and "predict" what comes next, represents the power of narratives as memory enhancers. The experiences we have with stories, starting as young children, establish a structure for storing information in patterns of childhood narratives. Listening to stories during childhood also provides memorable, pleasurable experiences that the brain recalls and continues to seek throughout life. Strong emotional memory connections are intrinsic to children's experiences of hearing stories. Often the memory connection is simply the cozy feeling of being snuggled in bed. Notably, though, even for children being raised in tumultuous circumstances, a bedtime story means that things are relatively—or at least temporarily—calm.

But why do children want to make the same "predictions" night after night, when they obviously "know" the answer? It's because the dopamine reward response is particularly generous in young children, releasing dopamine when a "prediction" is made even though it does not formally qualify as a prediction—that is, something not known with certainty. Nevertheless, even during the bedtime story years, the dopamine reward response for prediction is activated despite the child knowing, with great certainty, what is on the next page. The *Goodnight Moon* phenomenon, of wanting the same book repeatedly, triggers the brain's release of dopamine, with its feeling of deep satisfaction and pleasure.

Beyond the pleasure principle of these repetitive childhood narratives, the familiarity of the narrative pattern becomes a strong memory-holding template (Zak, 2015). As the brain seeks and stores memories based on patterns (repeated relationships), a narrative map forms and, because it is often repeated early in life, serves as an easily recognizable memory-storage pattern in new learning. This sequence manifests in the three-step progression of the childhood story narrative map:

1. Beginning (*Once upon a time . . .*)
2. Problem
3. Resolution (. . . *and they all lived happily ever after*)

When information is presented in that familiar narrative form, the memory structure helps the brain retain that information. With time, that map expands to include narratives in which the ending may not be "happily ever after." These become opportunities for the student to explore or discover possible outcomes. What follows are examples of narratives in algebra, science, and history.

Algebra narrative. For a lesson on exponential growth, you could provide a narrative that promotes inquiry and memory through the prospect of money making, such as this one:

Maria did her family jobs all week and loved waking up on Saturday and getting her allowance. When she turned 13, her parents offered her an exciting choice. They said she could change to a monthly allowance payment and either receive $100 at the end of the month, or have the money if, starting with 1 penny on the first day, the amount was doubled each day for the 30 days. Excited to get a sum as large as $100, Maria chose that payout option. What would you choose?

After students have a chance to make their choices and see the surprising result—that doubling the amount each day would result in a payment of $5,368,709.12—they are ready to learn about *exponents!*

Science narrative. Here's a story you can tell students before a physics lesson on fluid dynamics to make it more personally relevant to them.

There was a guy, call him Archie, who wanted to know why the level of water in his bathtub got so high that it sometimes overflowed when he jumped in. It is said that he tried lots of experiments that didn't work, but one day he figured it out and said, "Eureka!"

His name was Archimedes, and he offers you the same challenge, as you figure out why the water level in your cup rises when you float a coin on a bottle-cap boat and why the water level lowers when you drop that coin to the bottom of the cup.

History narrative. Using information from primary sources or ongoing current news stories with only a beginning and a middle, open a history lesson (e.g., on the Hindenburg, astronauts on Apollo 13, Orville and Wilbur Wright) with a narrative such as this:

It started as a beautiful day here as we awaited their landing. After a spectacular first journey, the people on board were pleased by their success until they heard a disturbing sound that caused them to fear for their safe landing. Any predictions about the who, *the* what, *the* when, *or* how *it turned out? That's what we'll explore.*

Weaving learning into a story makes the learning more interesting, activates the brain's positive emotional state, and hooks the information into a strong memory pattern template. Whether created by you or your students, the memory then becomes more durable as the learning follows the narrative pattern through sequences connected to a theme, time flow, or actions directed toward solving a problem or reaching a known goal.

Constructing and Sustaining Memories

Think about the last time someone gave you driving directions that seemed so clear when you heard them but were forgotten once you made the second right turn. *Working memory* is the component of the short-term memory system that lets us hold and manipulate information that will be used immediately (Chuderski & Necka, 2012; Foster et al., 2015; Konstantinou & Lavie, 2013; Ma, Husain, & Bays, 2014). Information is held in working memory for a minute or less (Eriksson, Vogel, Lansner, Bergström, & Nyberg, 2015). Working memory is in play when the brain holds on to the opening sentence of a paragraph as a guide to connecting the subsequent information in that paragraph.

You use working memory when you do the mental math task of multiplying 11 × 15 and first calculate that 10 × 15 = 150. You hold that 150 in working memory as you take the remaining 1 from the original 11 and multiply it to get 15. You then pull the 150 from working memory, add the 15, and conclude that 11 × 15 is 165. Working memory is limited both by time and storage capacity. That's why most people can't use mental math to calculate 173 × 4029.

Despite working (and short-term) memory's limited capacity, the amount of information it can hold can be increased by "chunking" bits of information into a sequence of small packets (Eriksson et al., 2015). Chunking information is the way we recall phone numbers and Social Security numbers. When taking notes, students can chunk topics in relational groupings (e.g., biologic genus-species names, states and capitals), forming groups of three or four items that ideally have some commonality, such as first letter, number of syllables, or length of the word.

When a new short-term memory is encoded, retrieving it early, frequently, and in a variety of ways prevents loss of detail and promotes retention over time (Sekeres et al., 2016). For these reasons, doing something with the information soon and then periodically after it is learned will help sustain the fragile short-term memory on its journey to becoming long-term memory.

Brain Cells

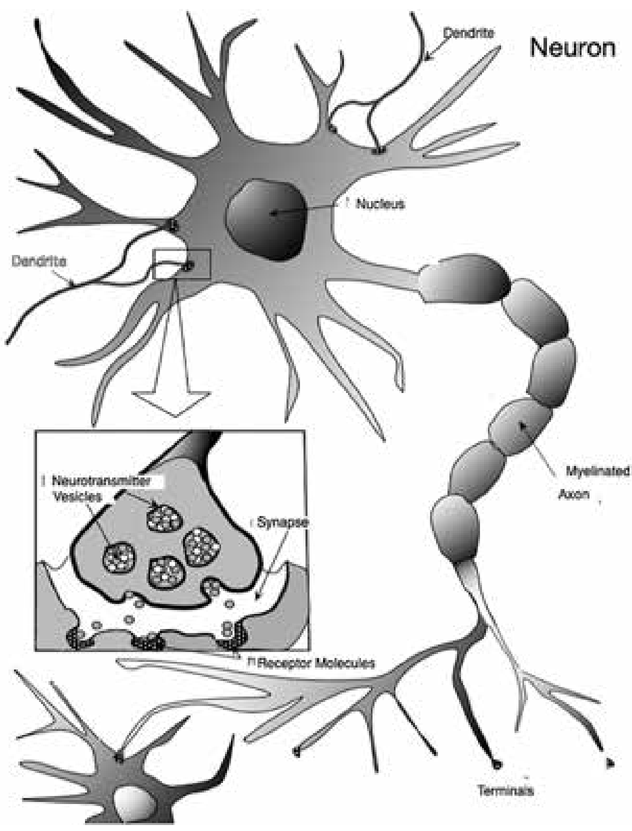
Recall the first few times you learned and practiced a new computer process, such as creating a web page or using e-mail. At first you may have followed step-by-step written or verbal instructions. Perhaps you needed to rely on those instructions multiple times as you repeated the task, until one day the process became automatic and you could even carry on a conversation while doing the job. That short-term memory was embedded by repetition into long-term memory, but it still needed periodic review to remain in your accessible memory storage and not gradually fade as a result of disuse. However, even if it did fade when you were away from your computer for a while, the neuronal circuit, or brain cell network, that was constructed by repetition remained physically present in your brain, just like a hiking trail persists under the winter's snow. The circuit was just in storage, like data taken off your computer desktop and put into the hard drive. As a result, it took less time to refresh the circuit than the time it did to create during the initial memory construction.

Although we commonly once believed that brain growth stops during childhood, then subsequently believed it extends into the 20s, we now know both concepts are untrue. New connections among brain cells holding information are formed throughout life. These connections or networks, similar to electric circuits, are the pathways that allow communication of information among brain cells, each of which holds a small part of a memory. Communication among connected brain cells is how memory is stored.

All learning (changes in knowledge or skills) is the result of physical change in the brain. *Neuroplasticity* is the process by which, after repeated use, newly formed short-term memories can become long-term memories. Neuroplasticity permits extensive interconnection of the brain cells. It allows memory information to be efficiently stored and conducted, and rapidly retrieved when needed. The result is like that of multilane expressways, which allow more and faster traffic. As we explore the process of neuroplasticity—and how we as teachers can promote this process to construct better learning in our students—let's look at its key components (see Figure 3.2).

FIGURE 3.2

Neuron



Neurons

The term *brain cells* generally refers to the brain's neurons. (As you'll soon read, the brain has other types of cells, such as *glial cells,* that are not neurons.) *Neurons* are specialized cells that are able to conduct electrical impulses. The human brain has an estimated 80 billion neurons (Von Bartheld, Bahney, & Herculano-Houzel, 2016). In its nucleus, each neuron holds a small bit of the information that constitutes a memory. What makes the difference, depending on a person's age and experience, is not the number of neurons but their interconnections. Each neuron holds only a tiny bit of information that by itself is meaningless. It is the connections among neurons—sharing these bits of information—that make up a complete memory or procedural system. This networking among neurons, each with hundreds to millions of *synapses,* or meeting points, allows us to retrieve a memory or perform a voluntary action.

Neural networks. Because single neurons cannot hold even a small memory, such as your date of birth, acquiring and storing new information in memory requires communication among thousands of neurons encompassing hundreds of feet of "wiring." The human brain continually changes through environmental stimulation and feedback as it constructs and revises communication networks among neurons. Networks of connections do exist in newborns, in response to genetic coding, but these are a mere framework. Consider, for example, a roadmap on a smartphone where the view from a great distance reveals only the major interstate roads. These roads are the equivalent of the connections between major parts of the brain that are present at birth. As time and experience build memories, the view magnifies, further revealing secondary roads that have developed, representing the increasing communication among neurons. These roads constitute the expansion from experience into more sophisticated and intricate memory circuitry.

Physiologically, these more complex neuron-to-neuron communication networks form as the neurons respond to attracting signals from neighboring neurons and sprout connections. Each neuron typically makes 1,000 to 50,000 connections with other neurons through nerve fibers called *axons* and *dendrites,* resulting in an estimated 100,000 miles of wiring (Chang, 2015; Neumann, Lotze, & Eickhoff, 2016).

Axons. *Axons* are the cables that carry outgoing messages from a neuron to its next destination. Although there is only one axon per neuron, it usually branches into multiple connectors, called *terminal branches,* near its end, allowing it to network with multiple other neurons. Axons are unique in that they have an insulating coating, known as *myelin,* which may thicken through the neuroplastic response.

Dendrites. *Dendrites* are connecting extensions that receive information sent across the synapse from the axon. Dendrites differ from axons in that there can be multiple dendrites per neuron—up to tens of thousands, carrying information into a single neuron at speeds of up to 300 feet per second (Chang, 2015; Neumann et al., 2016).

Myelin. As mentioned in the definition of axons, *myelin* is the white substance that acts like a coating of electrical insulation around the axons that connect neurons. Myelin is made of layers of fatty acids and proteins that wrap around axons and reduce leakage and loss of electrical signals, speeding conduction through the neural network. As the brain develops and brain circuits repeatedly activate, neuroplasticity promotes an increase in the density of the myelin. Thicker myelin increases the efficiency of the flow of the electric impulses along the axon.

Synapses. At the point between two neurons where connection is made via axon-to-dendrite communication, there is a gap called a *synapse.* While an electrical signal carries messages through the axons and dendrites, chemical neurotransmitters carry the message across the synapse. The patterns, numbers, and clusters of synaptic connections are constantly being modified by activity-dependent growth.

Glial Cells

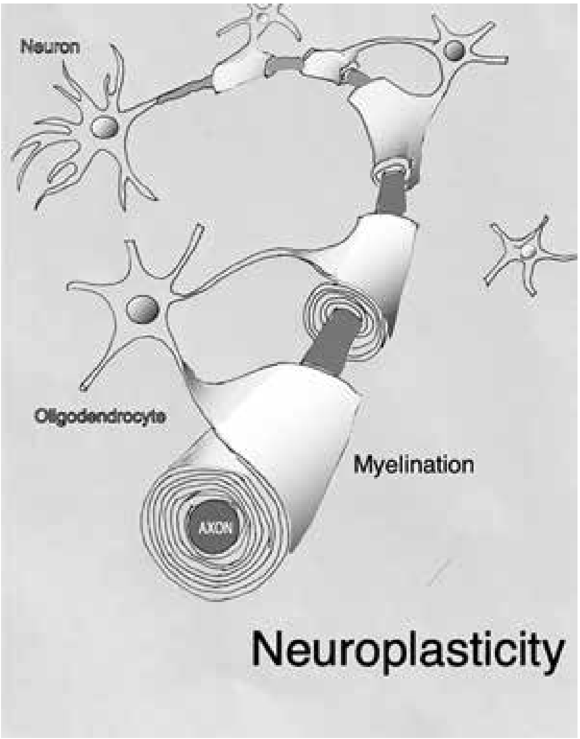
Glial cells, often just called *glia,* make up the majority of the other brain cells. Glial cells generate the myelin that latches onto axons as they strengthen with repeated use, and they also serve as a stabilizing, lattice-like support for neural networks.

Neuroplasticity to Build Long-Term Memories

Let's return to the process of neuroplasticity (see Figure 3.3) and how we can maximize its use to help our students construct long-lasting, transferable memory. Like hikers along a trail whose footsteps eventually create a firm pathway, repeated practice stimulates cells in the memory circuit so that the circuit is reinforced and becomes stronger. This means it can be quickly turned from "off" to "on," responding to a variety of cues coming in from the senses. The activity of neuron-to-neuron connections engaged in a learning task, which could be in the billions, stimulates and strengthens the memory circuits (Sardi et al., 2018). Through the neuroplasticity response to repeated activation, the dendritic connections expand and the myelin on the axons thickens. As a result, the travel of information between neurons becomes easier and more durable and rapid with use—as does hiking along that well-used trail.

FIGURE 3.3

The Myelination of Neuroplasticity



Like a strengthened muscle, these circuits become more efficient, and they become easier to access. Repeated stimulation and use further promote this development. The phrase "cells that fire together, wire together" succinctly describes this increased construction of more and stronger communication connections when the circuit is used (activated) (Chang, 2015).

We can see examples of brain plasticity when people repeatedly practice activities controlled by isolated parts of their visual, motor, sensory, or coordination systems for specialized learned activities. For example, right-handed blind people who read braille have significantly larger *somatosensory cortices,* where the sense of touch in their right fingers is processed. Similarly, violin players who use the fingers of their left hands for complicated maneuvers along the strings have larger somatosensory regions in the area of their parietal lobe associated with the fingers of the left hand (Merabet et al., 2008).

A 2004 report in *Nature* found that people who learned how to juggle increased the number of neural connections in their *occipital lobes* (visual memory areas). When they stopped practicing, the new neural connections vanished. A similar pattern of increased then diminished tissue seems to occur in people who learn a second language but don't practice it. The loss of secondary-language ability, juggling skills, or learned academic material that is unpracticed triggers the flip side of the brain's growth response to learning. Those brain pathways and connections that are not used regularly are no longer maintained and undergo elimination, or *pruning.* Following those early studies, more advanced neuroimaging techniques continue to demonstrate the neuroplastic response of building stronger and more durable neural networks of memory (Shaffer, 2016).

The information in Chapter 2 regarding interventions to individualize learning for student interest, mastery, and achievable challenge will connect with the strategies you'll soon learn about in this chapter. Together, these support the immense potential of neuroplasticity to help all students learn to their fullest potential.

Pruning: Use It or Lose It

Just as hedges are pruned to cut off dead branches that no longer "communicate" with their neighbors, the brain prunes its own inactive cells. Unnecessary or unused memory circuits are similarly broken down and pruned. Active cells require blood to bring nourishment and clear away waste, but inactive cells don't transmit messages to the circulatory system to send blood. (The brain cells receive circulation not from blood, as in the rest of the body, but rather from a colorless, filtered form of blood called *cerebral spinal fluid*.) This reduced blood flow means that calcium ions and other waste products accumulate around the cell and are not washed away. This buildup of calcium ions triggers the secretion of the enzyme *calpain,* which causes cells to self-destruct, circuits to wither, and memories to be forgotten (Riccomagno & Kolodkin, 2015).

Counterintuitively, though, pruning is not an enemy but rather a preserver of the brain. Consider the sluggishness of a computer with lots of data stored on the desktop; it takes longer to start up because all the data must first be activated. Removing some of the data increases the computer's efficiency. Similarly, pruning keeps the brain efficient. Without pruning, the brain would have too many crowded circuits to be thrifty in using its limited resources. What we need to keep in mind is that pruning dictates the "use it or lose it" phenomenon in which students forget learning soon after a test and have to relearn it the next year. As you'll read, you can take measures to prevent that from happening.

Gray Matter

Neurogenesis

Neurogenesis is the topic in this Gray Matter text box because it is a "gray area" in neuroscience. It is defined as the process by which new neurons are formed from differentiating neural progenitor cells in the brain (Marshall & Bredy, 2016). Over the last several decades, evidence has accumulated supporting neurogenesis: the capacity of new neurons to be born in the hippocampus region in the brains of adult laboratory animals—predominantly short-lived animals, such as rats (Vukovic, Colditz, Blackmore, Ruitenberg, & Bartlett, 2012). Because we know the hippocampus plays important roles in learning and memory, there is speculation as to whether, and to what extent, neurogenesis occurs in adult humans. For now, more research is needed to further evaluate the veracity and significance of these preliminary investigations (Andreae, 2018).

Yes, You Can!

"Yes, you can change your intelligence and skills" is a message we want to convey to students. Just knowing the neuroscience of neuroplasticity builds their confidence in the validity of that proclamation. Students, like many adults, mistakenly think that intelligence is genetically determined before birth and that no amount of effort will significantly change their potential for academic success. The realization that they can literally change their brains through study and review strategies is especially empowering for those who have been told they are "not smart." I've seen this sense of empowerment in my neurology patients who lost function due to brain disease or trauma. Through practice, simply beginning with visualizing moving the paralyzed limb or speaking again, neuroplasticity constructed new neural networks as undamaged parts of their brains took over the job of the damaged brain regions.

Students become motivated to take action when they learn about neuroplasticity, see documented brain scan evidence of positive brain changes, and become aware of the results of their own successes. They learn that their dedicated practice resulted in neurons firing together, wiring together, and building memories that last.

Neuroscience Read-Aloud

Practice Makes Progress

Just as when you learned to ride a bicycle, play a musical instrument, or rapidly keyboard on a computer or phone, it's practice that improves your skills. The same process, called *neuroplasticity*, is ready to work for you to make your learning stronger and more useful. Every time your brain practices a skill or reviews new learning, the memories and actions strengthen.

Not All Practice Is Equal

Not all practice is equal when it comes to what has the greatest effect on neuroplasticity and memory outcome. We'll now consider what mental manipulations best increase activity along the connections among neurons and most effectively strengthen the wiring of the neural pathways. The goal is to promote enduring understanding and long-term memory. We'll start with the more basic, self-contained memory circuits of rote memory and then expand into even more powerful mental-manipulation strategies.

From Short-Term to Automatic Rote Memory

So far, we've seen three major progressions of information along its journey to memory:

1. Information about the world enters the body through the senses.
2. The reticular activating system and the amygdala select or promote new sensory information into further response or memory processing.
3. In the hippocampus, the new input connects with previously stored memories (prior knowledge) to encode short-term memory.

In some cases, this progression leads to the formation of rote memory.

Rote Memorization as a Foundation for Learning

Neuroplasticity is at work any time a network is used (activated, stimulated), so it will strengthen memory networks through many types of use. Although rote memory to the point of automaticity is not the method we want in order for all learning to progress from short to long term, most academic subjects need to tap into it as foundational knowledge for extended learning (e.g., literacy, the arithmetic of multiplying fractions, foreign-language verb conjugation). Rote memory also provides a foundation for *procedural memory,* the skills and habits engaged without conscious recall, such as those involved in driving a car, decoding words, touch-typing, and playing the piano.

Neuroplasticity from Repetition

Recall that unless something is done with a newly encoded short-term memory within minutes or hours of constructing that memory, it will not progress to enduring, long-term memory. Construction of rote memory requires many repetitions over a period of time, especially by retrieving a new short-term memory shortly after it is encoded and then revisiting it to further promote its retention over time (Sekeres et al., 2016).

Just a few reactivations are not enough for neuroplasticity to sustain the memory correctly and on a long-term basis. Once the information is remembered correctly, it still needs regular review, at gradually lengthening intervals, to be sustained. The more frequently the neural connections are activated in practice, the more dendrites and axonal myelin accumulate and strengthen the connections between the neurons (Sekeres et al., 2016).

In this section, and more so in the upcoming section about mental manipulation, we'll look at a variety of ways to maintain new memory. Beyond single-pattern activation for learning and review (e.g., one question/one response, flash cards for arithmetic or spelling), it is clear that varying the methods of activating these circuits promotes greater consolidation of information.

The examples that follow describe various learning and practice scenarios that promote durable rote short-term memory. In some cases, they can also facilitate the expansion of isolated rote memory into complex networks of long-term, transferable memory.

- Introduce new information when students are engaged, with focused attention.
- Remind students of their goals and how acquiring and memorizing new foundational information provides the tools for them to reach these desirable goals. For example, if their goal, developed in collaboration with your unit goals, is building a model land-water amphibious vehicle (as a way to contextualize geometry), they will be more motivated to learn the basics they need as they make their designs.
- Invite students to repeat information you want them to remember in different ways, such as vocabulary words in conversation: "Isn't it *odious* how much chewing gum is on the bottom of some restaurant tables?" "Oh yes, and it is even more *odious* when you have to clean it."
- Pose practical, real-world problems for students to solve using the new knowledge.

The Importance of Moving Beyond Rote Memory to Long-Term, Transferable Memory

As we move beyond rote memory, let's consider the limitations of short-term memory that has been repeatedly activated, but only in the same way or applied to the same problem or question repeatedly. Activating rote memory is the most commonly required memory task for students in primary and secondary school. This type of learning involves memorizing and, unfortunately, soon forgetting facts that are often of little primary interest or emotional value to the student, such as a list of vocabulary words. Facts that are memorized by rehearsing them over and over in the same manner rarely have obvious or engaging patterns or connections.

Rote memorization is not understanding. The ability to retrieve content facts and procedures taught by drills alone, without applications in multiple contexts or opportunities for mental manipulation, is generally limited and requires the same prompts used in repeated practice. Information learned only by rote practice has limited representation in the brain and is stored as unincorporated, isolated circuits. These are like dead-end roads that don't get much traffic except with the specific cue that activates them, such as "What is the capital of this state?" or "What is the past tense of this verb?" With nothing to give them context or relationship to each other or to the students' lives, these facts—weakly represented and more difficult to locate—remain isolated, with fewer nerve pathways leading to their remote storage systems.

The explosion of all fields of knowledge has led to profound expansions of curriculum topics that must be "taught" in each grade. Moving beyond rote memorization, it is critical that learners construct understanding and make learning their own. This is not a time to limit learning to memorization of isolated "factoids," with no opportunities to evaluate and apply learning in a variety of ways. As psychologist Jerome Bruner (1960) wrote, "Grasping the structure of a subject is understanding it in a way that permits many other things to be related to it meaningfully. To learn is to learn how things are related" (p. 7).

Practice Makes Permanent

Memory can be thought of as the construction, expansion, and strengthening of neural networks in response to activation. Let's now consider what factors influence the construction of durable memory networks. As previously explained, each time a memory network is activated—as for the meaning of a word or a skill such as kicking a ball—the neuroplastic response is also stimulated. This action strengthens the networks of interconnecting neurons, each of which holds a piece of the memory. It is the mental manipulation of learning (practice, rehearsal, using information in new ways) that makes these networks grow stronger, faster, and more durable (Chang, 2015; Neumann et al., 2016).

Our earlier discussion made clear that new memories of information, tasks, and skills need be activated or practiced, or they will be pruned (McGaugh, 2013). Even if instruction—say, for decoding words during the last month of school—is successful, the same literacy skill may not carry over to the following school year. It takes practice, repetitive use of the pathway, and review to retain stored learning in neural networks. If students do no further work with the words during the intervening months, pruning will likely eliminate many of the constructed networks. Reactivating learning (preferably within 24 hours) in ways that individualize it through personal response or correlate the new with existing memory networks allows students to recognize its familiarity and its value as related to their goals.

Consolidation of short-term memory into long-term memory refers to a process during which new memory, initially encoded in the hippocampus, is transformed into more stable representation that becomes integrated into long-term memory (Dudai & Morris, 2013). However, for long-term memory to be durable and efficiently retrieved, it needs to be mentally manipulated (Wenger & Lövdén, 2016). Formally defined, then, the transitioning process from short- to long-term memory involves processing and organizing the selected material into coherent mental representations, and then integrating the mental representations with each other and relevant prior knowledge activated from long-term memory.

Building Foundational Knowledge

Most academic subjects require a base of foundational knowledge that is built from repeated experiences or practice. Learning to speak a foreign language requires foundational knowledge of the most frequently used vocabulary words. Mathematical computations require a consistent set of representations for specific quantities. To develop larger funds of knowledge and construct concepts, students need to know the characteristics represented by specific designations, such as the hours of a day or the distance represented by a foot or a meter. With a durable and transferable foundational knowledge in place, students can begin each school year motivated and prepared to embark on increasingly challenging coursework rather than being bogged down by having to relearn the previous year's skills and topics.

Without appropriate content knowledge, opportunities for creative representation and innovation will not prepare students for current or future success. The executive function skill sets (the topic of Chapter 4) need material to process. Students cannot perform critical analysis without foundational knowledge of what constitutes accuracy. They cannot express empathy without experiences of sadness. They cannot offer judgment without understanding the information to be judged.

Gray Matter

Effective Teaching for Memory

Brain-mapping techniques allow scientists to track which parts of the brain are active when a person is processing information. The levels of activation in particular regions can be associated with which facts and events will be remembered. Activity in the prefrontal cortex and hippocampus correlates with how well an experience is encoded and remembered (Neumann et al., 2016).

The implications for academic instruction seem clear. For new tasks and skills to be maintained, they must be practiced or they will be pruned (Riccomagno & Kolodkin, 2015). If we teach the topic of adding fractions, and the corresponding brain areas are primed with information about manipulation of fractions, students' neural networks grow. However, if these neural networks remain inactive for months, pruning will likely eliminate many of the constructed networks. If, on the other hand, students continually build upon prior learning—with periodic reviews and extension of thinking about fractions, such as connecting fractions with the concepts of ratio and proportion—the fraction-related networks in their brains will grow in terms of cellular stability and become permanent.

Neuroscience Read-Aloud

Mental Manipulation for Long-Term Memory

The information you learn must become integrated in your brain into durable, long-term memory circuits of connected neurons so that you can consciously retrieve it and remember it. This means that you, the learner, have to "do" something with the information so the neural network will be activated. It is the electrical current that flows through the network when it is used that promotes the neuroplastic changes that will sustain the learning as memory.

When you passively memorize information to fill in on tests, your brain experiences little actual learning. For your brain to process information and move it into your long-term memory banks, you must actively do something with it. Let's call this "mental manipulation." For example, to learn how to play baseball, you have to physically handle the ball and bat; to learn how to sew, you have to manipulate a needle and thread.

You mentally manipulate information by using it. You build stronger memory circuits through the "use it, don't lose it" system of neuroplastic growth. You can use the information in many ways to learn which ways work best for your memory. For example, you can take new learning and put it into patterns by classifying, categorizing, comparing, or contrasting, or you can use it to investigate, learn more, or solve challenging problems by enlisting higher-level thinking skills.

Mental Manipulation Strategies

It's not how much students know that's important; it's what they can *do* with what they know. Let's now look at ways to help students process newly taught information so that it travels beyond temporary short-term or rote memory into expanded and durable memory storage. These strategies provide opportunities for students' brains to connect new information to multiple brain pathways that lead into the memory storage areas. Using the strategies will give students more available roadways to drive information into their memory storage region and efficiently retrieve the stored knowledge when needed.

We'll start with graphic organizers, discussions, writing, and practice (via tests, quizzes, and flash cards).

Graphic Organizers

Graphic organizers coincide with the brain's natural tendency to construct meaning by recognizing, forming, and extending patterns. Recall that memories can be captured only after they've been encoded with prior knowledge in short-term memory. To reach the final stage of enduring memory—retention in long-term storage—the information needs to be consolidated and stored in an area where the otherwise transiently encoded event or information is patterned into a more enduring form (Alberini & Kandel, 2015).

Graphic organizers and other visual organizers help students see relationships, recognize patterns, make associations, and sort information. Graphic organizers have an intrinsic appeal. They facilitate student interpretation and interaction with the information acquired in patterns and relationships that connect new learning to prior knowledge.

Doris Lessing said, "That is what learning is. You suddenly understand something you've understood all your life, but in a new way" (Feagin, Hirschmann, & Müller, 2015). When students diagram their own connections, linking their newly acquired information to previously stored memories, they are deepening their understanding as they expand their graphic organizers.

Discussions

A clever study compared a direct instructional approach by a seasoned professor with that given on the same topic by a trained but inexperienced instructor. The control group heard the standard formal lectures given by the professor. The second group received no such lectures but worked in small groups to solve challenging problems, enhanced with frequent feedback from the instructor. The latter group's activities were designed to motivate students' full engagement to use reasoning, scientific thinking, predictions, collaboration, and self-critique. The results indicated significantly greater positive outcomes in the second group, including increased attendance, higher engagement, and an average score of 74 percent on the unit test, compared to 41 percent for the control group (Deslauriers et al., 2011).

The study results underline the value of discussions, leading us to recommend the following approach: Encourage inquiry and discussions that involve engaging mental manipulation—developing opinions, analysis, judgment, and decision making—especially aligned with students' interests or pertinent topical events. Frame open-ended questions that have more than one answer, and emphasize that you are inviting opinions so students won't feel anxious about saying something "wrong." Provide wait time before you accept any response, and encourage multiple responses, allowing students to offer support for their opinions.

You can use these questions to stimulate discussion:

Any subject.

- Why might this information be useful to you someday?
- In what occupations or hobbies could this information be useful?
- How could you use this information to build a better skateboard, advertise a product you invent, plan a party with a budget, or write a book for a younger child about this topic?
- How could you explain this new information to a child from another country who has never seen (fill in the topic subject)?

Science.

- What modern invention that you really like may have needed this science knowledge before it could be invented?

Literature.

- How are you like a character in this book?
- What would you do if you had the same problem?
- Why do you think the character (fill in an action the character took)?

Social studies and history. Discussing current or historical events through films, books, online sources, primary sources, or newspaper articles provides multiple perspectives to promote discussions—and at times, even debates, disagreements, and teachable moments. Students can select the position they want to defend in discussion and meet with a few classmates who agree. They can then consolidate their opinions and supportive information and challenge a differing group to sway their opinion on topics such as these:

- Was the French Revolution fair to the royal family?
- Should kids vote? At what age do you think someone should be allowed to vote?

Historical inaccuracies in films like *Amistad, Amadeus, Glory, Pocahontas, Braveheart, Anastasia,* and *Argo* can provide opportunities for enlightening discussions about biased representations of history in textbooks, films, and media. Even an "old" history textbook from the 1960s is a source of curiosity or disbelief when it shows clear evidence of bias. In viewing films with historical inaccuracies, you can promote students' curiosity and inclination to read the related textbook material before you show the video, setting up the fun from discovery while uncovering inaccuracies.

Writing

Reconstructing learned facts and procedures into writing, and communicating how these relate and interconnect, exemplifies the process of mentally manipulating facts into understanding. Writing presents countless possibilities to promote this valuable process. Writing can build stronger understanding and conceptual networks about what fractions really represent or how to see the patterns running throughout history, sports, art, science, or economics. When writing is an act of developing mental relationships that join isolated facts into conceptual knowledge bundles, students' brains construct understanding and increased ability to retrieve the formulas, facts, or procedures; these are now available when needed to evaluate new information and solve new problems.

Dend-*writes.* Mentally manipulating learning into dend-*writes* is another form of writing to summarize and consolidate new learning. (This punful brain-science term plays on the concept of constructing more dendrites through the neuroplastic response to writing.)

You select the dend-*write* prompt about the lesson or section of a lesson, and students respond on note cards. (These prompts are often the same and can be kept on a posted list so students can respond to the one you select, or you can give them a choice of two.) Here are some examples of dend-*write* prompts:

- One thing I learned today is . . .
- One thing that surprised me today was . . .
- Something I'd like to find out more about is . . .
- Something that confused me is . . .
- A question I have is . . .

When students write down what they learned, what surprised them, or what confused them, you get feedback from their dend-*writes.* If students' responses include misunderstandings, that tells you that parts of the lesson may not have been as clear as you intended, allowing you to reteach it in another manner to reach the objectives.

Put check marks on several dend-*writes* that are good concept summaries or reflect common misunderstandings. The next day, return the cards to the students. Invite the students who wrote the ones you checked to read them aloud, or read them aloud yourself, keeping the sources anonymous.

Exit cards. These are similar to dend-*writes,* as students each write a brief summary of what they think the key point of the lesson was and hand their cards to the teacher as they leave the classroom. Reviewing these lets you know which students may have missed the mark. You can select exemplar exit cards to post in class or on the class website for others to read and for absent students to review when they return.

Self-Corrected Quizzes

We've learned that mental manipulation for long-term, durable, transferable memory demands multifaceted interactions during the learning, which extend dendritic connections and expand related storage units. Profound benefit also comes by giving students *multiple avenues* to tap into the information's new and varied storage networks, allowing a variety of opportunities to retrieve and apply it (Sekeres et al., 2016). Students who repeatedly retrieve recently studied information are more likely to recall it in the future. Even if they can't retrieve it, the awareness that they missed something relevant furnishes motivating feedback to review what they don't know and recapture that achievable-challenge dopamine reward as well as apply stronger tools to achieve their goals (Adesope, Trevisan, & Sundararajan, 2017; Carpenter & Kelly, 2012).

Research on practice quizzes (with available answers) supports the beneficial impact that retrieval bestows on memory, beyond that garnered through the simple usual forms of restudying (e.g., rereading notes or text). A study evaluating sustained memory of foreign-language vocabulary words found that mixing study with no-credit practice quizzes, along with corrective feedback before returning to study, was more successful for recall than repeating the same daily review practices without practice tests. The interpretation was that repeated testing, involving retrieval of information, helps to consolidate the learning process (Karpicke & Roediger, 2008).

In another study, students who mentally manipulated learning through practice tests outperformed those who learned through routine study (e.g., review of notes and text) even when corrective feedback was not provided on the initial task and when the final test assessed memory from vantage points that had never been practiced during the initial task (Carpenter & Kelly, 2012).

Accurate memory is further promoted by checking answers and then going back to the book or notes to find the information needed to reach the right answer—all of which enable students to learn from their mistakes (Adesope et al., 2017; Carpenter & Kelly, 2012).

The subjects of another study were college students who began each class with quizzes taken on their laptops, followed by immediate and corrective feedback. Compared with those who did not take such quizzes, the quizzed students' exam performance was about a half letter grade above their classmates' (Pennebaker, Gosling, & Ferrel, 2013).

Another study that further demonstrated the benefits of frequent, feedback-laden quizzes showed that multiple-choice quizzing was just as effective as short-answer quizzing. Both multiple-choice and short-answer quizzes were followed by correct-answer feedback. The control groups received the same information as the students who had been frequently quizzed, but they were not quizzed daily. In this study, middle and high school students who had been frequently quizzed performed better on unit exams and on end-of-semester exams than the control groups. The study went further by providing end-of-semester exams not in the multiple-choice or short-answer format. Even with more extended questions and essay-type answers, students performed better if they'd been quizzed on the material (McDermott, Agarwal, D'Antonio, Roediger, & McDaniel, 2014). Evidence further suggested that the durability of memory increased when the challenge levels of the questions varied and intervals between review testing became gradually longer (Toppino & Gerbier, 2014).

Practice tests might work for these reasons:

- The daily or frequent benchmark testing prompts changes in how, what, and when students study and prepare for tests.
- The quizzes provide a structure for frequent feedback on progress, guiding students to engage in productive self-evaluation toward their goals.
- Seeing the results of their testing enhances students' focus when they restudy topics that prompted mistakes. The subsequent enhanced retrieval is consistent with the dopamine reward system.
- By virtue of which information is included, review via self-testing guides students to prioritize content to study.
- As the number of correct answers on practice tests gradually increases, students can directly see the progress they have made, enhancing the long-term benefits of self-paced practice.

Another benefit of self-corrected practice quizzes is feedback for teachers to use on modifying subsequent instruction or filling in missing gaps in understanding. It is helpful to assure students that when you collect and review their practice quizzes, you are using them to determine your next teaching steps rather than to judge their abilities.

Practice: Flash Cards for Self-Regulated Learning

Another example of progressively successful self-paced learning occurs when students use flash cards to practice foundational information at their appropriate level of achievable challenge. Flash cards naturally incorporate test practice by having a question on one side and the answer on the other, so students get immediate feedback after generating their answer. They get feedback on their progress toward their goal as the number of flash cards in the "to be learned" pile gradually decreases (Hsieh & Ranganath, 2014). In general, students who reported that they practiced with flash cards until the information became durable and remembered several days after it was originally retrieved showed even greater success at retrieving and maintaining memory (Lin, McDaniel, & Miyatsu, 2018).

Strengthening New Learning Through Symbolizing

New learning is fragile until something is done with it. It can be strengthened by simply repeating, rereading, and drilling on the specific information again and again, until it embeds as rote memory. Learning for retention for a single purpose (rote learning) differs from learning through which students' brains construct their own understanding of a concept. The distinction involves more sophisticated processing (recall the "neurons that fire together, wire together" system of neuroplasticity). Providing students with various directed ways to manipulate information promotes even stronger, more transferable memory (Dhindsa, Kasim, & Anderson, 2011; Markant, Ruggeri, Gureckis, & Xu, 2016).

When new learning is mentally manipulated by symbolizing, the brain is actively constructing knowledge through its neuroplastic response (Pilegard & Mayer, 2015). Providing learners *multiple ways* to "translate" their learning into new applications, representations, or innovations helps their brains build greater concept understanding as they progress from an initial storage of rote, unconnected facts to more abstract concept knowledge that they can transfer to new applications.

Symbolic Representation for Understanding and Memory

The concept of symbolizing came to life when I had students mimic the motion of planets by rotating, revolving, and circling their bodies around a chair (representing the sun) in the center of the classroom. Their enhanced understanding, long-term memories, and transfer (e.g., recognizing those same concepts in the movement of electrons around an atom) inspired me to uncover more ways for students' brains to actively process learning through symbolic representations.

Within the context of mental manipulation, we'll explore symbolizing as a way to translate information taught in an academic context (lecture, reading, discussion) into representations the learner constructs that emphasize the concept or big ideas of the topic. Symbolic representations arising from these mental manipulations can guide the understanding constructed as learners progress from initial concrete, unconnected facts to more abstract concept knowledge.

Symbolizing, at the rigor recommended for active mental manipulation of the new learning, should promote students' accurate foundational knowledge and guide their recognition and self-construction of the big ideas or concepts. Consider the translation of sentences in one's known languages to an unfamiliar language, using only a word-to-word dictionary, without changing the meaning and clarity. Without knowledge of the foreign language's structure, grammar, idioms, and so on, the symbolizing into that new language would be likely to be inaccurate, be incomplete, or fail to communicate the original meaning.

What if you did not speak Portuguese and were given an English–Portuguese dictionary and told to "translate" five English sentences? Without understanding the grammar, syntax, conjugations, and idioms of Portuguese, it is highly unlikely that you'd select the best translated "definition" for each word to construct a sentence that conveyed the full meaning of the Portuguese language. Similarly, symbolic representation of the allies and adversaries in WWII would not be achieved simply by molding a piece of clay into two parts.

The goal to be conveyed to students is that assignments to symbolize information include use and/or demonstration of being able to evaluate, understand, and represent the big ideas and concepts in the new way. This higher-level interpretation can be guided by these questions: Does your symbolizing provide a way for someone with no knowledge of this topic to gain some understanding? Does your symbolizing add further insights for others, such as classmates with understanding of the concepts?

Opportunities for linking new learning with related memories serve as "brain glue" through learners representing the new knowledge symbolically. Well-designed symbolic representation promotes creative innovation, as students' brains form new connections among previously unrelated areas of stored memory. This innovation process can be thought of as a self-scanning system, with the brain sending inquiry signals to distant regions of the cortex, seeking—and linking with—other networks assessed as having information that can be applied together (Durstewitz, Vittoz, Floresco, & Seamans, 2010; Moore et al., 2009).

With symbolic representations, the small networks of isolated bits of information incorporate into expanded neural networks of related memory that can be retained rather than pruned away as soon as regular practice stops (as in the summer "brain drain" phenomenon). Instead, the expanded networks can sustain the memory and enrich the repertoire of information connected together for future use.

Examples in Narratives

As mentioned previously, learning information in a narrative form helps us remember what we have heard or read. In addition, putting information in story (narrative) form—such as writing or speaking about electrons dancing circles around their friend the neutron—enhances memory, as evidenced by the strong pattern recognition of children who grow up with narrative stories.

After reading a section of text or listening to a lecture or discussion, students can turn the learning into a story format to promote memory strength and expand connections. Whether the information stems from a chapter in history, literature, or science, students can create stories or books for classmates or younger students, or to share with a sibling or parent at home. The learning becomes more personally relevant, and the symbolic translation means they will seek to understand the learning well enough to "translate" it accurately.

Narratives can include translations in forms other than stories; for example, they might take the form of videos, brochures, posters, news stories, songs, art, music, or skits. Fictionalized dialogues or interviews (written or performed) with individuals or characters from literature, history, or science are particularly useful. This approach works as long as students meet the goal of symbolizing the new learning in ways that represent their understanding of the underlying concept.

Some of the following subject-specific examples of symbolizing and other mental manipulations are from professional educators who participated in the Learning and the Brain Institute at University of California, Santa Barbara, I taught in the summer of 2018, and others are from students with whom Malana or I have worked.

Examples in Math

Math offers a number of ways to symbolize information. Here are some of the most effective.

Personalized and humorous symbolizing with images and movement. The more unusual or funny the symbolic representation, the more memorable it becomes. One student began her representation by drawing a newspaper page. Next, she drew a pot near the upper corner of the page. Because students knew we were studying right triangles, they soon came up with the right word for her symbolizing: "high-pot-in-news," or *hypotenuse.*

Students usually created these symbolic images as homework and shared them in class or on the class website, where I also posted favorites from past years' students. Classmates enjoyed looking at these earlier sketches posted online and guessing the word portrayed. To prompt their guess, the word was displayed in syllables, one revealed with each click, until the entire word was visible. For sketches on the classroom wall, I covered the word with a flap of paper that they could lift to check their prediction.

Another math pun works for complementary angles, which are angles that add up to 90 degrees, forming a right angle. Each individual angle is an acute angle—less than 90 degrees. For this visual pun, an image shows two acute angles "complimenting" one another. The 40-degree angle says, "You're a cute angle!" and the 50-degree angle responds, "You're a cute angle, too!" These complementary angles are doing the "right" (polite) thing by complimenting one another as they add up to a right angle. This double pun captures the concept of complementary angles forming a right angle by adding two acute angles in a humorous, or at least memorable, way. As a bonus, you can include a brief spelling lesson on the difference between complementary (angles) and complimentary (flattering).

One of my favorite math puns involved my drawing a square and telling the students that one day a new, inexperienced bus driver was on the road and hit the square. I then sketched the square after it was struck by this *wrong bus*—it tilted to the side and became a "wrong-bus," or a *rhombus*. After the students' groans subsided, I had them stand upright like squares and imagine that the wrong bus had tapped them, so they tilted a bit and turned into rhombus-like figures.

Symbolizing math with poetry. To explore the concept of symmetry, students write poetry in the symmetrical form of a haiku (5-7-5 syllables) or a diamante poem; for example, *Each side is the same / line of symmetry divides / a mirror image*.

Math synonyms. The vocabulary concept of synonyms can help students understand the idea that numbers with the same value can be represented in a variety of ways. In this activity, students list common synonyms for the word *hi,* linked with different ways to represent a value; for example, *hey, what's up, hello,* and *howdy* are linked sequentially with 12, 36/3, 4×3, and 12/1 to symbolize that *hi,* said different ways, still means *hi,* just like different number representations still symbolize the same quantity.

Math stories. Students can create brief narratives to symbolize math concepts, such as the characteristics of imaginary numbers. Here's an example: "*i* wanted to become real, so he went to a mad scientist who had a 'squaring machine' and became real because $i^2 = -1$."

Math videos and animations. Using stop-motion video with animation or claymation, students can demonstrate how number patterns or progressions evolve. For example, showing 3 objects, then 6 objects, then 9, 12, 15, and so on, would be a way to symbolize the concept of multiples.

Math photographs and illustrations. To see math in the real world, students can identify math concepts and vocabulary using visual imagery. For example, students observe an illustration or a photograph of a landscape and locate and define the four types of slope. They would see *positive* and *negative slopes* in mountains and rooftops. Vertical trees, fence posts, and walls would represent *undefined slopes,* and the horizon would represent a *slope of zero.*

Manipulatives. To symbolize fractions, students can make fraction bars using strips of paper. Each strip represents one whole. Keeping one strip for comparison, they divide the others into different numbers of equal sizes, such as two equal halves, four equal fourths, and so on. After labeling the parts with the fraction that they created, for example writing "1/2" on each of the two parts, they match up two labeled "1/2" parts next to the whole one and recognize that both representations symbolize the same amount—that is, two 1/2 pieces are the same as one whole piece. They continue to construct symbolic representation—for example, demonstrating that four 1/4 strips are the same as one whole.

Gray Matter

Fractions and Students' Futures

Fractions can be a major stumbling block in mathematics. The ability to understand them is considered a strong predictor of students' likelihood to take the advanced mathematics needed for higher education and the most desirable jobs (Fuchs et al., 2015). Studies show that students who develop their understanding of fractions through opportunities to symbolize the concepts with manipulatives, drawings, narratives, and other representations are more likely to develop conceptual understanding of fractions. Those in a control group, receiving the traditional instruction on fractions that emphasized procedural knowledge, with minimal opportunities to conceptualize the meaning or magnitude of fractional notations, achieved less (Gabriel et al., 2012).

Examples in Science

Dance. The dopamine-boosting power of movement along with deliberate choreography can make dance a powerful tool for symbolizing. For example, students can symbolize the life cycle of a butterfly, the water cycle, or planetary motion through a series of dance moves. Malana recalls an elaborate video she saw in a high school biology class that involved modern dancers demonstrating the complicated process of photosynthesis.

Symbolic analogies. Students can create analogies connecting familiar concepts with scientific processes. For example, the following relationship analogies demonstrate chemical reactions:

- A single displacement is when Brad Pitt left Jennifer Aniston for Angelina Jolie.
- Decomposition is a breakup of a band like the Beatles.

Examples in Social Studies

First-"person" narratives. Another way of exploring multiple perspectives is to take on the viewpoint of an animal or inanimate object. For example, what did Paul Revere's horse see during his famous midnight ride? What could a fleck of gold tell us about the journey from a prospector's pan to becoming part of gold bullion in a San Francisco bank?

Historical documents. Significant historical documents or primary source material can be rewritten in a contemporary or familiar format. For example, the Declaration of Independence could be reworked as a breakup letter with Great Britain.

Advertisements. Knowing enough about a topic to make someone very interested in it is another way to demonstrate understanding. For example, students could create a video or print ad symbolizing different inventions and contributions of ancient Mesopotamia, with the goal of convincing others where to spend their hard-earned shekels.

Examples in Language Arts or Foreign Language

Analogies. Making an analogy allows students to not only symbolize their learning but also compare what they are learning to something they already know. Analogies can extend memory patterns and multicentric brain connections by highlighting ways information can relate to previously stored memory. Here are some examples:

- *White* is to *snow* as *blue* is to *sky.*
- Reading makes me smarter like exercising my muscles makes me stronger.

Scaffolding analogies can promote students' understanding of the process or enrich their understanding of a concept as they try to uncover the relationships in classmates' analogies from previous years. For scaffolding, you would leave out one or two of the components, as in this example: A *royal approval* is to a *monarchy* as a ________ is to a *dictatorship.*

"Analogies *plus*" adds visual images that boost connections further. Students can initially create their analogies to correspond to curious pictures you provide and later to ones of their own choosing (these will be great to retain and show as examples for students in subsequent years). In making analogies about punctuation, as a response to a photo of a man doing a one-armed handstand, a student wrote: "Exclamation points, like this man, attract our attention and are vertical lines."

Book character transformations. Students can represent their understanding of literary characters by symbolizing character traits. For example, students could design a restaurant menu with items named after characters and reflecting some of their characteristics. A meal based on *The Wizard of Oz* might feature a Wicked Witch of the West Salad with bitter arugula and sour lemon dressing and a Good Witch of the North Soufflé topped with a generous portion of sweet berries.

Puns and humor. Using humorous puns to symbolize and explore new vocabulary is a helpful memory aid. For example, to remember the meaning of the word *claustrophobia,* a student could write: "Santa *Claus* can't be *claus*trophobic because he needs to squeeze down chimneys." Adding a humorous sketch of a jolly Santa wedged in a chimney would further strengthen this memory.

Categorizing

Research involving students in an advanced chemistry course found that those who had relevant conceptual knowledge from previous courses were likely to get better final grades than those who had primarily rote memory of facts. The researchers suggested that this outcome further supported the notion that factual knowledge alone—as opposed to understanding the interrelations between the facts—is inadequate (Hailikari, Nevgi, & Lindblom-Ylänne, 2007).

Learners who organize information with multiple interrelationships have been found to be more academically successful (Bischoff & Anderson, 2011; Pilegard & Mayer, 2015). One form of relational connections is categorizing. Learners can categorize information by commonalities. Actively building awareness of commonalities can promote and reinforce connections to prior knowledge, stabilize new memory in extended circuits, and facilitate memory retrieval or transfer.

Categorizing can promote conceptual understanding by creating links among information, thus incorporating previously isolated rote memories. The flow of information between many different areas of the brain is associated with deeper understanding and the creative formation of ideas or concepts (Jung et al., 2010). When the goal of instruction is to promote deep learning of meaningful material, categorizing provides the opportunity to construct understanding, reevaluate, and change understanding as students build more knowledge that they can use to adjust their categorization criteria. As the unit progresses and their understanding evolves, give students opportunities to create categories as they expand their interconnected neural networks of concepts.

As a tool for mental manipulation, categorizing can be applied in a variety of ways, including number patterns, ongoing student-centered classification, sorting into personally memorable categories, and comparing and contrasting. Let's look at each of these in turn.

Number Patterns

Number patterns are prevalent in math, and a color-coding strategy could be used for a wide variety of number-pattern topics, including multiples, prime numbers, geometric sequences, squared numbers, and the Fibonacci sequence, among others. For example, when teaching students to count by twos before they understand the concept of odd and even numbers, you can put up a number line that highlights even numbers in one color and odd numbers in a different color. Build curiosity and memory links between the category of counting by twos and even numbers by proclaiming, "You'll soon discover what makes the red and blue numbers belong to special groups."

Ongoing Student-Centered Classification

While learning about a topic such as animal classification, students are often given a template to use to classify different vertebrate animals based on specified characteristics, such as egg laying or live birthing, outer layer (fur, scales), ways of getting oxygen, and so on. A more mentally manipulative alternative would be for students to create their own categories to distinguish between the vertebrate classes. This method is a more active and student-centered approach.

After first making a "prediction" of classification categories that they think might be useful, students modify their categories as they learn more about different vertebrates. This approach could also work for creating their own classification categories for types of graphs; math terms calling for addition, subtraction, division, area, and volume; different types of transformations; classifying forms of matter; and characterizing categories of literature.

As students learn about more variations in the unit (e.g., different vertebrates or types of graphs), you could give them examples of an animal or a graph and they could use their categorization characteristics to identify which category it belongs to. When they get the correct answer, they could then use this information to confirm or revise categories, constructing ever stronger conceptual understanding of the essential elements contained in each category. See Figure 3.4 for an example of this practice.

Sorting into Personally Memorable Categories

When students have facts to memorize (such as states and capitals, foreign language vocabulary words, or spelling words), they can create their own ways of clumping these into categories. For example, they could put states and capitals into categories such as places they've been, geographic proximity to their home state, places they would like to visit, or size of state. The information in the categories is easier to remember because students sort the facts into patterns that make sense to *them* rather than into teacher-selected categories.

Comparing and Contrasting

Our brains file memories according to similarities, creating relational memories, so encourage students to create graphs, charts, metaphors, analogies, or diagrams that compare and contrast new information, especially when they can make some comparisons to topics about which they are passionate. For example, after practicing with simple analogies, a teenager fascinated by engines and currently studying the human digestive system created this comparison: "The interaction of digestive enzymes with food in the stomach is similar to the interactions of oxygen and gasoline in a carburetor."

Interleaving of Instruction and Review

Traditional instruction is delivered, practiced, and reviewed in blocks of information. For example, we would first teach students how to spell words ending in *-ing;* next, give them a chance to practice spelling words ending in *-ing;* and then, give a test on the *-ing* words. We would then move on to the next spelling pattern.

FIGURE 3.4

Teacher-Constructed Categories Versus Student-Constructed Categories

Teacher-Constructed Categories: The teacher provides the categories and students use them to identify which class an animal is in.

Name of Animal	Category 1 outer layer (e.g., fur, feathers, scales)	Category 2 type of birth (e.g., live birth, hatched from egg)	Category 3 newborn diet	Class?

Student-Constructed Categories (Step 1): Students select categories that they think (predict) will be useful for identification.

Name of Animal	Category 1 prediction: skin color	Category 2 prediction: type of home (nest vs. den)	Category 3 prediction: diet (meat-eater vs. plant-eater)	Class?

Student-Constructed Categories (Step 2): After using the categories they created to try to identify which class an animal is in, and discovering which ones don't work, students revise their categories.

Name of Animal	Category 1 revised: fur or no fur	Category 2 revised: hatch from egg or born alive	Category 3 revised: do newborns drink milk from mother	Class?

An alternative to this blocked approach is called *interleaving*. In general use, this term refers to something being incorporated into layers—for example, blank pages interleaved between the pages of text in a book. In education, it refers to the layering and intermingling of topics of study. Whereas traditional blocked instruction and review focuses on one topic from its introduction until examination, interleaving integrates a mixture of topics in a variety of formats at varying intervals throughout the learning. We use the somewhat cumbersome term *interleaving* because it is the term researchers use to describe this valuable style of instruction and review that both activates mental manipulation and boosts memory and conceptual understanding. The next sections describe some specific examples.

Interleaving Instruction

As an example of interleaving instruction, let's compare two approaches to teaching a geometry unit on finding the area of various shapes. In a traditional classroom with blocked instruction, students would first learn how to calculate the area of a square. They would practice the necessary procedures, be tested on them, and then move on. Instruction would continue, covering rectangles, then triangles, and then circles, with each subgroup following a similar pattern of teach, review, test, and move on.

An interleaved approach would look similar to begin with, as students learn the concept of area and the calculations for finding the area of squares. When rectangles are added, they'd be guided, with frequent feedback, to consider similarities and differences between the calculation processes for squares and rectangles. As each new shape is added, connections to the previous shapes would be interleaved (layered) throughout. Guided instruction would continue to show how the area of objects depends on variations like shape and symmetry and abides by constant rules as to how much space is contained in two-dimensional shapes. Students remain active, analyzing and categorizing knowledge as they develop the larger concept of area, not just separate rote memories of formulas.

Researchers have proposed that interleaving is especially beneficial when students need to discriminate between important concepts that are easily confused (Rohrer, Dedrick, & Stershic, 2015). Therefore, the geometry unit on area could also interleave explorations of perimeter, because students often mix up the topics of area and perimeter.

Taking this proposal a step further, researchers wanted to know how interleaving would affect a lesson in which students were asked to analyze examples and come up with their own understanding of characteristics and categories (inductive learning). This question was explored in an experiment in which participants reviewed multiple paintings by 12 artists (Kornell & Bjork, 2008). The paintings were presented with the name of the artist printed underneath. The paintings by half the artists were presented consecutively (blocked). For example, participants would see six paintings by Picasso, then six paintings by Monet, and so on. The other half were interleaved. For example, participants would see a painting by Matisse, then one by Magritte, then one by van Gogh, and so on, until they had seen a total of six from each artist. Later, the participants were shown new paintings by the same artists, but without the artists' names. As a test of their understanding of the artists' styles, the participants had to deduce who had painted each of the paintings. The participants were more successful at identifying the artists who had been interleaved than they were at identifying the artists that had been presented in a blocked format. The researchers inferred that the learners benefited from the opportunity to discriminate between the artists when they were interleaved, thus focusing on the differences in their styles. They were able to revise and consolidate accurate understanding of the artists' styles, as they continually had to contrast them in the interleaved exposure.

Interleaving Review and Practice

The traditional approach to review and practice is for students to study the daily or subunit material until it has been tested and then move on to the next segment of the unit material. Using this approach, students are usually reviewing and practicing material that is fresh in their minds. It is relatively easy to parrot back what they have learned in the short term. Although the information might burn hot in the students' minds while they are being tested, afterward it drifts from memory like smoke from a recently snuffed candle.

The strategy of interleaving offers an alternative form of learning, review, and practice to enhance memory and deeper conceptual understanding. For example, after instruction in subtraction, the review would include questions on both addition and subtraction. Therefore, instead of proceeding blindly through a review sheet, using subtraction for every problem, students would come upon a problem and investigate its characteristics (in this case, determining if they needed to add or subtract) before solving it. The review is also spread out at varying intervals. The idea is to let a bit of time pass before revisiting it, and to allow this cycle to repeat. By allowing some forgetting, you also promote opportunities for thoughtful information retrieval as an active, memory-building process. In addition, along with interleaving the topics covered during the review period, the practice problems could include questions presented in ways that are different from the way they were taught. These approaches require intentional effort by the students' brains. Recalling previous learning over time and applying it in new ways requires active processing of knowledge for construction of memories and understanding.

Interleaving appears to be supported by neuroscience and outcome studies (Kang & Pashler, 2012; Putnam & Roediger, 2018), encouraging many educators to successfully try it, especially when it fits their subject matter.

Interleaving of review can reduce the pitfalls of drilling on one topic, then leaving it behind and moving on to practice the next topic without constructing concept understanding. Often, just getting correct answers in class or on homework on the day a topic was taught gives students a false sense of their mastery. Findings suggest that waiting a day or two after learning and practicing one topic, then coming back to it, gives students important insight into what they did not fully know or understand. This interleaving of review and practice helps students develop stronger and more conceptualized memory because they need to *actively* consider what information or procedures are most appropriate to use for their response (Zulkiply & Burt, 2013).

One theory behind interleaving review strategies is that when students can't count on consecutive questions requiring the same type of answer or solution, because each question is different from the last, rote responses won't work. They need to choose a strategy based on analyzing what best suits each question. Interleaving forces the brain to learn (and categorize in relational-memory storage) critical features of skills and concepts. Students must distinguish which information they learned is most appropriate to apply to the question, analysis, or problem (Rohrer et al., 2015).

Researchers have further evaluated the value of interleaving based on the response of medical students practicing the interpretation of electrocardiograms (Hatala, Brooks, & Norman, 2003). Practice sessions were either presented in blocks by specific topic or interleaved, with examples from various categories mixed together. Students exposed to the interleaved approach in the practices had 30 percent superior diagnostic accuracy compared to those who practiced in same-category blocks, suggesting that the organization of interleaving in review and practice can result in a significant gain in learning.

It appears that, for appropriate topics, mixed instruction can facilitate students' recognition of characteristics that define and distinguish related topics or procedures. This could promote student-constructed understanding of when, which, and why a procedure, historical event, or ball-playing skill is most pertinent to apply to a new question, application, or problem (Colvin, 2016; Kang, 2016). Further confirming research is ongoing, but it is reasonable to consider including interleaving, when appropriate, in your teaching toolkit.

Although Malana and I both recall the dread we felt during our own school days when a teacher requested that the class work on the mixed review problems (from all previous chapters) at the end of a chapter, we can now see the assignment's merits as a tool for building understanding and enduring memory. At the time, it felt unfair and hard! Why couldn't the teacher just assign the chapter review problems related to recently learned information? We each found it challenging to revisit topics we didn't remember well or hadn't really understood in the first place. We also felt frustrated when a problem differed from the way it had been taught or in terms of the memorized procedural steps. However, this effortful brain work is exactly what is required when we want students to comprehend a topic and store it in memory successfully enough to access it as a foundation for future learning.

Connected Curriculum

Cross-curricular instruction of related topics is a way to guide the brain to recognize and expand memory pattern circuits and interconnectivity. One of my Williams College Winter Study students recognized the value of a curriculum connected through categories and concepts as particularly valuable:

> *The highly scheduled coursework orderings in high schools and elementary schools seem counterproductive to the way memory is constructed.*

This raises the question of whether having such distinct separation of courses like chemistry, biology, and physics is preferable, or whether it stunts learning by not interconnecting each of these topics so that similar neural pathways are activated in a consistent manner. Wouldn't it be most useful if each subject could build on the previous year's knowledge, and the neural pathways that were previously developed could be increasingly reinforced and extended?

One example of how a subject can build over time is the way that math curriculum is often spiraled through the school years, each year building on the previous foundations. For example, students cover geometry throughout the school years, from identifying shapes in kindergarten to studying complex theorems in high school.

My student also mentioned his desire to have more integration between subject areas as a tool for enhancing memory formation and storage. An elaborate example of cross-curricular study in action occurs yearly during spring study week at Crane Country Day School, where Malana taught 4th grade. The lower-school faculty would choose a theme and design lessons to bring the theme to life. On the preceding Friday, the theme would be announced, to the delight of the students. They would arrive on Monday eager to embark on their lessons. Throughout the week, all students, kindergarten through 5th grade, would rotate through over 15 mixed-age experiences. For example, during a week centered on ancient China, students took classes in everything from exploring the religions of Buddhism, Taoism, and Confucianism to using abacuses to solve math problems; practicing the martial arts of kung fu, qigong, and tai chi; cooking savory dumplings; building a replica of the Great Wall; painting with ink on rice paper; and learning about the history of tea. Many more lessons incorporated music, literature, history, math, drama, movement, geography, social studies, and art. This integrated approach allowed students to lay a rich foundation for strong memories about the marvels of ancient China.

Although this special week epitomizes the goal of connecting curriculum across the subject areas, smaller-scale opportunities can occur throughout the year. A history teacher and a literature teacher could collaborate on a deep dive into the struggles of the Great Depression through an exploration of primary-source documents and reading *The Grapes of Wrath.* A math teacher and an economics teacher or physics teacher could collaborate on the types of equations needed to solve problems about interest rates or force and speed. Even discussions about how subjects tie together can go a long way in helping students form deeper understanding and memory.

Synthesizing

Albert Einstein once said, "If you can't explain something simply, you don't understand it well enough." Concise and clear synthesizing of new learning generates active learning, as it must be both understood and mentally manipulated in order to construct that "simple" explanation (Benassi, Overson, & Hakala, 2014). You've no doubt experienced "memorizing" something for a test and finding that the next time you took a similar class, you had no recall of the information you had parroted back successfully the previous year. If you had synthesized the earlier learning, you probably would have had a much better experience.

Minimal active mental manipulation takes place when students passively write or type the words of a lecture without thinking about the information, and the same is true if they primarily copy the bold subheadings and the first sentence of paragraphs when taking notes from reading. Those notes are boring and unhelpful in building strong memory circuits.

Having them synthesize the information to most succinctly and accurately reflect the essential meaning or concept promotes students' active interaction with the information in a manner that expands stronger memory and conceptual connections.

Let's look at some strategies for active mental manipulation that involve having students simplify new information into short, conceptual summaries with limited word counts. By synthesizing information into the compact format of a tweet, a haiku, a rap song, or a blog, students mentally manipulate and can develop deeper understandings of the content. In addition, the social media aspect of tweets and blogs will likely trigger sufficient interest to encourage students to read and analyze each other's concise representations.

Tweets, Haikus, and Rap Songs

Tweeting the gist of new learning requires the use of precise vocabulary and a clear understanding of the content. In a small study (Sullivan, 2010), students who synthesized the main points of poetry stanzas into text messages got 80 percent of the questions about the poem correct on a state test. Classmates who were taught the same poem in the traditional way—reading, reciting, and discussing—got only 40 percent correct.

I recommend using the original 140-character limit for student tweets. A computerized device or a paper template with 140 spaces facilitates this task, which students can do in class after a section of lecture or reading, or as homework. When assigned tweets are posted on a class blog or website (by name or anonymously), it is gratifying to see how many classmates read and think about the tweets and later respond as their concept of the gist of the learning grows.

Haikus and rap songs have similar limitations that make them effective ways to produce concise summaries. Here are some tweets, haikus, and a rap from educators in a course I taught during the summers of 2017 and 2018:

- Revise, regroup, rename—memories stay in my brain.
- To learn something new, start with something OLD. Connecting with the known is short-term memory GOLD.
- If you can say it in 140 characters, you can save it. #brevityisthesouloftwitter, #useitorloseit, #shortandtweet.
- Manipulation has a bad reputation, but when it's done mentally, it can result in stored memory.
- Real**ize** we need to Categor**ize**, Symbol**ize**, Summar**ize** not only with our **Eyes** but with our minds to create the brain's POWER LINES.

Just think about how much meaning can be found in perfectly crafted haikus like these:

Build understanding—
They make their own connections
while I'm doing less!

The three eyes of "ize"
Categorize, summarize
Symbolize, new eyes

The same is true of this rap:
The mind is a circuit board
Make electricity flow
Dopamine is my fuel
Past memories rule
Laying tracks of myelin
Long-term memory frees my mind
To coincide through my network.

Blog Posts

Like tweets, blog posts can be an effective method for concise synthesizing, and they offer a similar bonus in terms of social media interest if students can read each other's posts. These would be with controlled access (limited to the school or class, at least for undergraduates as an assignment) through the school's computer system. Students would write blogs (names optional on the class view page, but identified to the teacher by a number or code word) on an assigned topic and be required to respond to at least one classmate's blog (identifying themselves to discourage hurtful comments).

Blog posts have the added value of being written for readers and accessible to response, such that students may give more thought to the information, having the added incentive of knowing that the readers are their classmates *who have had exposure to the same material*. They'll gain new insights while building the skills of concise communication, and as you read the posts, you'll have formative assessment information you can use to give corrective feedback as needed.

Quickwrites

For synthesizing purposes, students can use *quickwrites* to record their free-flowing thoughts, and then use their "gold nuggets" to write their concise summary in a tweet, haiku, rap, or blog. To do quickwrites, students respond to a prompt by writing for two to four minutes (depending on age) without stopping. They write continuously with no editing, rereading, or concern for grammar and punctuation. If they don't know what to write next, they write the last word again and again until inspiration hits. Because they don't hand in the quick-writes and there is no required outcome, they can write their thoughts without stress as they synthesize their learning. When time is up, they silently read what they wrote and underline one or two phrases they consider important (the gold nuggets). They can share these with the class or in small groups before using them as prompts for their subsequent concise summary.

Performance Tasks and Project-Based Learning

Performance tasks are projects that involve ongoing mental manipulation. As explained by author Jay McTighe in a tweet: "I define a performance task as any learning activity and/or assessment that engages students in applying their learning to develop a product or performance. Performance tasks are described as 'authentic' when they are set in a genuine (or simulated) real-world context."

When you give students opportunities to apply learning—especially through authentic, personally meaningful activities—and provide formative assessments and feedback throughout a unit, facts move beyond simple memory to take on value and permanence. Authentic performance tasks and project-based learning draw on knowledge as it accumulates and promote its application in a variety of personally relevant ways. These further prime students' brains to *want to know what they have to learn*. The process increases their awareness of the usefulness of building on the knowledge throughout a unit. When students add new learning to solve problems or create new products, they activate and strengthen the extended memory network. These memories won't be pruned away from disuse after the test (Luckie et al., 2012).

Students will find value or relevance in the "boring basics" when they get to use them through authentic performance in a desirable application. A sports analogy is a favorite representation that I've heard Jay McTighe use for this phenomenon. He contends that if children were required to master all the skills of a soccer player before they were allowed to play soccer on the field, their boredom and frustration would quickly make them less eager to join soccer clubs.

The same is true for students having to plod through all the facts of a unit before doing something relevant with the information. Think of the greater personal relevance and sustained engagement that will likely occur if students know in advance what they'll get to do during a unit. Consider this example: Before a unit on the fall of the Roman Empire, you can tell students about a project that will have them working in groups, assuming the roles of stakeholders tasked with preventing the fall of Facebook or another company that currently dominates the global market. They can create plans to help the company avoid mistakes like those that led to the fall of the Roman Empire.

Obviously, the possibilities for performance tasks are endless. The following are some additional examples.

Newspaper editorials. Forming an opinion and presenting it in writing is an excellent way to deepen understanding and create a lasting memory of a topic. For example, after learning about a particular historical period or event—such as the Lewis and Clark expedition—students could take on the role of newspaper columnists and present their take on a situation. Pretending to report from the scene of the Lewis and Clark expedition, they could make a case for who the real leader was by representing the perspectives of Lewis, Clark, Sacajawea, or one of the lesser-known party members. Any assignment that encourages students to look beyond conventional historical perspectives is a powerful tool for deepening empathy, understanding, and memory.

Contemporary scenarios. Students can strengthen their comprehension by representing abstract concepts through familiar scenarios. For example, students can work in teams to design a pizza shop run under different types of governments, such as a monarchy, a dictatorship, and a representative democracy. They can consider the pros and cons of each type, considering the factors of financial success and customer and employee satisfaction.

History 2.0. Students can take what they have learned about a historical period and "rewrite" history to make improvements. For example, after Malana's 4th graders finished their reports on topics pertaining to the California gold rush, she had them take what they had learned to create a "new and improved" gold rush–era California. Students who had researched the poor treatment of women, children, and people of color rewrote laws to address the inequities. Students resolved environmental concerns by redesigning mining equipment and imposing regulations. Pony Express riders and horses got more breaks, and some of the most infamous bandits were caught. Students found that they had to make compromises as their improvements sometimes worked at cross-purposes. This activity also led students to consider how and why our current laws and regulations may have evolved.

Active Learning

Learning that incorporates inquiries, projects, and authentic performance tasks can deepen understanding and promote extended memory network cross-connections (Anderson, 2007).

The benefit increases when students are guided to become increasingly independent in making decisions such as choosing appropriate projects and revising approaches as they evaluate their progress. For example, in a unit of study exploring the Mayan, Incan, and Aztec civilizations of the pre-colonial Americas, each student would begin by choosing a civilization to focus on and consider life in that civilization from the perspective of a person their own age.

Throughout the unit, students would create a project, such as the preparation of a meal, the creation of a tool or item of clothing, or a piece of artwork or writing. Students would be responsible for learning and presenting the details behind their creation. If their project was to prepare a traditional Mayan meal, for example, they would need to demonstrate their understanding of the reasons why maize or fish were such strong dietary staples and why they were prepared their particular way. By assuming the persona of a child their age from the civilization, they would be responsible for learning *why* the Mayan, Incan, and Aztec lifestyles evolved as they did, rather than simply cooking tortillas because they found a recipe in a history book.

As the students learn more throughout the unit about the customs, lifestyles, and resources of the pre-colonial Americas, and how people made the best use of those resources for their homes, food, and safety, they would have time each day to incorporate the new learning into their projects.

When they participate in the unit culmination day, they could be guided to talk to others from the perspective of a person from their civilization and ask pertinent questions that a person their age would be curious about, such as daily activities or burdens brought on by seasons or their environment. They can live the part as they promote their independence as learners and responsive decision makers, making connections between the region and resources of their civilization, as well as those chosen by classmates. Whether presenting a dish they made or teaching a game or craft representing their civilization while taking on behaviors representative of a child their age, they'll have constructed their knowledge through the authentic performance task.

Scaffolding for Performance Tasks and Project-Based Learning

Struggling through setbacks is part of constructing enduring understanding and the executive function skill sets of perseverance and goal-directed focus. Give students the chance to productively struggle, interpret complex problems in their own way, and try new approaches if one doesn't work. Along with choices based on their interests and strengths, students need varying amounts of structure accompanied by opportunities to evaluate and use multiple sources of information and technology for researching, analyzing, organizing, or creating.

Although they do not apply to all projects, you can consider the following suggestions to help students understand goals and develop buy-in, and to allow them to take variable routes from personalized, achievable challenge to mastery:

- Start with an initial presentation appealing to a variety of interests you know are relevant to your students.
- Help students narrow their topic for a project, and guide them in setting their own clear goals and designing clear plans about how to reach them.
- As students develop their inquiries or projects, invite them to provide ongoing observations and analyses, to ask questions, and to continually revise and refine their projects or their hypotheses.
- Encourage students to check sources for factual information and to distinguish between fact and opinion. In addition, help them learn how to identify their own opinions versus facts in their writing or presentation.
- Engage students in critical thinking with your questions as their work progresses.

- Provide opportunities for students to reflect not just about their work but also about the learning strategies they used that were beneficial. Which of those will they use again?
- Ask these questions:
  - What was surprising?
  - What was challenging?
  - Where did you get stuck?
  - How did you get unstuck?

Authentic performance tasks and projects stimulate multiple previously independent neural circuits, securing new interconnections and knowledge banks that expand into even larger, more powerful concept networks. Opportunities for knowledge transfer beyond the domain in which it took place, such as through symbolic representation, are abundant. This fusion of students' skills and interests allows them to use their strengths to enrich the repertoire of multicentric connections in their brains—now and in the future.

Metacognition

Metacognition is the process of evaluating our own thinking. This self-awareness can further optimize learning and memory as well as build skills to monitor future learning.

Optimal learners practice distinct behaviors. Guidance in metacognition can help students develop better understanding, study skills, and executive functions as they reflect on their ideas, approaches to learning, and choices. Students benefit from multiple opportunities to practice the metacognitive process of making the unconscious conscious—to examine their learning experiences and develop this self-awareness.

Self-Directed Learners

Help students make the connection between achieving their goals and the executive functions or skills they have used or could use more frequently. Help them consider what they were thinking or hoping to achieve when completing an assignment by choosing to review and revise their work rather than being satisfied with just "getting it done."

Your input helps students see the link between taking responsibility for class participation, homework, studying, and their resulting feelings. For example, a student might think, "When I started taking better notes in class, I found I understood the homework better and got more of it right; that made me feel that I was in charge of my own success and could be successful with effort" or "I let myself down when I just did the least I could to get it done instead of the best I could." Encourage the satisfaction of active participation, proactive collaboration, and setting high self-standards for all classwork and homework, so that students can say, "I did all I could to do my best."

Metacognition Prompts

Depending on the goals of a particular metacognition opportunity, prompting questions might be more specific or more open-ended. Here are a variety of prompts:

- What was easy and what was difficult for you?
- What parts of the lesson or presentation do you think were most helpful to your understanding of the topic?
- What worked well and what would you do differently next time?
- What did you learn about working in a group?
- What did you try that you'd do again?
- What approaches were most valuable to your learning and test success—for example, rereading, study groups, practice tests, rewriting your notes each evening after school in a different way?
- What was the best, most productive use of your time? The least productive?
- Why were you so successful this time, and what can you do to continue this good work?

Multicentric Brain Activation: What Is It and Why Is It Important?

Multicentric cross-brain connections can serve as extended superhighways connecting previously unlinked information stored in more regions of the brain. The term *multicentric brain activation* refers to expanded networks of connections among a variety of memory storage bins throughout the cerebral cortex covering all the lobes of the brain. This interconnectedness can be promoted by neuroplasticity from their communications with each other. Providing opportunities for students to connect knowledge and skills not previously learned or applied together can build more efficient memory retrieval and provide a foundation for new, expanded, or innovative applications of learning.

Gray Matter

Multicentric Brain Activation Under the Scanner

Using a variety of ways in which students acquire and apply learning can increase accurate recall of the information (Anderson & Contino, 2010; Dhindsa et al., 2011). Looking at brain images of subjects applying knowledge from various separate brain storage areas, we can see how multiple areas of the brain light up together when the subjects perform mental and physical tasks they have never before tried or are asked to improvise or innovate. Regions of the brain that are widely separated (in space) are seen being activated simultaneously or in rapid, coordinated sequence during these novel tasks and problem-solving efforts. The connected activity reflects expanded communication among areas in the sensory, motor, attentional, emotional, and language centers.

A pivotal study recognizing this phenomenon conducted brain scans of trained musicians who were asked to improvise new music. Immediately *before* the musicians' reports of creative insights, researchers noted previously unseen, widespread activations of multiple regions of the memory cortex throughout both hemispheres (Berkowitz & Ansari, 2008; Limb & Braun, 2008).

Gray Matter

Strengthening and Expanding Networks of Knowledge Through Multicentric Experiences and Applications

Brain-mapping techniques, such as diffusion tensor imaging, have revealed *connectomes* (connections among neural networks throughout the brain), allowing scientists to track which parts of the brain are active when a person is processing information. Multicentric connectivity among different regions of the brain seems to increase with repeated multicentric brain activations—for example, mental manipulations (Dance, 2015).

When we engage with new problems that offer the opportunity to apply multiple areas of previous learning, seek to innovate, or seek alternate interventions, our brain activates memory from separate storage regions. When these regions are simultaneously activated for a new purpose (e.g., symbolizing new learning in a different manner), the brain's neuroplasticity responds to their communications by constructing more extensive and faster networks of multicentric communication—that is, more dendrites, synapses, and myelin.

Because the memory is stored in multiple networks, it is strengthened each time any of its connecting *hubs* (way stations in the brain with particularly extensive connections to other brain regions) are activated. Hubs optimize brain connectivity, yielding more efficient connections between information stored in distant regions of the brain (Sporns, Honey, & Kötter, 2007; Zatorre, Fields, & Johansen-Berg, 2012).

Multisensory Learning

When you need something right away and can't find it, it's great to have a duplicate in a second location. With an extra set of car keys in a drawer by the front door, you are much more likely to retrieve car keys quickly when you need them. Similarly, you can think about multisensory learning opportunities as a way to duplicate memories in multiple regions of the brain. Multiple cues are available, with the bonus of more multicentric brain connections available for transferable concept memory (Meyer, Kaplan, Essex, Damasio, & Damasio, 2011).

Gray Matter

Multiple Retrieval Pathways

This brief description of brain geography will provide you with the background to further understand the multisensory memory-storage system. The brain is divided into lobes (see Figure 3.5), each with many functions, and each interconnecting to the other lobes through neural networks. In the context of memory, each brain lobe has neural structures specialized to store its own kind of sensory information.

After information is constructed into long-term memory by the hippocampus and the prefrontal cortex, it can be thought of as being then separated into specific sensory components. Each component would be distributed to the cortex of its sensory-relevant lobe for storage; for example, visual information is stored primarily in the occipital lobe, auditory information in the temporal lobe, tactile in the parietal lobe, language in the prefrontal and temporal lobes, and movement memory in the frontal lobe and cerebellum, among other places (Goswami, 2009).

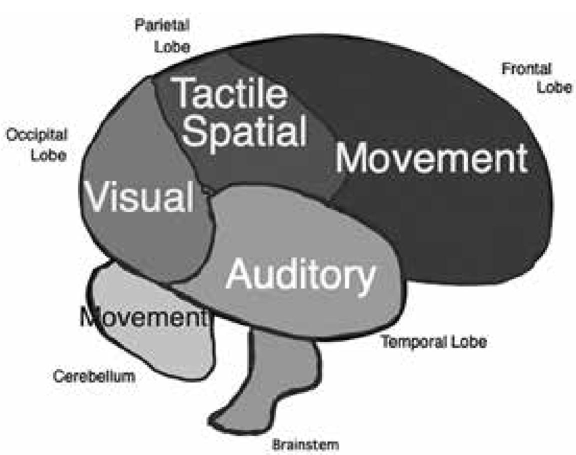
Because each sense has a separate storage area in the brain, multisensory memory is easier to install, store, and remember through multiple access points. When one sensory storage area holding its part of the memory is activated (e.g., recall of what was seen), the others' sensory components of that memory (what was heard, felt) are often coactivated. Just remembering one sensory cue can activate the others, so if students process information about how sound waves work through reading, visualizing, and touching an object vibrating in response to sound, they'll have the potential of three brain storage boxes for that knowledge. It doesn't matter which one comes to mind when they are trying to remember facts about sound waves. The recall of the one, such as the feel of the vibrations, can trigger related memory components such that what was heard, read, or visualized could pop into their recall.

Each new sensory approach to the same information can promote more connecting brain circuits. These brain cell networks, like multilane highways, mean more efficient and rapid traffic flow—easier and more rapid memory retrieval when needed.

Let's further consider the impact of neuroplasticity related to multisensory storage with respect to research on brain changes in subjects who were deprived of visual input. Recall that each sensory component of a memory is ultimately stored in a region of the brain that specializes in interpreting that type of sensory input (e.g., visual in occipital lobe). However, with that specialized (and connected)

FIGURE 3.5

Where Sensory Input Is Stored in the Brain



sensory storage, consider that neuroplasticity can be at work even when it is borrowing space from a sensory storage area not occupied.

In a normally sighted person, visual input recognition and storage take place in the occipital cortex. Yet, when deprived of visual input, there is evidence that an unused sensory storage area can take on processing from a busy neighbor. In one study (Merabet et al., 2008), subjects were blindfolded for five days and received no visual or light input to their brains. Initially, their occipital cortexes showed a big drop in activity. After five days of intense study and practice in reading by touch, using braille, their occipital cortexes showed neural activity in new circuits that had been constructed and were quite similar to those found in people blind from birth. Using their touch increased their memory storage in both their parietal lobes, where the sense of touch is activated, and the visual responses in their occipital lobes, even though there was no visual input.

Multisensory Expansion of Networks

Decades ago, my high school chemistry teacher slowly released hydrogen sulfide from a hidden container he had opened just before my classmates and I entered his classroom. A few minutes after we took our seats and he began his lecture, the putrid odor of rotten eggs permeated the classroom, grabbing our attention. We groaned, laughed, smirked, and looked around for the offending source. To an outside observer, we would have appeared unfocused and off task. However, this demonstration literally led me by the nose to follow his description of the diffusion of gases through other gases. It is likely that during that class I created two or three pathways to the information about gas diffusion—not only through smell, but also through verbal descriptions, diagrams, and demonstrations. Since then, that knowledge has been available for me to retrieve by thinking of a rotten egg or by remembering the emotional responses as the class reacted to the odor permeating the room. Whichever part of the memory I activate, there is coactivation and additional memory input. With diverse sensory inputs of information—for example, touching, seeing, moving, hearing, or visualizing—the multiple regions of the brain mutually support each other, because thinking about one activates the others (Anderson, 2011; Mayer, 2005).

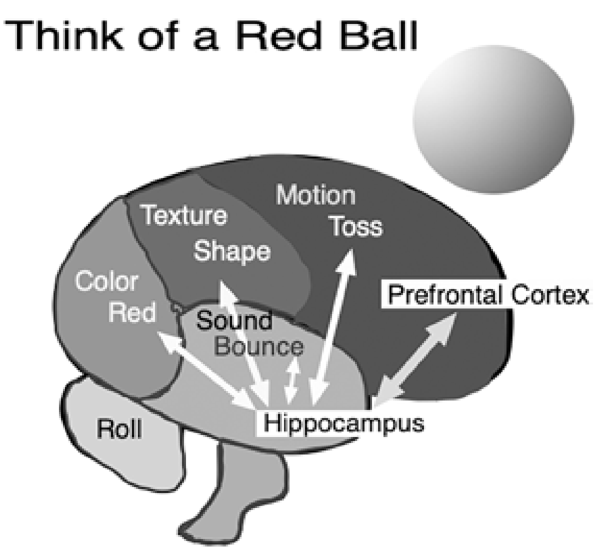
Memory Recall

Think of a red ball. You did, instantly. But in that mere moment your brain activated multiple locales and reconstructed the memory of a red ball by pulling together the color red from the occipital lobe, the sound of bouncing from the temporal lobe, the feel of a ball from the parietal lobe, and associated movements experienced with balls from the frontal lobe and cerebellum (see Figure 3.6). It is stunning how efficiently the brain can reassemble a memory from its diverse, separated, yet interconnected regions.

For the brain to coactivate all the components of an idea, concept, or type of object as rapidly as your brain reconstructed a red ball requires multiple exposures and activations. The more ways students have the information represented in the brain (through seeing, hearing, being involved with, etc.), the more effective their recall may be. Again, stronger, more durable, and more efficient retrieval of the memory represents the enhancement of its communicating pathways (Goswami, 2009; Jung et al., 2010; Luna, Padmanabhan, & O'Hearn, 2010).

FIGURE 3.6

Think of a Red Ball



The more sites in which neuronal circuits store a memory, the greater the number of access hubs to that information (Rinne, Gregory, Yarmolinskaya, & Hardiman, 2011). Beyond construction of stronger and more efficient storage in multiple regions, extended circuits can expedite retrieval through the variety of sensory memories through which learners have experienced the information.

For example, when children learn about cars, they experience multisensory intake that builds their conceptual knowledge of cars—so they can generalize to recognize different kinds of cars. They store the information in brain association areas under multiple categories that relate to the context in which new information about cars is learned. When they see a car, the visual memory network of cars is activated from the visual cortex of the occipital lobe. The sound of its motor is recognized with the related auditory storage in the temporal lobe. When they see C-A-R spelled out, that information is recognized by the related associated patterns of language in parietal lobe language association regions.

Because the information about cars has multiple storage sites and cross-referencing occurs among these areas, when students think about cars across the expanded network of connecting memories, they can call forth their other related car knowledge (Noesselt et al., 2007). These cross-connections can further promote conceptual and relational memory circuits. After learning about the internal combustion engine, memories of cars can be activated so they make associations of car engines with jet and rocket engines. As those associations are made, the new learning about rocket engines extends networks of the various memories related to cars.

Another example of the enhancing multisensory experience could relate to learning about electricity and electrons. To experience other modalities after seeing the definition of an electron, students may visualize an electron orbiting the nucleus of an atom, mimic the buzz of electricity as it whizzes by, or feel a tingling associated with the electron's negative charge by rubbing a balloon against their arms. If they then draw a sketch of their visualizations and verbally communicate them to partners or write about them in their own words, multiple brain pathways activate to further carry the new information into long-term memory.

Multisensory learning does not have to involve props such as balloons or the odor of sulfur wafting through the classroom. We can also apply multimedia design principles using tools such as PowerPoint presentations. In one study (Issa et al., 2013), medical students were divided into two groups for a PowerPoint lecture on shock. One group saw a traditional didactic presentation with the lecture. The other group received the same lecture content, but their presentation had multimedia representations (e.g., sound, video clips, animation). The latter group significantly outscored the traditional-condition group on immediate tests of retention and on delayed tests of memory and understanding given one week and four weeks after instruction.

Neuroscience Read-Aloud

Multisensory Studying

You cement new memories more efficiently and remember them more successfully when you experience, practice, or review through multiple senses.

Each new sensory approach to the information can increase interconnecting brain circuits. These extended highways can link various parts of the brain containing the related learning. Just like traffic flow in a busy city, the more alternate pathways there are to connect with a memory, the more efficiently the traffic will flow, and the more rapidly and easily that memory can be remembered when you need it.

Remembering the initial sensory way in which you experienced the information can activate the others. For example, if you process information about sound waves through reading about, visualizing, and touching a vibrating object, you'll have at least three brain storage boxes holding that knowledge. It doesn't matter which one you think of first when you are trying to remember facts about sound waves. When you recall any one, such as the feel of the vibrations, the related information about what you heard, read, or visualized can flow into your recall.

Multisensory Strategies

As we have noted, multisensory strategies promote more areas of memory storage and more extended connections among related memory circuits in multiple regions of the brain. Here are examples of strategies related to visualization, sound, touch, and movement, and ideas about how they can be combined.

Visualization.

- We know that after a stable long-term memory is constructed, it is distributed to sensory-specific regions in the cerebral cortex; all storage areas in the network are particularly responsive to activation by recalling a visualization (Meyer et al., 2011). Just as athletes may visualize a move before they execute it, students can be encouraged to visualize. After front-loading with factual information, students can visualize the learning on topics as varied as biological processes and historical events. They can visualize the layers of the earth in rainbow colors, the expressions of people reacting to the fall of the Berlin Wall, or the characters in a literature book as actors on stage in a play.
- For some topics, students find that the more humorous or outlandish the visual image they create, the more memorable the associated learning becomes. More of their brains can be engaged by giving imagination free rein. Even more boost comes from applying their visualization to other sensory modalities, such as describing their images to each other, writing them in words, or drawing sketches. For example, they might imagine the word *osmosis* with the letter *O* written very large and the other letters trying to get out through the membrane it represents, or they might visualize children on a seesaw as parts of an equation that needs balancing in order to work properly.

Sound.

- Having students read aloud adds the auditory sensory information related to hearing the words while seeing them.
- While reading, students can look for key words and whisper or say them out loud.
- Just as it is easier to recall lyrics to a song than to memorize a poem, or to recall those lyrics when you hear the music, students can increase memory by putting information into a familiar tune. When gestures are part of that sound memory, the movements add another storage locker for the information to further increase access to memory.

Touch.

- Touching manipulatives in math or elevated maps in geography are direct ways of using touch.
- You can add a touch component to memory by having students connect information they are learning with a part of their body. For example, to add a tactile link to the concept of supply and demand in economics, they could touch their stomachs and consider how much they'd pay for cafeteria food when their stomachs are empty compared to when they are full.
- Touch can be incorporated in a visualization. Students can describe what it might feel like if they touched the surface of Mercury and Jupiter: hot, cold, firm, soft, wet, and so on.

Movement.

- Students can make a physical movement they predict they might see if they met a character from a book or a person they studied in history or science. For example, they might peer through an imaginary single-lensed microscope to mimic the movement of Dutch scientist Antonie van Leeuwenhoek looking through the microscope he developed to see tiny microbes for the first time.
- Pantomiming vocabulary words adds to the sensory memory store; for example, students could mime climbing the rungs of a ladder to represent the word *ascending.*

The benefits of multisensory input apply to any subject area. Here are examples from history, geography, and science, respectively:

- Have students visualize the arrival of the first moon landing, adding imagined details to the scene. The more dramatic, bizarre, and memorable the image, the better. For the addition of yet another sensory modality, they can then describe, draw, or write about their visualization.
- Invite students to imagine a sunrise during the fall equinox at the North Pole, including references to the direction they look toward, the surrounding environment, the time of sunrise, and the quality of darkness.

- If you are teaching planetary movement through lecture or reading, students can augment the learning with visual and movement activity. They can become moving balls of different sizes around a beach ball "sun" or walk in circles around a chair while simultaneously rotating their bodies.

Imagine the time you would save if you didn't have to reteach, several times during the year, topics such as the least common denominator, the difference between *concave* and *convex,* or the sequence of events in the passage of a law. How great would it be if you didn't have to spend the first six weeks or more reteaching things that students had already "learned" adequately enough to pass last year's tests but no longer remember? And it would be nice to not have to reteach the same material for midterm exams and finals. Fortunately, employing the arts, writing, and other methods for concept and skill development can overcome the lamentable effects of fleeting recall, of students having memorized rote facts just for a unit test.

Constructing and activating memory through multiple senses and mental manipulations makes learning more engaging and allows students to connect through a variety of strengths. These active learning experiences can expand understanding and cross-connections among the brain's storage centers. This integration among related information can contribute to enduring, conceptual memory, available for transfer to new applications (Macedonia, Müller, & Friedrich, 2010).

Helping students access and use more effective types of memory storage and retrieval will literally change their brains. As information incorporates into large networks of interconnected, related information, the expanded memory circuit mobilizes whenever retrieval signals access any given part of the network.

Just as learning how to walk, speak, and read do not emerge with full proficiency, the construction of understanding and concept networks has no smooth pathway to perfection. Going from the unknown to the known involves detours through uncertainty and mistakes. Your support will be needed along the way, so students understand that setbacks provide opportunities. They can revise their brains' erroneous circuits and, by working through periods of confusion, strengthen the accurate networks their brains ultimately construct.

4

Building Powerful Executive Functions: Skills for the School Years and Beyond

The positive development of a society in the absence of creative, independently thinking, and critical individuals is as inconceivable as the development of an individual in the absence of the stimulus of the community.

—Albert Einstein

The term *executive function* refers to the top-down neural processing that guides the conscious, goal-directed control of higher cognition; decision making; and self-regulation of thoughts, feelings, and actions. There is also executive function network communication with the hippocampus and other hubs involved in memory holding and retrieval. The term *top-down* indicates the directional control flow from the prefrontal cortex, where the neural networks of executive functions reside, down to the lower brain that implements these directions (Petersen & Posner, 2012; Zelazo & Carlson, 2012).

Earlier chapters covered top-down attention focus, memory consolidation through the hippocampus, and emotional self-management related to the amygdala and its connections. In this chapter, we explore the other executive functions. Think of these as the skills that would make a corporate executive successful. They include goal setting and achieving, prioritizing, organizing, judgment, critical analysis, and cognitive flexibility. Here are brief descriptions of each of these as related to students:

- **Goal setting and achieving—**This function includes setting limits and sticking to realistic and manageable goals. Further, it involves using reflection, metacognition, and self-monitoring strategies to plan goals and resist impulsive choices that interfere with achieving them.

- **Prioritizing—**Prioritizing helps students separate low-relevance details from the main ideas of a text or topic of study, use their time efficiently, and recognize how separate facts relate to broader concepts. It guides students when they plan an essay, select information to include in notes, or evaluate word problems in math for the relevant data.
- **Organizing—**Successful organization is needed to prepare for and complete the responsibilities and requirements of schooling. Organizing includes understanding the logic of how information or materials are arranged and determining effective ways of arranging one's own space, materials, and academic output. Well-developed organizing skills become more critical as these responsibilities and requirements increase.
- **Judgment—**Developed judgment promotes students' ability to monitor the accuracy of information as well as of their understanding and work. It allows them to form reasoned opinions backed by evidence. The use of judgment is also necessary for successful navigation of social and emotional choices and decisions.
- **Critical analysis (critical thinking)—**Critical analysis includes recognizing and evaluating information and situations as to their value, validity, and application. It includes the capacity to determine the meaning of questions, problems, and communications with awareness of the context and goal. Critical analysis promotes recognition of what information needs to be gathered, which resources are needed to achieve success, and where to find the most appropriate sources of information. Interpreting source bias or accuracy is critical as it becomes increasingly challenging for students to evaluate the blurred margins between fact and opinion in articles, in books, on the internet, or heard on the nightly news. With the expanding variety of sources, analysis also includes comparing multiple sources of information and synthesizing this information into coherent understanding.
- **Cognitive flexibility (flexible thinking)—**Cognitive flexibility encourages students to be receptive to and open-minded about

new experiences, unfamiliar customs, variations of opinions and interpretations, alternative points of view, and multiple approaches to problem solving. Cognitive flexibility allows students to be open to a variety of outcomes, adapt to changing data or new technology, interpret information from multiple perspectives, and apply knowledge to new applications and creative innovations.

You've probably noticed that the executive functions overlap. Ultimately, assigning a name to an executive function and distinguishing one from another are far less important than understanding the essence of what they represent as a collective—our highest-order thinking skills. In this chapter, we'll also explore how the executive function neural networks mature in the prefrontal cortex and why and how your intervention in their development can promote student success.

Scattered Is the New Normal

Our students live in a time when their still-developing executive function networks' efficiency is often inadequate for the accelerating quantity, accessibility, and questionable validity of information. Growing demands on their executive function skill sets will continue to increase as better technology advances more knowledge in almost all subjects, and globalization yields a greater pool of information. In addition, their brains may still be more responsive to immediate gratification than to long-term goal planning. For example, to a 9th grader, doing well on a test for the goal of taking a more advanced language or math course may not be as compelling to their brain's short-term programming as their attraction to the internet and social media. Strong executive function networks are needed to override the pull of the immediate desire and to pursue the long-term goal.

Throughout the school years, students' executive functions continue to develop strength and efficiency. These increasingly important control systems will not reach adult capacities until their late 20s. Critically notable, though, is that the demands placed on these skill sets seem increasingly burdensome and can exceed students' still-developing capacities.

Children born after 2000 are growing up in a world where their developing brains are not yet equipped to handle the heavy demands and temptations they now face. In the past, most students could keep up with the pressures on their neural networks of executive functions as these skill sets improved with their maturation rate and progress.

Now, scattered is often the new normal. Our students can't wait another 5 or 10 years to achieve success in school and life. They need help *now* to build their executive function supplies to meet the current challenges. It's possible that some of the rising incidence of ADHD diagnoses may be misguided. Perhaps the difficulties some students seem to have with inattention, behavior management, and a limited ability to keep up with the expectations of school (as well as home, community, and social engagement) relates to their brains' stress reactions when executive function network effectiveness is inadequate for the myriad demands they face.

Preparation for Future Demands and Opportunities

The future is expected to sustain the trend of an increasing amount of information, changing facts, and new demands for jobs as yet unknown. A 2018 World Economic Forum report predicted that 50 percent of facts memorized by children entering school today will no longer be fully accurate or complete in 10 years. Additionally, by some estimates, 65 percent of today's grade-school children may work in jobs not yet invented. The report predicted that additional skill sets employees will seek include cognitive flexibility, successful communication, collaboration, and creative innovation.

To be adequately prepared for success in higher education and careers, students need guided opportunities to construct stronger neural networks directing executive functions, such as evaluating new information and modifying understanding as "facts" change. With this development of executive functions during the school years, students can be more prepared for the requirements of higher education and the competitive job market and for taking advantage of the opportunities their futures will offer.

School Readiness

Even before the earliest exposure to school, there is a valid rationale for strengthening executive functions. Research supports correlations between the strength of children's executive functions and their readiness for school success—social-emotional success as well as academic competence and the development of literacy and numeracy (Allan, 2014; Pears et al., 2013). Additional studies support the importance of developing social-emotional and peer relationship skills and positive attitudes toward school, as well as academic competence, in preparing children for school readiness and academic achievement (Mann, Hund, Hesson-McInnis, & Roman, 2017; Razza, Bergen-Cico, & Raymond, 2015). Low-level functioning of the foundational neural networks related to executive function and cognition can have extensive consequences for later learning; thus, it is reasonable to stay informed about the research and to promote environments and experiences that are linked to more successful development of executive function before school and throughout the school years (Razza et al., 2015).

Secondary School and College Demands

Despite their still-developing executive functions, students have often been able to navigate elementary school successfully—in part because of teacher guidance and scaffolding. However, as they reach secondary school, things can happen that could increase the demand on their executive functions:

- They're exposed to changing classes and multiple teachers with diverse expectations.
- Teachers have multiple classes and cannot provide as much personalized guidance for assignments and long-term projects.
- Parents may have trouble keeping tabs on their children's assignments and tend to be less involved in organizing their assignments for them.
- The breadth of the curriculum widens each year, bringing an increased burden on students' capacity for learning, remembering, and understanding the abundance of information.

Although the challenges students face when entering secondary school are significant, the support they receive is still relatively greater than what they find when they enter college. In high school, students may have relied on their teachers to keep them on track. High school teachers check attendance, call on students to answer questions, and even hold parent–teacher conferences. However, in large college classes, students are often anonymous. In a cavernous lecture hall, they may hide behind their laptops, surfing the web instead of maintaining attentive focus on the lecturer. Their still-maturing judgment can limit their recognition that the information they are missing out on during the lecture could limit their success in the class, hamper their learning, and more importantly hinder them in reaching their potential.

As more students enter college with inadequate executive functions, colleges have to do more remediation. These remedial courses often delay graduation and extend the semesters in school, adding increased financial and time costs for the students.

Two areas that require more specific attention are memorization and self-directed learning. Memorization techniques that may have been adequate in the elementary grades will not suffice as students move on. They need strong guidance and opportunities to progress from memorization to mental manipulation with construction of their own conceptual understanding. Additionally, they need structure to become self-directed, independent learners. For students to develop personal responsibility for learning, they need both explicit instruction and opportunities for trial and error, with corrective feedback in how to organize, prioritize, analyze, set and achieve goals, and apply knowledge as it is constructed.

Getting Ready for Jobs of the Future

In the book *A Love for Learning,* Carol Strip Whitney writes, "Tomorrow's problems will require multidisciplinary, creative, and sophisticated solutions. Students will have to be adept in applying concepts and principles from many different branches of knowledge" (2007, p. 175). Her words reinforce the need for supporting the active development of students' executive functions.

The skill sets employers seek have changed over the years. Rote memorization of facts and technical skills (e.g., familiarity with Excel) that were previously high priorities are inadequate in today's world. Now, with much procedural work being done by computers, robots, or other artificial intelligence technology, these qualifications are no longer the most sought-after.

If you look back at the list of executive functions presented at the start of this chapter, you'll recognize qualities that promote success in college and careers, such as the following:

- Self-directed and goal-motivated learning
- Thinking critically about information, checking the reliability of sites/sources, challenging assumptions, and seeking contradictory evidence
- Selecting targets for attentive focus and avoiding distractions
- Adjusting to change by thinking in creative and connective ways
- Organizing ideas and materials thoughtfully
- Prioritizing and identifying the most meaningful data to use
- Recognizing where to apply time and effort
- Communicating and collaborating successfully
- Anticipating consequences and outcomes
- Evaluating choices and decisions

As you guide students in going beyond information acquisition to analysis, connecting to prior knowledge, and expanding understanding into new problem solving, they will be able to more successfully transfer their knowledge and skills in response to changing information, technologies, jobs, and social conditions (World Economic Forum, 2018). As you'll read in the next section, executive function strength and capacity build not only with time, but also through experiences you can provide. Thanks to the brain's neuroplasticity, your guidance can prepare students with the executive function skills and depth of knowledge that will position them to take advantage of new opportunities that await them.

Interventions for Developing Executive Functions Through Neuroplasticity

Humans are uniquely skilled in analyzing and reflecting on their thoughts and behaviors to guide their successful planning and fulfillment of goals. Your guidance for their building of these skills and of opportunities to activate these executive functions will help students strengthen these high-level cognition and self-regulation control systems.

Gray Matter

Phases of Rapid Maturation

Different regions of the brain undergo their phases of rapid maturation during different stages of children's development. Neural networks in the prefrontal cortex, like those elsewhere throughout the brain, remain responsive to neuroplastic construction throughout life. When a region goes through its rapid maturation phase, however, a more profound neuroplastic responsiveness emerges. Highly accelerated construction (more myelin, dendrites, and synapses) occurs in the used networks, and those that are unused undergo extensive pruning. This pruning frees up available resources for the circuits that are most used (Best & Miller, 2010).

Having recognized the importance of the executive functions and the rationale for aggressively supporting and enhancing them during the formative school years, we can now look at interventions. These are designed to activate the developing neural networks related to executive functions and to strengthen the top-down control systems of cognitive, social, and emotional resources that students will carry into adulthood (Mann et al., 2017).

Goal Setting and Achieving

Recall from Chapter 2 that students' engagement in personal goal setting, coinciding with the teaching goals, promotes buy-in for exerting their effort to connect and remain engaged with a unit of instruction. Goal setting focuses students' attention on the purpose and value of their efforts and actions. Personally desirable goals invoke the dopamine reward pleasure of anticipating and progressing toward goal achievement. Setting manageable goals and acknowledging progress fall under the executive function umbrella and require nurturing (Best & Miller, 2010; Mann et al., 2017).

Early Guidance to Develop Students' Long-Term Goal Setting and Planning

When embarking on a unit, give students the opportunity to set some of their own goals. At the start of the unit and throughout, lead students in self-reflection and group discussions about their goals and progress. Here are some examples of guiding statements and questions for students to respond to:

- Identify the short- and long-term goals that you want to achieve and that coincide with the learning goals of the unit for the class.
- Identify what you think you'll need to reach your goals, such as knowledge, materials, and steps along the way. For example, what skills do you need to learn before you can succeed in balancing the checkbooks we're using in class?
- What problems might arise, and how could you plan for them (resources, references, questions to ask)?
- How will you recognize your progress toward your goal throughout the assignment?
- When will you reassess your route to your goals so that you can make adjustments early on and throughout?

These suggestions are not necessary or appropriate for all goal-planning opportunities you provide, but you can select and modify those that would be helpful for your students.

Quickwrites That Incorporate Goal Setting

Quickwrites were described in Chapter 3 as a way to promote memory and concept building. You can also use them to prompt students' learning goals (and motivation). For example, after viewing a video opening a unit on the Fertile Crescent in Mesopotamia, students can reflect on it and then do a quickwrite about things they remember from the video. They could also note their learning goals—what they want to know more about. They can include these goals in the flowing text of the quickwrite or add them separately during the last minute of the exercise. As with other quickwrites, students would underline their goal-related "gold nuggets." Then, in small groups or as a whole class, they can share their nuggets. These can be posted on a class list to give others an opportunity to consider—and perhaps buy in to—additional learning goals. Here is an example of a student's quickwrite:

> *I want to know why this part of history is important to my life and my future. I have learned this year that some of the things I study about*

history help me understand why things happen today. I believe people can learn from mistakes and from successes. I also know that when I took good notes and read them before the last test it helped me more than just reading the book. Last month some of my notes were messy and I couldn't read them. This time I have the goal of writing my words larger, so even if I rush, I will still be able to figure out what I meant when I read them later.

At intervals during a longer unit, students benefit when they reread their goals and reflect on their achievement. Asking students to journal about, or share with the class, their successful progress toward goal achievement will further activate the dopamine reward.

Envisioning an Optimistic Future

Optimism is one of the brain's dopamine boosters. Some evidence suggests that the dopamine-related motivation activated by optimism may also correlate to positive expectation of setting goals and wanting to achieve them. In a study in which students envisioned themselves in a future where they've achieved their set goals, the students' attention focus, sustained effort, and academic performance all improved (Prabhakar, Coughlin, & Ghetti, 2016).

Neuroscience Read-Aloud

Motivation and Planning Help You Reach Your Goals

You've learned that neuroplasticity strengthens your memory and brainpower. It's important to know that the same system of brain strengthening, with practice, can help you boost your executive function skills. To build stronger neural pathways to help you choose and achieve learning goals, you can reread your notes or jot notes during class about things that catch your interest relating to the learning. Set your learning goals to keep your brain interested in achieving the goals so your brain is eager to remember what you read and are taught.

Include sub-goals to achieve on the way. If your goal is to complete a 100-page book in a month, make a list of sub-goals and when you plan to reach them. For example, you may plan to reach 25 pages by the end of the first week, 50 pages by the end of the second week, 75 by the end of the third week, and 100 by the end of the fourth week. You can even put sticky notes every 25 pages to see the goal getting closer with each page you read. If you come to the end of week one and find you have only read 15 pages, you could give yourself more time to read each day.

Another way to use goals as motivation is to make a note of things in the lesson that seemed so boring that you felt your attention wandering. Give yourself a chance to find a way to connect even that part of the learning to a possible future or even an imaginary goal. (How could learning Newton's laws help me if I were in charge of creating something that could save the earth from an oncoming, potentially devastating meteor?) Your brain will pay more attention and remember more—even of those boring parts—when you link a goal to them.

As you build your mental muscle for planning and achieving goals, it helps to keep a personal list to motivate your effort to follow through on those activities designed to build executive functions. Include things that will be improved by better goal planning. Here's a list to give you some ideas:

- I'll stay on top of assignments.
- I'll plan for my goals to make good decisions about how to spend my time.
- I'll have my goals in mind so I'll more likely work on the assignment over time instead of leaving it for the last minute.
- After I achieve each sub-goal, I'll take a moment to write down the accomplishment and keep adding to this list to remind me of my progress when I'm frustrated or stuck.

To support the effort needed to achieve your goals, make a graph that plots your effort against your progress. You'll prove to your brain that with greater effort and practice, you can increase your success. This long-term evidence showing how your greater effort helped you to achieve more progress will help cement perseverance as a habit.

Prioritizing

Prioritizing is an executive function that guides students in planning for long-term projects or tests, determining which parts of homework to do first, selecting what information to take down in notes, separating low-relevance details from the main ideas of a text or topic of study, and evaluating the relevant data in math problems. Prioritizing for time management is also correlated with better grades, more effortful work, and future success (Liu, Rijmen, MacCann, & Roberts, 2009).

Until students develop strong executive functions for prioritizing, they are limited in their capacity to set and stick to realistic and manageable goals. To build prioritizing skills, they'll need direct guidance on strategies, with opportunities to try them and revise them. As with your guidance for developing other executive functions, giving students an optimistic opening will help, especially for those who have taken on the labels they've previously heard about their poor planning or faulty decision making. Before beginning direct skill building in an executive function, encourage students to recognize prior successes in that skill. Ask age-appropriate questions such as these:

- How do you select what to bring on a trip when you have limited space?
- How do you decide what to spend your money on?
- When you have free time on the weekend, how do you decide what to do?

After they respond, help them realize that the related achievements required them to use their prioritizing skills, and tell them you'll give them more opportunities to do so as they learn.

Neuroscience Read-Aloud

How Prioritizing Helps You

When you build your prioritizing skills, you'll be better able to focus your time and attention on where it best serves your goals. When you successfully prioritize what's important, you'll trim down the amount of information you need to deal with, and you'll make thoughtful choices about what to write down about assignments, what notes to take from lectures and reading assignments, and what to review for tests. You'll be more efficient and effective doing homework and long-term assignments as you prioritize what to do first and how much time to allot to each subject or segment of an assignment. When you prioritize, you'll be able to plan your time to get the most out of your effort, and as an added bonus you'll have more free time for your other interests.

Using Prediction for Planning and Prioritizing Time

You can build students' prioritizing and planning skills by having them estimate how long something will take, and then, after completion, assessing the accuracy of their estimate and revising for future planning. For example, have them make and write predictions about something they do regularly, such as homework or portions of long assignments. More specifically, ask them how long they estimate it will take them to complete each part of one night's homework or each section of a long-term project. Have them write down their predictions in class and then record the actual time it took on their accumulating list. Encourage them to think about the accuracy of their estimates, and have class discussions about what they tended to over- or underestimate and why they think that was the case. Follow up every few days with additional comparisons of predicted time and actual time spent, again assessing the accuracy of their planning estimates.

Initiate class discussions in which students share strategies they find helpful in planning and prioritizing their time. Emphasize the positive outcomes that result when they hone their ability to estimate, plan, and prioritize. They will likely recognize that they have more time, less stress, and better outcomes; that they increase their enjoyment (or decrease their dislike) of the activity or assignment; and that they eliminate the bickering that may occur with their parents over finishing on time. Repeat these self-monitoring activities periodically so students continue to evaluate their own progress or ask for help if they are trying but not succeeding.

For prioritizing related to long-term assignments, you can provide a rubric specifying all the requirements for the project, with a point value for each part, such as the one described below. During the course of the assignment, provide times for students to work in class specifically to review plans, evaluate their progress, and adjust their emphasis during the time remaining before the due date.

Neuroscience Read-Aloud

How a Rubric Helps You Prioritize

This rubric describes the requirements for this project and the number of points for each part of the assignment (e.g., cover, title page, content, grammar, bibliography). Using the rubric, you'll now create a schedule to prioritize where you'll spend your time and how much time you'll need for each part of the assignment. Start by listing the tasks that are needed to progress to a finished project. Then prioritize them by order to be done, and estimate the amount of time to spend on each.

When you don't prioritize in advance, especially considering the grade-point value for each part of the assignment, it is natural to want to spend more time on the more enjoyable parts, like creating a cover using sketching and art software or adding extra details to a model. However, when you prioritize based on the parts of the assignment that are designated as most important, you'll be more successful and see the benefits of managing your time carefully.

Prioritizing Importance

Students need to be able to distinguish what is important, whether in a paragraph, in instructions, during note taking, in deciding what to study, or in knowing what information in a word problem is most important for a solution. They benefit from experiences that require them to analyze the relative importance of the information they see, hear, or read.

Following a lesson in which students are asked to identify the main idea in a written passage, the key takeaways from a lecture, or the steps in a complicated word problem, provide some time for reflection on how they prioritized the most important parts and what criteria they used.

Prioritizing during note taking is a skill that will become increasingly important as students progress through the school years. Explain that this prioritizing skill is what they will develop as they think about what is most important to write in notes, to remember, to reread, to use as a resource, to study, and so on. Students can use these questions to guide their prioritizing of note taking:

- Did I recognize visual clues, such as type that was boldface, larger, colored, or italicized? Sidebars? Section headings?
- Did I write down information that the teacher emphasized by saying, "Write this down" or "I'll stop for a minute here, so you can include this in your notes" or "In conclusion . . ." or "This chart or diagram shows how it all comes together"?
- Did my notes need to include specific names and dates that I missed? (Metacognition applies here to answer the questions

"Why didn't I include this information in my notes?" and "Why would I include this type of information in the future to improve my note-taking success?")
- Did I leave out examples of the real-world connections discussed in class or written about in the text?
- Did I separate my notes into appropriate categories, include page numbers and important definitions, and distinguish fact from opinion?
- When there were multiple interpretations—for example, causes of a war, of epidemic disease spread, or of the disappearance of the dinosaurs—did I include supporting information for each?

Prioritizing in the Early Years

Young children can practice prioritizing skills as a natural part of their days at home and at school. In preschool or early elementary school, students can participate in conversations about prioritizing, responding to questions such as these:

- How would you plan which stuffed animals to bring if you could bring only two on a trip?
- How do you choose which three books to read at bedtime?
- How do you decide which activity to do first during playtime?

At the Oaks Parent–Child Workshop preschool in Santa Barbara, California, the director greets students as they enter. As she welcomes them and gently helps them with their nametags, she often asks about their "play plan." What do they plan to do first? Are they going to check out the new activity stations? Look for a particular friend? Head to the beloved sandbox? Are there any materials they need to get started? These simple conversations help students transition into the school day and feel prepared to separate from their parents. These young students are learning that a little bit of prioritizing and planning can set them up for fun and success.

Organizing

No doubt there are several areas of your life you'd love to have better organized. Whether it's your work plans, your files, or the things in and on your desk, it would likely feel good to get them more organized—and keep them that way. Similarly, students have many things they'd like to have or keep in better order. Instead of starting out with instructions to build their organizational skills, you can use the approach previously suggested for engaging students in any learning—goal buy-in and achievable challenge, with scaffolding as needed.

To promote buy-in to build organizing skills, launch a class discussion of all the things students would like to have better organized. You can start with your own organizational wish list. A posted class list can give students additional areas they had not considered. The class discussion and list will also reassure students—especially those who feel they are hopeless at organizing—that most classmates, even the "smartest," have their own challenges.

The achievable-challenge element again starts with students recognizing that they already have organizing skills they use successfully. You can prompt their awareness of their existing organizing skills or recognition of organizational systems with questions such as these:

- How do you sort your music on playlists?
- How are categories organized for film awards?
- How have you helped organize an event (e.g., a party, a club meeting, a fundraiser)?
- How do you organize your room—or wish you could?

You can further promote students' awareness of their organizational insights as you build this executive function network by activating it. Sustain the buy-in of personal relevance by posing questions about the organizational systems of things they are interested in, such as schedules for sports leagues. The plan now is to have them think about how these things are organized. After they share their ideas on the "how," they next share ideas about how the planning might be improved. You can apply the process to various topics, including these:

- The schedule of the school year in terms of start and end dates and vacations
- How their textbook is organized
- Where materials are kept in the classroom

The teachable moments when students complain about an organizational system they don't like present another opportunity to motivate their brains to think about organizing. Perhaps they complain about the organization of the school day, including start time, or the procedures they have to follow to sign up for electives. What a great time to turn class attention to why they think it is organized the way it is, and what they would do or suggest to make it better! Their suggestions could be ideas you take back to school administrators, sharing any feedback or responsive changes made with the students.

Guided Skill Building for Upper Elementary Grades and Beyond

Using the class list of what students would *like* to be better at organizing, you can prepare templates of lists or self-questions for them to use to evaluate and improve their organization for the goals they choose. The purpose is not to make students dependent on your checklists, but rather to build their metacognition about what works for them. This process increases their motivation to keep using strategies they find helpful by recognizing additional things they could organize more successfully with those same strategies. Here are some organizing strategies that students can select to try and then, with your guidance, evaluate in terms of outcomes:

- Keep a record of successful strategies and predict (in writing) when you think you could use them again. As one student noted, "Organizing my notes with color coding helped me study for the test. I think a color-coding system could also help me organize the information I gather for the next report and project. I can use different-color note cards to keep my notes for different parts of the assignment."
- Prepare a set of note cards to take to school each day to fill in new assignments and due dates, as well as what you need to bring home and things you need to bring to school the next day for that class.
- Use color-coded folders to organize what you need for each class and project. Store these in a designated file drawer in your room or in named, color-coded folders on your computer.

- Use your smartphone, computer, or tablet's reminder program or calendar to organize and keep track of your due dates for assignments, sports practices/games, club meetings, plans with family or friends, and anything else you plan to do.
- Keep a master list of the names of all your active computer desktop folders and file folders. Once a month, remove items no longer needed from each folder and the master list.
- Create a study plan for long-term assignments, breaking them into a task to be done each day.
- Use sticky notes to post reminders in a place you always see or touch before leaving your home—for example, on your bathroom mirror or near your hairbrush, backpack, or keys.
- Keep a strategy file—a list of what worked and when to use it.

You can offer more specific strategies for students to use as they build their toolboxes for the organization of long-term assignments. Here are some examples:

- Have complete and accurate information about assignments—for example, instructions, where to get resources, due dates for each section, how many grade points will be given for each area, extra-credit options.
- Prioritize a list of when to do each part and how long it will take.
- Keep a list of items to work on when you have unexpected extra time (e.g., when a club or sports practice is canceled due to weather). These can be items that don't have to be done in a certain order. Having this list readily available and doing productive things with this "found" time is a way to get work done on time and avoid last-minute pressure.
- Print a monthly calendar with large sections for daily plans and a time line of dates when key components will be started and completed.
- Get materials needed (note cards, documents, books, internet access).
- Use the following items as a section-by-section checklist to make sure that each section of your report is complete.
    - Topic sentence, to include question being answered or category of information

- ◦ Supporting evidence from multiple sources (with saved references)
- ◦ What parts of this section should be emphasized using original or referenced charts, diagrams, photographs, or graphs
- ◦ Transition sentence that shows relationship between this section and the next
- ◦ Check of grammar and spelling

Guided Skill Building for Preschool and Lower Elementary Grades

Learning about organization can start with young children, especially when the subject is approached playfully and organically throughout the day. For example, when Malana and her 4-year-old son approach the entrance to his preschool, he places his lunch bag in the appropriately colored tub. The blue tub is for children staying for the full day, and the red tub is for the kids leaving after lunch. The groups eat in separate places, and separating the lunch bags ahead of time makes for a much smoother start to the lunch hour. Malana and her son have playfully imagined the huge pile of lunches that would be mixed up and overflowing if there were only one tub, and how challenging it would be for the hungry students to find their bags. At the grocery store, they've chatted about the convenience of keeping similar items grouped together and laugh about how tricky it would be if all of the produce were jumbled together or the cereal boxes were spread throughout the store.

With children in preschool or lower elementary grades, you can have a guided conversation in which you consider how familiar places and objects are organized. Your discussion can cover organizational strategies such as grouping similar items, using a consistent order, making sure everything has a place, and using colors, words, and pictures to identify where things go. The following questions can help spark this discussion:

- How do you organize your toys (books, games, puzzles, etc.) at home?
- How are art supplies (paints, crayons, paper, etc.) organized in the classroom?
- How do our classroom cubbies help us to stay organized?

- How is the book we're reading organized? Where is the beginning, the middle, and the end?
- How is the grocery store (toy store, library) organized?

When providing instructions and organizational strategies for procedures, projects, or transitions, emphasize them clearly, invite questions, and practice together. Young children love the ability to predict routines and to know where to find objects that are important to them. Although their play can be messy, it is comforting for them to be able to count on the organization of the world around them—and to contribute to keeping it that way from time to time!

Judgment and Reasoning

Judgment is the executive function that, when developed, promotes students' abilities to monitor their behavior, decisions, and choices. They need to use judgment to successfully navigate academic requirements—and many other things in life.

Like judgment, reasoning can also guide students' abilities to interpret information and think logically based on prior knowledge, new information, pattern expectations, and deviation from expected patterns. Reasoning guides recognition or construction of rules, principles, or concepts—for example, evaluating the rules that appear to apply to situations and using those consistencies to make accurate predictions or interpretations of new, related information.

Students today are faced not only with an exponentially growing amount of information to learn but also more decisions and choices than ever before. As their judgment, decision making, reasoning, and risk assessment are still developing, they can be overwhelmed and excessively stressed by the decisions and choices they need to make throughout the day (and night, if they keep their phones set to alert them to texts around the clock). As a result of the stress response to the high demands on their judgment and reasoning, their brain's processing of decisions and choices can become less reflective and more reactive.

Developing Judgment and Reasoning in Adolescents

Looking at physically maturing adolescents and teens can cause adults to forget that the brain is the last part of the human body to mature fully. Although students at this stage look like, and sometimes act like, young adults, their judgment control networks are not likely to be as developed. The guidance and structure students receive during these years are particularly critical, not only for their safety but also for promoting their future as lifelong learners and active participants in a democratic society.

The reorganization taking place in their brains and hormonally in their bodies can cause adolescents and teens to be emotionally erratic, unpredictable, and prone to blowing things out of proportion. At this stage, changes that seem inconsequential to adults may seem huge to these learners and can provoke stresses we don't foresee. An important way to guide adolescents and teens through this period of flux is to provide them with a sense of community and help them build their experiences of self-efficacy.

In addition, when their judgment is less analytical, adolescents and teens, not unlike young children, often jump to conclusions without considering their options or outcomes. Lapses in judgment, risk taking, decision making, and focus challenge this age group and may account for the disproportionate rate of potentially life-threatening actions by teens, such as driving under the influence, using illegal drugs, drinking alcohol, and consuming an excessive amount of highly caffeinated drinks.

During these volatile years, with increasing temptations and access to potentially dangerous actions, from drugs to driving, students need their decision-making and judgment skills to be as strong as possible. As you incorporate learning opportunities for them to build their judgment and reasoning cognitively, you'll help them strengthen these critical executive function circuits.

Strategies for Building Judgment and Reasoning

Opportunities to help stimulate students' developing executive function networks for judgment and reasoning are most authentic and meaningful when they are integrated into their daily experiences and activities. Throughout the grades and across subject areas, there are a variety of creative ways to help students practice using their skills of judgment and reasoning. Giving learners the chance to present a point of view and explain their reasoning through open-ended questions, class discussions, or formal debates allows them to hone their abilities to use judgment to make and support decisions. Opportunities to make choices, analyze risk, and evaluate decisions before acting can help students be more successful self-directed learners now and beyond school as they'll continue to make critical decisions.

Estimating. Estimation is a form of judgment that students can begin to learn in the lower grades. For example, they can estimate the number of beans in a jar and discuss strategies that helped them make more successful estimates.

Judgment for estimation is not limited to the lower grades, however. In a science lab or other class where students need supplies, they require judgment to determine the quantity of supplies and which supplies will best fit the needs of their own group. They must also consider the appropriate amount of supplies to take when the whole class must share them. Students can discuss in advance within their groups the quantity of each chemical solution they will need for the day's experiment and their reasons for those judgments. A spokesperson can share the group's judgment and reasoning with you before selecting their supplies. An opportunity to discuss consequences of judgments can come at the end of class. Possible topics include which groups had inadequate supplies, which groups had taken more than they needed, and what measures could be used to make more accurate judgments in the future. This scenario could be applied to judging time needed for parts of a group project, planning for the cost of materials, predicting delays or complications that might arise, deciding how to divvy up the work equitably, and many other factors.

Regaining control of behavior. Judgment allows us to decide how to behave in a given situation. Behaviors such as calling out, being disruptive, and zoning out may be reactive, but students can exert control over these behaviors with supportive feedback from teachers. Collaborate with individual students on a secret word or a subtle gesture you will use when they need to regain their top-down control so they can do their best.

Resisting impulsive decisions. Impulsive decisions are costly to students' academic success. Students need to develop judgment to resist the temptation of procrastinating or abandoning homework altogether in favor of leisure activities such as playing video games or browsing social media. They need guidance to remember to take the time to read all information carefully on an exam and to look thoughtfully at all multiple-choice answers before selecting one based on their hasty first impression. Again, following the video game model discussed in Chapter 2, start with buy-in related to personal relevance and move through achievable challenge with feedback and authentic consequences. Prompts such as these can help establish buy-in regarding the value of considered decision making:

- When reading e-mail, social media postings, blogs, or books describing problems resulting from other people's poor choices, stop to think about what might have been a better decision.
- When you have an important decision to make, even if you are pretty sure, take a full minute to think if there could be potential bad results from the choice you are about to make.
- When you solve problems in math or science, take the time to find another way to get the same solution.
- When you're designing something for art or planning a report and come up with an idea or plan, consider one more way of doing it. Then decide which of the two will be likely to have the best outcome.
- When problems or historical disputes come up in a novel or history book you're reading, create your own way to solve the problem for an even better outcome.

Self-editing. Self-editing provides opportunities for students to judge the quality and accuracy of their own work and consider possibilities for improvement. Initially, it is helpful to scaffold self-editing with written or verbal prompts to guide students to look out for improvements they can make as they revise content and proofread to catch errors in spelling, grammar, and punctuation. Gradually, you can withdraw the prompts to build more self-directed learning. Peer editing also allows for carefully considering another person's written work, as well as developing the executive function skills of collaboration and communication as students provide supportive corrective feedback.

Judging fairness. It is important for students to consider the idea of what is fair. To help them build their capacity to judge fairness, students could evaluate the fairness of rules, such as the rules athletes must follow to participate in competitions. For example, they could evaluate the following ethical dilemma:

> *Consider that runners living at high altitudes have higher amounts of oxygen in their blood compared with those living at low altitudes. These high-altitude athletes will usually have higher amounts of hemoglobin in the blood to carry oxygen when they compete. However, "blood doping" to enhance one's hemoglobin with transfusions of an athlete's own stored blood is considered an unfair practice.*

Teachable moments can come from government rulings that students investigate when they are concerned about a local issue or policy that affects them. For example, if students think it is unfair for the city council to prohibit skateboarding on public streets, they can evaluate the records of discussions that took place in the city council meeting and make judgments about what information was fair. They can analyze the amount of weight given to citizen comments versus discussions held by the council in private subcommittees. These types of analyses and uses of judgment are particularly engaging and relevant when students know they will have an opportunity to share their impressions and recommendations with the people or committees involved. They might attend a council meeting, hold a classroom discussion with a council member, or write letters to the editor of the local paper. Websites such as www.cyberbee.com/intclass.html have examples of cross-curricular topics and web links you can consider for incorporating executive functions like judgment, reasoning, and critical thinking into academic instruction.

Asking open-ended questions. To encourage students to build their judgment and present their reasoning, ask open-ended questions that do not have a single correct answer. Here are two examples:

- Why do you think this cartoon shows the cows talking and all the other animals silent?
- What strategies do you think are best to use when playing the games of checkers, chess, or Monopoly? Why?

Judgment and Reasoning Across the Curriculum

As is true for all of the executive functions, opportunities to practice judgment and reasoning arise naturally across all subject areas. Testing by trial and error, making educated guesses, and evaluating rules are skills that students can build across the curriculum. Here are some examples:

- Use trial and error to evaluate underlying rules of science and mathematics, or the best ways to plan defense in a soccer game.
- Predict how much clay can successfully be molded into a tall vase on a wheel without it collapsing.
- Consider why there are different rules for conduct, timing, and scoring in college versus professional football.
- Select and bring to class three similar items you consider good quality (e.g., print advertisements, maps, photos). In class, evaluate the three items and rank them in order from best to worst. Next, tell partners or share with the class the criteria you used to judge your items.

Any of these specific examples could be adapted for other subjects.

Supporting Opinions

Part of developing the executive function of making considered judgments is having the skill and confidence to present your opinion, defend your position, and listen critically to learn from and reflect on the judgments of others. Provide students with scaffolded opportunities to share their judgments with others. Here are some ideas for doing so:

- As opportunities arise in your curriculum, pair students with classmates who have the same opinion regarding topics that are open to debate—for example, an approach to a math problem, the best type of government, the cause of dinosaur extinction, or the best way to deal with erosion. After building their confidence and ideas with partners, have them move seats to meet with someone with a different opinion and engage in focused, open-minded exchange of ideas with their new partners.

- Help students learn to defend their judgments by asking them to provide supporting evidence for their opinions. Here are some examples:
    - Ask students to provide evidence to demonstrate why they disagree with a particular rule or law.
    - Bring in and read news of a local government ruling with which students would likely disagree—for example, rezoning of a community playground into a space for residential home building; approval of increased building of commercial spaces and high-cost residences; or less funds for recreation such as team sports and art programs. After they hear the news item, let them debate their reactions, encouraging them to add supporting details.
    - Any time students say, "That's not fair," consider it a teachable moment for building their executive functions of judgment and thoughtful decision making by inviting them to come up with reasons and reasonable alternatives.

Critical Analysis

Salman Khan, founder of Khan Academy, says, "Since we can't predict exactly what today's young people will need to know in ten or twenty years, *what* we teach them is less important than *how* they learn to teach themselves" (2012, p. 180).

Critical analysis of information is an essential executive function that students can develop as they learn to process information. We live in an age when information overload is prevalent, and distinguishing between valid and fictitious information or claims can be difficult. To build students' skills in critical analysis, you can incorporate activating opportunities such as having students consider and discuss the following types of self-reflection questions during classroom instruction:

- **Interpreting the meaning of questions and instructions.** For example, what is this math problem really asking me to do? Do I need to write a full essay, or does the assignment want me to make a list?
- **Selecting which information needs to be gathered.** For example, is this website the best use of my search time? Does the

information directly relate to the topic I'm working on? Does the information fill a gap in the data bank I am trying to build?
- **Evaluating whether sources of information are accurate and authentic.** For example, is this information truthful or exaggerated? Does this graph really support the claim it is making?
- **Distinguishing fact from opinion.** For example, does this website clearly separate facts and opinions? Does the website provide valid references for the claims presented? What can I use to decide if a website, claim, or article is fact or opinion?

Media Literacy

Media literacy, which encompasses both print and digital sources, includes the abilities to seek valuable information, evaluate its validity, and communicate that information to others. Proficiency in media literacy requires guided opportunities to experience, organize, evaluate, and analyze relevance in media.

You can guide students in activating, building, and strengthening their information analysis skills through class discussions, research-supported inquiry or reports, project-based learning, and opportunities to discriminate fact from opinion. These experiences will not only build the executive functions students need now for school but also guide them in continued education and career readiness (and flexibility).

As an example, read aloud a biased article without the students knowing the source of the information. Their job is to ask questions to evaluate the validity of the article using questions from a list you provide, such as these:

- What is the background (academic, political, financial connections, etc.) of the person who wrote the article?
- Where was the article published? Is that news source known to be biased?
- Are there sufficient data to support any conclusions the article draws?

After building their experience using your questions as guides for subsequent biased articles the class reads, have students come up with their own questions to evaluate validity.

Evaluation in Units of Instruction

Have students evaluate multiple sources of information—for example, visual images, graphs, charts, maps, cartoons, photographs, artwork, and eyewitness accounts—related to the topics of your units of instruction. Guide them in discussing with partners or small groups whether they think the information is valid and, most important, *why*. In doing so, they will build their skills of developing criteria for analyzing validity. The following examples illustrate various approaches to critical analysis involving history, literature, and art, as well as numerical analysis.

History, literature, and art.

- **Comparing historical images.** Have students compare a variety of images of a historical event or person and consider the perspectives or biases of the illustrator, artist, or author who created the representation. For example, students could compare various images of Pocahontas as she was illustrated in the Disney film, painted in a classic portrait, and described in writing. Why do the images look different? Who is the target audience? Which is most realistic? How is it possible to judge their accuracy or authenticity?
- **Experiencing our own biases.** Divide your class into two groups, and show each group a painting that depicts a very different representation of a historical event or time period. You will know that the images show different biases, but initially your students will not. Over the course of the lesson or unit, it will become clear how much the perspective of an artist can influence our understanding about an event. The following is an example from a unit on westward expansion:
    - Show one group of students a painting that depicts Native Americans walking along the treacherous Trail of Tears. This artist's rendition would show the suffering that the Native Americans endured as they were forcefully removed from their lands. Show the other group of students an image that presents a view of Native Americans as warriors attacking a wagon train of travelers heading west. Ask that students not share their images with each other at this time.

  - At the beginning of the unit, as the students evaluate the painting they have been given, encourage them to describe the emotions it evokes in them. Ask them whether they consider it to be representative of what really happened during that period.
  - As the unit of study progresses and you introduce more content about the events of the time period, have your students journal or describe any changes in their feelings about the scene depicted in their image.
  - At the end of the unit, ask them to give their analysis as to who might have created the painting and if art such as this is a valid depiction of history or a limited depiction based on the perspective of different groups of people.
  - Have the students exchange images, share opinions, and discuss how their experience of the unit was influenced by the initial image that they encountered.
- **Comparing sources.** Choose a topic from history that is fairly widely understood. For example, ask students to start off by filling out a KWL chart (described in Chapter 2) about the women's suffrage movement. They will write a few examples of what they think they know about the period in the "Know" column, and then a few questions they have in the "Want to Know" column. Divide the students into five groups, providing each group with a different source of information: (1) a traditional history textbook; (2) a reference book such as Howard Zinn's *A People's History of the United States,* which strives to include the perspectives of individuals often left out of the mainstream historical narrative, such as people of color and immigrants; (3) a primary-source document, such as a letter or diary entry, from the perspective of a suffragette; (4) a newspaper article or another primary-source document from the time; and (5) a passage from a historical novel. Students will discuss their source in their small group and then fill in their "What I Learned" column using that (limited) information. They will then share what they learned with members from the other groups, adding to their "What I Learned" column, noting each source of their newly added information with a different color or label. Follow this step with a

whole-class discussion comparing the usefulness and validity of these sources, paying particular attention to how and why they might differ. Finally, have the students present arguments for which types of informational sources they find valuable and want to use more of (or less of) in class.

Numerical analysis. To guide students in evaluating data, statistics, and other numerical information or claims, start with buy-in experiences so they are curious or surprised. For example, create a list of outlandish past or current claims that have been made about a topic you are teaching, such as chemical products for house and garden, the solar system, girl/boy stereotypes, criteria for diagnosis of a disease, or identifying witches during the Salem trials. Embed accurate criteria, statements, or components in these lists and have students make predictions about which are true or valid and which are false. As they then compare their predictions with the accurate ones, have students share in groups the ones that surprised them.

Securing buy-in not only promotes attention but also shows students the value of building critical analytic skills. For example, have them compare bar graphs that seem to demonstrate a great difference between two products. After their evaluation, show them that the promotional graph is misleading because it shows only the very top of two bars, and the data actually show very little difference between the two. They'll see, for example, that the visible graphs did not start at zero, but rather at 600, so a difference between 601 and 605 appeared significant when the graph included only the values between 600 and 608. They will then learn that the tip-off was the absence of any measurement unit for each bar, or the tiny indicator at the bottom of the graphs showing that the graphs do not start at zero. With their new awareness, students can share graphs they find or make that misstate claims of causality or interpretations because of how numbers are represented.

Critical Analysis of Websites

Another way to promote students' developing abilities for critical analysis is to have them construct their own rubrics for assessing websites. We cannot predict how information will be disseminated in the future, so giving students a list of qualifiers to determine the validity of websites won't serve them as well as helping them build and revise their own. This activity also includes buy-in through personal relevance and achievable challenge, with opportunities for feedback and revision. Here are suggestions for how to proceed:

- Make it clear to students that, rather than giving them premade checklists, you'll be guiding them to construct their own criteria so they can build their executive functions to serve them now and in the future.
- Ideally, students would choose any topic of interest to evaluate on the web, but time constraints and practicality may make it more feasible for them to seek examples relevant to a current topic of study.
- Their assignment is to evaluate several websites on the topic and select the website they think gives the best-supported information and the one they think is most biased or not supported by sufficient evidence.
- After making their selections, they specify the criteria they used in forming their opinions of website validity and bias.
- In class, small groups share their criteria (not the details of the website) and discuss which ones the group would select as most useful. During these small-group discussions, students are guided to be open-minded listeners (perhaps aided by modeling) as the group members describe the individual criteria they used for validity evaluation. As additional buy-in for this active-listening activity, let students know the benefits they derive from it, including the following:
    - Paying attention to the criteria used by others might give them ideas they had not thought of that they'll find valuable for evaluating validity in the future.
    - If they disagree with the criteria someone is describing, their disagreement provides an opportunity to build executive functions of self-control, judgment, and thoughtful decision making—if they resist their impulse to interrupt or jump to a conclusion before hearing the person's entire explanation. For those students who repeatedly call out in class, this is an opportunity to demonstrate to classmates that they can collaborate thoughtfully.

    - They will experience how taking time to listen carefully increases their understanding. The time will allow them to further examine their opinions in comparison to their classmates'. Their brains will search prior knowledge (making connections) for information to support their opinion, as they build their executive function skills of considered decision making, judgment, and critical analysis.
- After group sharing of individual criteria, students create a group-consensus list of the criteria they agree are most helpful.
- These group-consensus lists are shared in whole-class discussion, leading to a whole-class list of criteria you can record and have available in the classroom for evaluating website validity.
- After subsequent work using website sources, especially for academic work, the class discusses revisions they think should be made to the student-generated list to improve future assessments of validity.

With ongoing opportunities to test and evaluate criteria and revise those they find most useful in assessing websites and other sources of information, students can continue to refine their "personal rubrics" for checking validity and to transfer these to new information sources in the future.

Cognitive Flexibility

Author H. G. Wells predicted that our future would be a race between education and catastrophe. We live in exciting times. As educators, we have the opportunity to unleash students' creativity and build their foundational understanding of the neuroscience of learning. Given the growing volume of, access to, and globalization of information, those students with strong executive function networks for cognitive flexibility will be the ones best prepared for problem solving, global collaboration, and creative innovation. They will confront the dilemmas awaiting them by building and applying their expanding knowledge. They will enjoy enhanced abilities to consider alternative points of view, predict a variety of outcomes, find multiple ways to approach a problem, and assess changing data or new information from multiple perspectives.

A common understanding is that what we see depends on what we look for. Students whose memory linkages are limited to isolated rote responses will not have the cognitive flexibility to see beyond the obvious or one "right" answer. When the brain repeatedly uses mental processing geared to rapid efficiency and single responses, it grows increasingly "successful" and automatic. Students unfortunately develop the limited cognitive habit of accepting the first retrieved response as the correct and only accurate one. But today's students face higher education and career challenges that require interpreting, reasoning, communicating, and transferring knowledge to novel applications. The recitation of facts is no longer adequate for being "smart."

Learning experiences need to go beyond single answers and applications and push students to resist assuming that their first response is the only correct response. In the class setting, when students are empowered with opportunities to use and strengthen their cognitive flexibilities, they remain receptive to collaboration, new experiences, alternative points of view, unfamiliar customs, variations of opinions and interpretations, multiple approaches to problem solving, and creative innovation.

Strategies for Building Cognitive Flexibility

Students need explicit instruction and opportunities to practice flexible thinking in order to take advantage of the rapid developmental response of executive functions during the school years. The following are activities that you can adapt and use throughout the grade levels to build cognitive flexibility:

- Play the "This is not . . ." game by bringing in or selecting a classroom object that is known for the specific job it does, such as a paintbrush. Students sit in a circle and pass the paintbrush around as each has the opportunity to create a different function it could perform:
    - "This is not a paintbrush. It is a sweeper for cleaning a desktop!"
    - "This is not a paintbrush. It's a tickle tool!"
    - "This is not a paintbrush. It's a cupcake-frosting applicator!"

- Present translations of fairy tales such as the Cinderella story from different countries, and compare them to the story the students are familiar with.
- Share different perspectives—for example, retell stories from the point of view of another character, such as the whale in *Moby-Dick* or a blood cell as it circulates through the body and visits the organs.
- Create variations of outcomes in literature, art, or history—for example, what would you have done differently than Winston Churchill regarding the participation of Great Britain in World War II? Or draw a sketch as if you were Picasso taking on the style of an impressionist like Monet.
- Challenge students to find more than one solution to a problem. The goal is for them to build the habit of going beyond the first answer that comes to mind. The problems could include historical disputes, ways to divide odd amounts of supplies equitably, different endings for a story, improvements in rules for playing or scoring a sport, multiple ways to solve a math problem, or alternative ways to test a scientific hypothesis.
- Provide exposure to diversity, reminding students that there is not just one way to be.
- Don't teach young students how to use a toy; invite open exploration instead.
- Promote original thinking by asking provocative questions such as these:
    - Would you rather fly like a bird or swim deep in the sea like a whale? Why? (questions that trigger the imagination)
    - What could we use if we didn't have buttons or zippers? Cars and airplanes? Phones? (problem-solving questions)
    - How could you make a better shopping bag? Spoon? Lunch box? Backpack? Bedspread? (questions that spark innovation)
    - Show a photograph of a familiar object and ask, How would this object look to a mouse? A bird? A baby? (questions that require taking a different perspective)

Modifications in Teaching Style

Some teaching practices limit creativity and cognitive flexibility. Sometimes, guided by the best of intentions, or merely because our days as teachers are so busy and class time is limited, we take actions that ultimately hamper our students' contributions. When we oversimplify or overexplain, ask closed-ended questions, rush through discussions, and reward speed, we may limit the extent to which our students take the risk of exploring alternative solutions and perspectives. Modifying a few of these teaching habits can promote more student self-directed learning and cognitive flexibility. Here are some suggestions:

- **Provide fewer teacher-dispensed conclusions.** Instead of wrapping up each lesson with a tidy teacher-led conclusion, make time for students to use the data, evaluate the information, and then draw, compare, and revise their own conclusions. You can check for understanding (and misunderstanding) using tools such as exit tickets and dend-*writes* (discussed in Chapter 3) and reteach, follow up, and clarify as needed.
- **Use less restrictive language.** Avoid language that suggests a single correct answer or approach, such as "What's *the* answer?" Instead use language such as this: "What's one/an answer?" or "Share your thoughts about ____" or "What else?"
- **Offer more wait time.** When you ask a question, request that students not raise their hands until you have allowed time for everyone to consider (and possibly write down as a prediction on their individual response devices) their own opinions. For many students, even seeing a classmate with a hand up, ready to answer, blocks their dopamine-reward pleasure that comes from finding out if their prediction or answer is correct. Providing more wait time also allows students to think past an automatic response and give a more thoughtful answer.
- **Ask open-ended questions.** Allow discussion in which there are no wrong answers because the discussion is open for opinions and all ideas are welcome. Fun practice topics to discuss could include these:
    - Which color is best, and why?
    - If you could eat only one food for an entire day, what would it be, and why?

After building students' comfort with these types of "no wrong answer" discussions, you can use the approach in your subject area. For example,

- Which type of math equations do you find most useful, and why?
- Which style of art best represents your personality, and why?
- Which character from the novel reminds you most of someone you know, and why?
- Would you rather have the scientific background to survive in the ocean or in space, and why?

As students develop cognitive flexibility, watch for them to display a greater willingness to be creative, find alternatives, and see mistakes not as indications of failure, but as opportunities to increase understanding. These insights about building cognitive flexibility were shared in the following tweets written by workshop participants:

- Build cognitive flexibility so students don't miss things they are not specifically TOLD to find.
- When the expectation is one right answer . . . that is problematic; it limits focus beyond the task.
- Avoid using language that implies there is one right answer: build cognitive flexibility!

By guiding students to activate and strengthen their neural networks of executive functions, you'll become a brain changer, optimizing their potential to preserve and sustain their curiosity, ingenuity, creativity, and imaginations. You'll see their progress in self-management, organizing, making thoughtful decisions, goal planning, media literacy, flexible thinking, and creative innovation. Your guidance will provide them with opportunities to build their skill sets and wisdom for successful, joyful engagement with the challenges and opportunities in their wonderfully open-ended futures.

Afterword

Education is not the filling of a pail, but the lighting of a fire.

—W. B. Yeats (reworded from the original by Plutarch)

It is said that a brain once stretched never returns to its original shape. Stretching students' systems of neural networks by promoting directed attention focus, supporting self-regulation, sparking memory links of the new to the known, scaffolding understanding at the conceptual and transferable level—plus stimulating the executive function to build these strong skill sets—is what you do as an educator. You literally change your students' brains.

The effort, planning, and class time dedicated to neuro*logical* teaching and learning will pay off even beyond the improvement you'll see in students' engagement, memory, and thinking skills. As students grow and learn, they continue to expand their experiential database. The more experiences they have, the more likely they are to see connections when they compare new experiences with previous ones. In this context, the neural correlates of intelligence might be considered a measure of students' abilities to make accurate, expanded connections between new information and existing patterns in the brain's networks of stored information—to acquire new learning and apply what they know to make accurate predictions and solve new problems. These extended memory circuits can then be available for transfer to new applications and creative innovation.

The experiences you provide can build students' abilities to use prior knowledge to understand ever-increasing amounts of new information, analyze it for accuracy, evaluate opinion versus fact, and identify bias. Your students will be able to deduce new uses for new information and technology, solve as-yet-unknown problems, and contribute innovations and ideas to expand the reach of advances to people throughout the globe.

As neuroscience research continues to be available to educators who can apply it to the classroom, it will not only drive the learning process but also allow those who have the relevant background knowledge to energize and enliven the minds of their students. It will be up to you as an education professional to develop and use new strategies that bring the research applications to students. Doing so will be a challenge—but a fascinating and exciting one!

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APPENDIX

A Neuro*logical* Lesson/ Unit/Presentation Planner

Title/Topic:____

Audience/Participants:________________________________

Lesson/Unit Elements	Your Plan
Getting Attention: How will you begin this lesson to engage participants' attention? What is your hook? The **attention filter (RAS)** gives priority to sensory input that is different from the expected pattern. Novelty, such as changes in voice, unusual objects, songs playing when participants enter the classroom, and so on, will ignite their curiosity and increase the likelihood of the related lesson material being selected by the RAS attention filter.	

Lesson/Unit Elements	Your Plan
Building Top-Down Attentional Control: How will you build this top-down focus skill? Examples: doing slow observations and slow-paced activities, finding subtle differences, playing games requiring impulse control, practicing mindfulness, avoiding multitasking	
Positive Climate: What will you do to create a positive climate? How will you promote a culture in which participation and mistakes are encouraged? Examples: teaching social-emotional development, using restorative justice protocols **Building Top-Down Emotional Control:** How will you build emotional self-regulation? When students are in a positive emotional state, the information they learn may be directed by the **amygdala (emotional filter)** to flow to the **prefrontal cortex.** Examples: building emotional awareness; practicing mindfulness, visualization, and stress-reduction techniques; busting stereotypes; teaching students about their brains	

Lesson/Unit Elements	Your Plan
Motivation and Perseverance: Which dopamine boosters will be included in your lesson? **Dopamine** can promote pleasure, decrease stress, and boost curiosity, attention, and motivation. It also contributes to memory formation and retention. Dopamine boosters include music, being read to, humor, interacting with peers, movement, choice, optimism and kindness, gratitude, making correct predictions, and achieving challenges.	
Syn-Naps Brain Breaks: Where can you build in opportunities to shift modes of learning/processing in order to replenish neurotransmitters and encourage mental manipulation?	
Video Game Model **Buy-In:** How will you help participants see value and relevance in what they are learning? Buy-in examples include personal relevance, prediction, and performance tasks connecting to participants' interests and strengths.	

Lesson/Unit Elements	Your Plan
Video Game Model **Achievable Challenge:** How will you differentiate the lesson to address variations in participant readiness and interest? Differentiation allows students to work at their **achievable challenge level.** The students who understand the new topic, if required to keep reviewing with the group, may become **bored and therefore stressed.** If it is too challenging, they will become **frustrated.** By providing learning opportunities within their range of achievable challenge, students engage through the expectation of positive experiences.	

Lesson/Unit Elements	Your Plan
Video Game Model **Frequent Formative Assessment and Feedback:** How will you monitor participants' progress toward acquisition, meaning making, and transfer during the lesson? How will students get the feedback they need? How will participants be able to make use of feedback? Breaking down learning tasks into segments, in which students experience and are aware of success, builds confidence and encourages them to persevere toward their learning goals. Monitor and reflect upon progress frequently. Provide feedback to students regarding their goals. Students should have the opportunity to use feedback.	
Short-Term Memory Encoding: How will you activate prior knowledge to promote the brain's ability to acquire new input? Helping students to realize what they already know about a topic activates an existing memory pattern to which new input can link in the **hippocampus.** Examples: graphic organizers, cross-curricular units, bulletin boards	

Lesson/Unit Elements	Your Plan
Mental Manipulation for Long-Term Memory: How will students make meaning of learning so neuroplasticity constructs the neural connections of long-term memory? When students acquire information in a variety of ways through **multisensory learning** and "translate" learning into other representations (e.g., create a **narrative, symbolize** through a video, **categorize** by various criteria, **synthesize** into the concise summary of a tweet, or participate in an **authentic performance task**) the activation of the short-term memory increases its connections (dendrites, synapses, myelin) to construct long-term memory.	
Multisensory Learning: What opportunities will you provide for multisensory learning? Examples: visualization, movement, reading, listening, tactile exploration	
Executive Functions: Which additional executive function boosters will you embed in your lesson/unit?	

Lesson/Unit Elements	Your Plan
Goal Setting and Achieving: This function includes setting limits and sticking to realistic and manageable goals. Further, it involves using reflection, metacognition, and self-monitoring strategies to plan goals and resist impulsive choices that interfere with achieving them.	
Organizing: Understanding the logic of how information or materials are arranged and determining effective ways of arranging one's own space, materials, and academic output.	
Prioritizing: Distinguishing low-relevance details from the main ideas, deciding upon the most essential or important aspects of a paragraph or a project, and setting goals and determining the best order of tasks within a larger goal.	
Judgment/Reasoning: Navigating social and emotional choices and evaluating academic information; one's ability to interpret information and think logically based on prior knowledge, new information, pattern expectations, and deviation from expected patterns.	

Lesson/Unit Elements	Your Plan
Critical Analysis: Evaluating situations to determine the meaning of questions, what information needs to be gathered, what resources are needed to achieve success, and where to find the most valid sources of information.	
Cognitive Flexibility: Encourages students to be receptive and open-minded to new experiences, unfamiliar customs, variations of opinions and interpretations, alternative points of view, and multiple approaches to problem solving. Cognitive flexibility allows students to predict a variety of outcomes and assess changing data or additional information from multiple perspectives.	

Glossary

achievable challenge A level of difficulty for goals that is challenging yet attainable for an individual. *See also* **zone of proximal development.**

affective filter *See* **amygdala**

amygdala Part of the limbic system in the temporal lobe of the brain. It was first believed to function as a brain center for responding only to anxiety and fear. However, it is now believed to be related to many kinds of intense emotions. It appears to play a major role in emotional processing and impulsivity. In a stress state (which, for students, can mean feelings of stress, anxiety, frustration, or helplessness), the amygdala can become increasingly active (increased use of glucose and oxygen). In this state of overactivation, flow of new information through the amygdala into the hippocampus and the prefrontal cortex can be reduced.

axon The connection that extends from a neuron and carries an electrically coded message to the dendrites of other neurons.

brainstem Consisting of the midbrain, hindbrain, and diencephalon, the brainstem regulates our most primitive behaviors, such as breathing, sleep, sexual behavior, drinking, and eating.

buy-in Motivation and effort increase when the brain expects pleasure. Examples of factors related to buy-in include personal relevance, prediction, and learning activities connecting to students' interests and strengths.

cerebellum The hindbrain structure that controls motor coordination and coordinates movement.

cerebral cortex The outermost layers of the cerebrum where the highest density of neurons are found.

cognition Thinking and all of the mental processes related to thinking and awareness.

computed tomography (CT) scan A type of imaging method that produces a static image of the brain (or an image of the brain at rest).

control group The group in an experiment that is not experimented on. It receives either no manipulation or treatment, or receives a placebo.

correlation A connection or relationship between two or more things or sets of scientific data. Correlation between two things or situations is *not* the same as causation, in which one is proven to directly cause the other.

dendrites Branched extensions from neurons that receive electrical impulses from the axons of the neighboring neurons, thus connecting neurons into circuits of related information. A single neuron may possess many dendrites. Because new dendrites grow as branches from frequently activated neurons, the size and number of dendrites increase in response to experience and practice.

discrepant event Something that does not appear or turn out in the way the brain expects. The sense of disequilibrium experienced with a discrepant event can motivate students' attention and curiosity as the brain seeks an explanation for its incorrect prediction.

dopamine A neurotransmitter most associated with reward-stimulated learning. On neuroimaging, dopamine release has been found to increase in response to rewards and positive experiences. Scans reveal greater dopamine release while subjects are playing, laughing, exercising, and receiving acknowledgment (e.g., praise) for achievement.

dopamine-reward cycle In response to elevated dopamine release and circulation in the brain, an increase in pleasure, curiosity, attention, and motivation to pursue goals that are the source of the motivating arousal.

electroencephalography (EEG) A type of imaging method that records the electrical activity of the brain. It produces a dynamic image of an electrical representation of brain activity.

encoding The process by which the brain converts information into short-term memory.

executive functions The information-processing neural networks centered in the prefrontal cortex that allow us to exercise conscious control over emotions and thoughts. This processing includes top-down attention focus, emotional self-management, goal setting and achieving, prioritizing, organizing, judgment, reasoning, critical analysis, and cognitive flexibility.

experiment A scientific endeavor in which researchers manipulate one or more variables to determine what effect the manipulation has on another variable.

experimental group The group in an experiment that is experimented on. It receives some sort of treatment or manipulation.

extrinsic motivation Motivation that comes from the external world driven by a desire to get a tangible reward or outcome.

focused attention Intentional or effortful directing of one's attention to and focus on sensory input, information, or an experience.

frontal lobe The most anterior lobe of the cerebrum. It contains the motor cortex and centers of executive function that organize and arrange information and coordinates the production of language and the focusing of attention. *See also* **prefrontal cortex.**

functional magnetic resonance imaging (fMRI) A type of brain imaging method that uses magnetic fields to produce dynamic images of activity in the brain (usually using the amount of oxygen used in a brain region as measurement of its activity).

glial cells Non-neuronal cells in the nervous system. They nourish, support, and complement the activity of neurons in the brain.

goal-directed behavior Behavior that is directed toward the completion of a goal. It includes the ability to monitor one's progress toward the goal and make adjustments as needed in response to setbacks or new information.

gray matter A term referring to the brownish-gray color of the neurons (nerve cell bodies) and dendrites of the brain. Neurons are darker than other brain matter, so the cortex or outer layer of the brain, which has a high percentage of neurons, appears darker gray and is called gray matter.

growth mindset A state of mind in which we feel confident in our abilities to learn and change our brain.

hippocampus The structure in the brain where new sensory intake links with related information activated from long-term memory to encode new short-term memory.

inductive reasoning The ability to recognize or construct the rules or concepts drawn from existing information and understanding. Examples include evaluating the rules that appear to apply to situations and using those consistencies to make accurate predictions or interpret new, related information.

intrinsic motivation Pleasure or satisfaction resulting from one's own actions, predictions, or decisions without the need for external rewards. *See also* **dopamine-reward cycle.**

KWL A graphic organizer for a unit of instruction with columns to be filled in throughout the unit for What I (Think I) *Know*, What I *Want* to Know, and What I *Learned*.

limbic system A group of interconnected deep-brain structures, including the amygdala, hippocampus, and portions of the frontal and temporal lobes, involved in emotion, motivation, behavior, and reactions.

long-term memory A form of memory that lasts for an extended period of time. It is derived from connections that develop into strong interneural links when information is repeatedly activated by repetition or applying it to a task.

metacognition The ability to think about what we know; higher-order thinking that helps promote understanding and control of our cognition.

myelin Fat-protein layers that form sheaths around most axons to insulate them and protect the nerve fiber. Myelin increases speed of conduction of nerve impulses through the axon, resulting in more efficient access and retrieval of information.

myelination The formation of a myelin sheath around a nerve fiber, which insulates it and makes it more efficient.

nervous system One of the body's major organ systems, consisting of the brain, the spinal cord, and the extensive pathways of nervous tissue located throughout the body.

neural network Neurons communicating with each other in circuits by sending coded electrochemical messages through connections (axons, dendrites) and across synapses.

neuroimaging The use of techniques to directly or indirectly demonstrate the structure, function, or biochemical status of the brain. *Structural* neuroimaging reveals the overall structure of the brain; *functional* neuroimaging provides visualization of the processing of sensory information coming to the brain and of commands going from the brain to the body. This processing is visualized directly as areas of the brain "light up" in response to increased metabolism as measured by increased blood flow, oxygen use, or glucose uptake in the most active regions.

neuronal circuits Electrochemical connections through which neurons communicate with each other by sending coded messages. Repeated stimulation of specific patterns between the same group of neurons makes their connecting circuit more developed and more accessible to efficient stimulation and response (neuroplasticity). This is how practice results in more successful recall.

neurons Specialized cells in the brain and throughout the nervous system that conduct electrical impulses to, from, and within the brain. Neurons are composed of a main cell body, a single axon for outgoing electrical signals, and a varying number of dendrites for incoming signals in electrical form. An average adult brain has more than 80 billion neurons. Neurons are different from other cells because of their unique ability to communicate rapidly with one another over great distances and with great precision.

neuroplasticity The ability of synapses, neurons, dendrites, and the myelin-coated axons to change their properties in response to use (stimulation). When there is repeated stimulation of a circuit of linked neurons, the connections can become more developed and there is more efficient retrieval of the information they hold.

neurotransmitters Brain proteins that are released by the electrical impulses on one side of the synapse (axonal terminal) and then float across the synaptic gap carrying information to stimulate the nerve ending (dendrite) of the next cell in the pathway. Once the neurotransmitter is taken up by the dendrite nerve ending, the electric impulse is reactivated in that dendrite to travel along to the next neuron. Neurotransmitters in the brain include serotonin, tryptophan, acetylcholine, dopamine, and many others that transport information across synapses and also circulate through the brain. When neurotransmitters are depleted by too much information traveling through a nerve circuit without a break, the speed of transmission along the nerve can slow down to a less efficient level.

nucleus accumbens (NAc) A small structure deep in the limbic system on each side of the brain that holds a large quantity of dopamine, which it sends through channels into upper regions of the brain. The primary receiving area is in the prefrontal cortex, and the dopamine is released in response to feedback about the accuracy of a prediction (choice, answer, response, outcome).

occipital lobe The most posterior lobe of the cerebrum. It processes visual information.

outcome goals Larger overall achievement goals. They are best reached by meeting process goals along the way.

patterning The process whereby the brain perceives sensory data and generates patterns by relating new information with previously learned material. Education is about increasing the patterns that students can use, recognize, communicate, and apply to understand new, related information. Whenever new material is presented in such a way that students see relationships, they can more successfully connect the new learning with prior, related knowledge as more stable and extended memory networks are constructed.

positron emission tomography (PET) scan A type of imaging method that measures blood flow to different areas of the brain by injecting patients with a radioactive isotope. As brain areas become active, more blood flows to the particular brain area carrying the isotope linked to glucose.

prefrontal cortex A hub of neural networks with intake and output to almost all other regions of the brain. In the prefrontal cortex, long-term memories are constructed and emotions can be consciously evaluated. This anterior region of the frontal lobe also holds neural networks of executive functions.

prior knowledge Information that students have already acquired through formal teaching, personal experience, or real-world associations that is stored in their long-term memory banks.

pruning The process by which neurons are destroyed when they are not used. In a baby, the brain overproduces brain cells (neurons) and connections between brain cells (synapses), and then starts pruning them around the age of 3. The second wave of synapse formation occurs just before puberty and is followed by another phase of pruning. Pruning allows the brain to consolidate learning by removing unused neurons and synapses and wrapping white matter (myelin) around the axons in the neuronal networks that are more frequently used to stabilize and strengthen them.

receptor sites Locations on the dendrites of a postsynaptic neuron that are specialized to bind with a particular neurotransmitter molecule.

reticular activating system (RAS; reticular formation) A group of neurons located in the brainstem that alerts the forebrain to important stimuli. This lower part of the posterior brain filters all incoming stimuli and makes the "decision" as to what sensory input is attended to or ignored. The main categories that focus the attention of the RAS include novelty (changes in the environment), surprise, danger, and movement.

scaffolding Providing different levels of support during instruction to respond to the individual needs of students. Rather than simplifying the goal, the instructor provides alternative ways for progressing to mastery that are well suited to the learner's level of achievable challenge.

schema A mental representation of how something occurs. Creating a schema occurs when an individual organizes many elements into one category or concept.

scientific method A procedure for conducting and carrying out research. It includes making observations, asking questions, forming a hypothesis, creating an experiment, recording and analyzing results, and making conclusions.

serotonin A neurotransmitter in the brain involved in learning, memory, mood regulation, attention, sleep, and arousal level.

short-term memory A form of memory that represents new input linked with existing memory through pattern linking.

synapse (synaptic gap) A space that separates the axon extensions of one neuron from the dendrite that leads to the next neuron involved in information transfer. Neurotransmitters such as dopamine carry information across the space. Before and after crossing the synapse as a chemical message, information is carried in an electrical state when it travels down the nerve.

synaptic vesicles Sacs located at the terminal end of axons, just before the synapse, containing neurotransmitters. The electrical action potential that reaches the end of the axon cannot travel across as an electrical impulse. The neurotransmitters, held in synaptic vesicles at the end of the axon, respond to the electrical impulse by transporting the information across the synapse to dock at the dendrite.

temporal lobe The most inferior lobe of the cerebrum. It is key to auditory processing and contains the hippocampus and the amygdala.

top-down processing Processing of information by the brain directed by higher cognition or executive functions. For example, top-down processing for attention focus refers to our ability to intentionally direct our attention to a particular stimulus, sensory input, or object in the environment.

validity The accuracy of the measurements in a study or how well a test measures what it says it measures.

white matter Connections between neurons, including myelinated axons (thicker white connections) and support cells called *glia* that are found in a layer just under the brain's gray matter. It makes up the bulk of the deep parts of the brain.

working memory An element of short-term memory that allows individuals to hold incoming information in mind while actively working on it (such as holding the procedural memory of doing long division while applying these steps to solve a problem). It is limited in capacity.

zone of proximal development The difference between a learner's actual developmental level and that learner's potential to develop. This zone represents abilities in the learner that are in the process of progressing.

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About the Authors

Judy Willis, MD, MEd, is a board-certified neurologist who combined her 15 years as a practicing neurologist with 10 subsequent years as a classroom teacher to become a leading authority in the neuroscience of learning. With her unique background in both neuroscience and education, she has written 9 books and more than 200 articles about applying neuroscience research to classroom teaching strategies.

After graduating Phi Beta Kappa as one of the first seven women to graduate from Williams College, Willis attended UCLA School of Medicine, where she was awarded her medical degree. She remained at UCLA and completed a medical residency and neurology residency, including chief residency. She practiced neurology for 15 years before returning to university to obtain her teaching credential and master's degree in education from the University of California, Santa Barbara. She then taught in elementary and middle school for 10 years.

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Malana Willis, MEd, has taught elementary school across the grade levels in Oakland and Santa Barbara, California. She taught at the American School of Bilbao in Spain and worked at the Koegel Autism Center at the University of California, Santa Barbara. She received her master's degree in education and multiple-subject teaching credential from the University of California, Berkeley, and her BA in psychology from Williams College. Willis presents annually at the Learning and the Brain summer institute in Santa Barbara, California, and has been writing and presenting with her mother, Dr. Judy Willis, on the neuroscience of learning since 2010.

Related ASCD Resources

At the time of publication, the following resources were available (ASCD stock numbers in parentheses).

Print Products

Attack of the Teenage Brain! Understanding and Supporting the Weird and Wonderful Adolescent Learner by John Medina (#118024)

Engage the Brain: How to Design for Learning That Taps into the Power of Emotion by Allison Posey (#119015)

How to Teach So Students Remember, 2nd ed. by Marilee Sprenger (#118016)

The Power of the Adolescent Brain: Strategies for Teaching Middle and High School Students by Thomas Armstrong (#116017)

Teaching Students to Drive Their Brains: Metacognitive Strategies, Activities, and Lesson Ideas by Donna Wilson and Marcus Conyers (#117002)

Upgrade Your Teaching: Understanding by Design Meets Neuroscience by Jay McTighe and Judy Willis (#119008)

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Research-Based Strategies to Ignite Student Learning relates to the **engaged** and **challenged** tenets.

*For more about the ASCD Whole Child approach, visit **www.ascd.org/wholechild.***

WHOLE CHILD TENETS

1. **HEALTHY**
   Each student enters school healthy and learns about and practices a healthy lifestyle.

2. **SAFE**
   Each student learns in an environment that is physically and emotionally safe for students and adults.

3. **ENGAGED**
   Each student is actively engaged in learning and is connected to the school and broader community.

4. **SUPPORTED**
   Each student has access to personalized learning and is supported by qualified, caring adults.

5. **CHALLENGED**
   Each student is challenged academically and prepared for success in college or further study and for employment and participation in a global environment.

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Thanks to unprecedented advances in brain science, we know more about the brain today than ever before. But what does that science tell us about how we learn? How can we capture the power of neuroscience research so that it benefits our students?

Judy Willis and Malana Willis answer these questions with clarity and insight, translating recent research on the brain and learning into understandable concepts and practical strategies to use across the curriculum, spanning all grade levels from preK through postsecondary.

In this revised and expanded edition of the best-selling *Research-Based Strategies to Ignite Student Learning*, readers will learn how to

- Arouse students' curiosity and interest in pursuing wide-ranging topics, including those they might typically find boring.
- Counteract the negative effects of stress, boredom, and frustration on memory.
- Defuse undesirable behaviors that are the result of the brain's natural "fight/flight/freeze" response.
- Incorporate the motivating characteristics of video gaming—including clear goals, achievable challenges, predictions, and continual feedback—into classroom learning.
- Break through stereotypes that deter students from reaching their full potential.
- Use the power of neuroscience research to develop students' executive function skills, such as focus, prioritization, organization, collaboration, critical analysis, and innovation.

Willis and Willis describe how the brain converts a vast amount of sensory input into long-term memory and durable understanding—and how educators can use this knowledge to guide students to more successful experiences in school and beyond.

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