PROUST *and* the SQUID

The STORY *and* SCIENCE *of the* READING BRAIN

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I dedicate this book to all the members of my family . . . past, present, and still to come

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PART I

HOW *the* BRAIN LEARNED *to* READ

Words and music are the tracks of human evolution.
—John S. Dunne

Knowing how something originated often is
the best clue to how it works.
—Terrence Deacon

Chapter 1

READING LESSONS FROM PROUST AND THE SQUID

I believe that reading, in its original essence, [is] that fruitful miracle of a communication in the midst of solitude.

—Marcel Proust

Learning involves the nurturing of nature.

—Joseph LeDoux

We were never born to read. Human beings invented reading only a few thousand years ago. And with this invention, we rearranged the very organization of our brain, which in turn expanded the ways we were able to think, which altered the intellectual evolution of our species. Reading is one of the single most remarkable inventions in history; the ability to record history is one of its consequences. Our ancestors' invention could come about only because of the human brain's extraordinary ability to make new connections among its existing structures, a process made possible by the brain's ability to be shaped by experience. This plasticity at the heart of the brain's design forms the basis for much of who we are, and who we might become.

This book tells the story of the reading brain, in the context of our unfolding intellectual evolution. That story is changing before our eyes and under the tips of our fingers. The next few decades will witness transformations in our ability to communicate, as we recruit new connections in the brain that will propel our intellectual development in new and different ways. Knowing what reading demands of our brain and knowing how it contributes to our capacity to think, to feel, to infer, and to understand other human beings is especially important today as we make the transition from a reading brain to an increasingly digital one. By coming to understand how reading evolved historically, how it is acquired by a child, and how it restructured its biological underpinnings in the brain, we can shed new light on our wondrous complexity as a literate species. This places in sharp relief what may happen next in the evolution of human intelligence, and the choices we might face in shaping that future.

This book consists of three areas of knowledge: the early history of how our species learned to read, from the time of the Sumerians to Socrates; the developmental life cycle of humans as they learn to read in ever more sophisticated ways over time; and the story and science of what happens when the brain can't learn to read. Taken together, this cumulative knowledge about reading both celebrates the vastness of our accomplishment as the species that reads, records, and goes beyond what went before, and directs our attention to what is important to preserve.

There is something less obvious that this historical and evolutionary view of the reading brain gives us. It provides a very old and very new approach to how we teach the most essential aspects of the reading process—both for those whose brains are poised to acquire it and for those whose brains have systems that may be organized differently, as in the reading disability known as dyslexia. Understanding these unique hardwired systems—which are preprogrammed generation after generation by instructions from our genes—advances our knowledge in unexpected ways that have implications we are only beginning to explore.

Interwoven through the book's three parts is a particular view of how the brain learns anything new. There are few more powerful mirrors of the human brain's astonishing ability to rearrange itself to learn a new intellectual function than the act of reading. Underlying the brain's ability to learn reading lies its protean capacity to make new connections among structures and circuits originally devoted to other more basic brain processes that have enjoyed a longer existence in human evolution, such as vision and spoken language. We now know that groups of neurons create new connections and pathways among themselves every time we acquire a new skill. Computer scientists use the term "open architecture" to describe a system that is versatile enough to change—or rearrange—to accommodate the varying demands on it. Within the constraints of our genetic legacy, our brain presents a beautiful example of open architecture. Thanks to this design, we come into the world programmed with the capacity to change what is given to us by nature, so that we can go beyond it. We are, it would seem from the start, genetically poised for breakthroughs.

Thus the reading brain is part of highly successful two-way dynamics. Reading can be learned only because of the brain's plastic design, and when reading takes place, that individual brain is forever changed, both physiologically and intellectually. For example, at the neuronal level, a person who learns to read in Chinese uses a very particular set of neuronal connections that differ in significant ways from the pathways used in reading English. When Chinese readers first try to read in English, their brains attempt to use Chinese-based neuronal pathways. The act of learning to read Chinese characters has literally shaped the Chinese reading brain. Similarly, much of how we think and what we think about is based on insights and associations generated from what we read. As the author Joseph Epstein put it, "A biography of any literary person ought to deal at length with what he read and when, for in some sense, *we are what we read*."

These two dimensions of the reading brain's development and evolution—the personal-intellectual and the biological—are rarely described together, but there are critical and wonderful lessons to be discovered in doing just that. In this book I use the celebrated French novelist Marcel Proust as metaphor and the largely underappreciated squid as analogy for two very different aspects of reading. Proust saw reading as a kind of intellectual "sanctuary," where human beings have access to thousands of different realities they might never encounter or understand otherwise. Each of these new realities is capable of transforming readers' intellectual lives without ever requiring them to leave the comfort of their armchairs.

Scientists in the 1950s used the long central axon of the shy but cunning squid to understand how neurons fire and transmit to each other, and in some cases to see how neurons repair and compensate when something goes awry. At a different level of study, cognitive neuroscientists today investigate how various cognitive (or mental) processes work in the brain. Within this research, the reading process offers an example par excellence of a recently acquired cultural invention that requires something new from existing structures in the brain. The study of what the human brain has to do to read, and of its clever ways of adapting when things go wrong, is analogous to the study of the squid in earlier neuroscience.

Proust's sanctuary and the scientist's squid represent complementary ways of understanding different dimensions in the reading process. Let me introduce you more concretely to the approach of this book by having you read two of Proust's breath-defying sentences from his book *On Reading*, as fast as you can.

> There are perhaps no days of our childhood we lived so fully as those . . . we spent with a favorite book. Everything that filled them for others, so it seemed, and that we dismissed as a vulgar obstacle to a *divine pleasure*: the game for which a friend would come to fetch us at the most interesting passage; the troublesome bee or sun ray that forced us to lift our eyes from the page or to change position; the provisions for the afternoon snack that we had been made to take along and that we left beside us on the bench without touching, while above our head the sun was diminishing in force in the blue sky; the dinner we had to return home for, and during which we thought only of going up immediately afterward to finish

> the interrupted chapter, all those things with which reading should have kept us from feeling anything but annoyance, on the contrary they have engraved in us so sweet a memory (so much more precious to our present judgment than what we read then with such love), that if we still happen today to leaf through those books of another time, it is for no other reason than that they are the only calendars we have kept of days that have vanished, and we hope to see reflected on their pages the dwellings and the ponds which no longer exist.

Consider first what you were thinking while reading this passage, and then try to analyze exactly what you did as you read it, including how you began to connect Proust to other thoughts. If you are like me, Proust conjured up your own long-stored memories of books: the secret places you found to read away from the intrusions of siblings and friends; the thrilling sensations elicited by Jane Austen, Charlotte Brontë, and Mark Twain; the muffled beam of the flashlight you hoped your parent wouldn't notice beneath the sheets. This is Proust's reading sanctuary, and it is ours. It is where we first learned to roam without abandon through Middle Earth, Lilliput, and Narnia. It is the place we first tried on the experiences of those we would never meet: princes and paupers, dragons and damsels, !Kung warriors, and a Dutch-Jewish girl hiding with her family from Nazi soldiers.

It is said that Machiavelli would sometimes prepare to read by dressing up in the period of the writer he was reading and then setting a table for the two of them. This was his sign of respect for the author's gift, and perhaps of Machiavelli's tacit understanding of the sense of encounter that Proust described. While reading, we can leave our own consciousness, and pass over into the consciousness of another person, another age, another culture. "Passing over," a term used by the theologian John Dunne, describes the process through which reading enables us to try on, identify with, and ultimately enter for a brief time the wholly different perspective of another person's consciousness. When we pass over into how a knight thinks, how a slave feels, how a heroine behaves, and how an evildoer can regret or deny wrongdoing, we never come back quite the same; sometimes we're inspired, sometimes saddened, but we are always enriched. Through this exposure we learn both the commonality and the uniqueness of our own thoughts—that we are individuals, but not alone.

The moment this happens, we are no longer limited by the confines of our own thinking. Wherever they were set, our original boundaries are challenged, teased, and gradually placed somewhere new. An expanding sense of "other" changes who we are, and, most importantly for children, what we imagine we can be.

Let's go back to what you did when I asked you to switch your attention from this book to Proust's passage and to read as fast as you could without losing Proust's meaning. In response to this request, you engaged an array of mental or cognitive processes: attention; memory; and visual, auditory, and linguistic processes. Promptly, your brain's attentional and executive systems began to plan how to read Proust speedily and still understand it. Next, your visual system raced into action, swooping quickly across the page, forwarding its gleanings about letter shapes, word forms, and common phrases to linguistic systems awaiting the information. These systems rapidly connected subtly differentiated visual symbols with essential information about the sounds contained in words. Without a single moment of conscious awareness, you applied highly automatic rules about the sounds of letters in the English writing system, and used a great many linguistic processes to do so. This is the essence of what is called the alphabetic principle, and it depends on your brain's uncanny ability to learn to connect and integrate at rapid-fire speeds what it sees and what it hears to what it knows.

As you applied all these rules to the print before you, you activated a battery of relevant language and comprehension processes with a rapidity that still astounds researchers. To take one example from the language domain, when you read the 233 words in Proust's passage, your word meaning, or semantic, systems contributed every possible meaning of each word you read and incorporated the exact correct meaning for each word in its context. This is a far more complex and intriguing process than one might think. Years ago, the cognitive scientist David Swinney helped uncover the fact that when we read a simple word like "bug," we activate not only the more common meaning (a crawling, six-legged creature), but also the bug's less frequent associations—spies, Volkswagens, and glitches in software. Swinney discovered that the brain doesn't find just one simple meaning for a word; instead it stimulates a veritable trove of knowledge about that word and the many words related to it. The richness of this semantic dimension of reading depends on the riches we have already stored, a fact with important and sometimes devastating developmental implications for our children. Children with a rich repertoire of words and their associations will experience any text or any conversation in ways that are substantively different from children who do not have the same stored words and concepts.

Think about the implications of Swinney's finding for texts as simple as Dr. Seuss's *Oh, The Places You'll Go!* or as semantically complex as James Joyce's *Ulysses.* Children who have never left the narrow boundaries of their neighborhood, either figuratively or literally, may understand this book in entirely different ways from other children. We bring our entire store of meanings to whatever we read—or not. If we apply this finding to the passage from Proust that you just read, it means that your executive planning system directed a great many activities to ensure that you comprehended what was there, and retrieved all your personal associations to the text. Your grammatical system had to work overtime to avoid stumbling over Proust's unfamiliar sentence constructions, like his use of long clauses strung together by many commas and semicolons before the predicate. To accomplish all this without forgetting what you already read fifty words back, your semantic and grammatical systems had to function closely with your working memory. (Think of this type of memory as a kind of "cognitive blackboard," which temporarily stores information for you to use in the near term.) Proust's unusually sequenced grammatical information had to be connected to the meanings of individual words without losing track of the overall propositions and context of the passage.

As you linked all this linguistic and conceptual information, you generated your own inferences and hypotheses based on your own background knowledge and engagement. If this cumulative information failed to make sense, you might have reread some parts to ensure that they fit within the given context. Then, after you integrated all this visual, conceptual, and linguistic information with your background knowledge and inferences, you arrived at an understanding of what Proust was describing: a glorious day in childhood made timeless through the "divine pleasure" that is reading!

Then, some of you paused at the end of Proust's passage and went somewhere beyond what the text provided. But before tackling this more philosophical point, let's turn back to the biological dimension and look immediately below the surface of the behavioral act of reading. All human behaviors rest on layers on layers of teeming, underlying activity. I asked the neuroscientist and artist Catherine Stoodley of Oxford to draw a pyramid to illustrate how these various levels operate together when we read a single word (Figure 1-1). In the top layer of this pyramid, reading the word "bear" is the surface behavior; below it is the cognitive level, which consists of all those basic attentional, perceptual, conceptual, linguistic, and motor processes you just used to read. These cognitive processes, which many psychologists spend their entire lives studying, rest on tangible neurological structures that are made up of neurons built up and then guided by the interaction between genes and the environment. In other words, all human *behaviors* are based on multiple *cognitive* processes, which are based on the rapid integration of information from very specific *neurological structures*, which rely on billions of *neurons* capable of trillions of possible connections, which are programmed in large part by *genes*. In order to learn to work together to perform our most basic human functions, neurons need instructions from genes about how to form efficient *circuits* or *pathways* among the neurological structures.

This pyramid functions like a three-dimensional map for understanding how any genetically programmed behavior, such as vision, happens. It does not explain, however, how it can be ap-

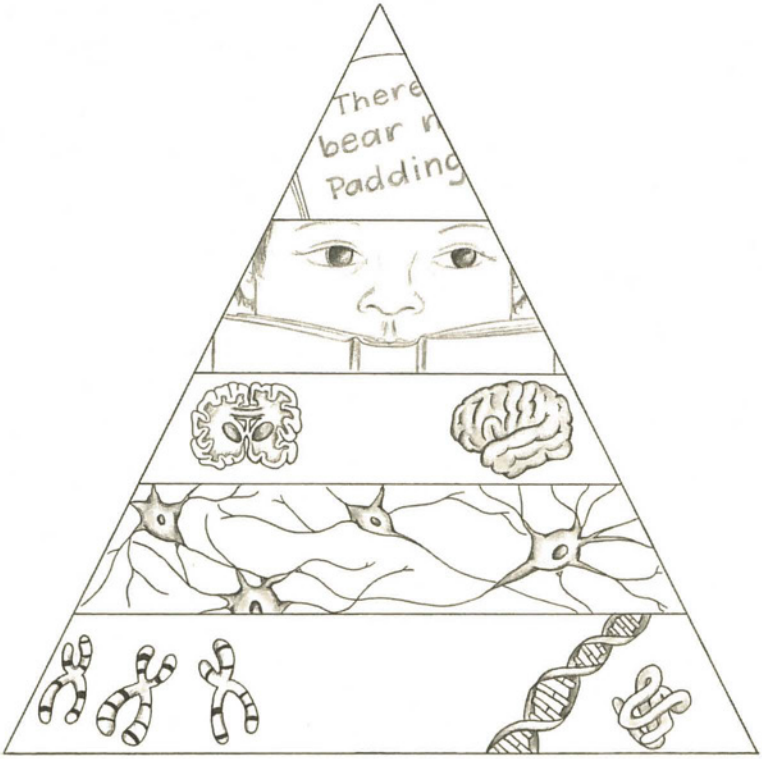

Figure 1-1: Pyramid of Reading

plied to a reading circuit, because there are no genes specific only to reading in the bottom layer. Unlike its component parts such as vision and speech, which *are* genetically organized, reading has no direct genetic program passing it on to future generations. Thus the next four layers involved must learn how to form the necessary pathways anew every time reading is acquired by an individual brain. This is part of what makes reading—and any cultural invention—different from other processes, and why it does not come as naturally to our children as vision or spoken language, which are preprogrammed.

How, then, did the first time ever occur? The French neuroscientist Stanislas Dehaene tells us that the first humans who invented writing and numeracy were able to do this by what he calls "neuronal recycling." For example, in his work with primates, Dehaene shows that if you put two plates of bananas in front of a monkey—one with two bananas and one with four—an area in the monkey's posterior cortex will activate just before he grasps the more bountiful plate. This same general area is one of the regions of the brain we humans now use for some mathematical operations. Similarly, Dehaene and his colleagues argue that our ability to recognize words in reading uses the species' evolutionarily older circuitry that is specialized for object recognition. Furthermore, just as our ancestors' capacity to distinguish between predator and prey at a glance drew on an innate capacity for visual specialization, our ability to recognize letters and words may involve an even further in-built capacity that allows "specialization within a specialization."

If one were to expand Dehaene's view somewhat, it would seem more than likely that the reading brain exploited older neuronal pathways originally designed not only for vision but for connecting vision to conceptual and linguistic functions: for example, connecting the quick recognition of a shape with the rapid inference that this footprint can signal danger; connecting a recognized tool, predator, or enemy with the retrieval of a word. When confronted, therefore, with the task of inventing functions like literacy and numeracy, our brain had at its disposal three ingenious design principles: the capacity to make new connections among older structures; the capacity to form areas of exquisitely precise specialization for recognizing patterns in information; and the ability to learn to recruit and connect information from these areas automatically. In one way or another, these three principles of brain organization are the foundation for all of reading's evolution, development, and failure.

The elegant properties of the visual system provide an excellent example of how recycling existing visual circuits made the development of reading possible. Visual cells possess the capacity to become highly specialized and highly specific, and to make new circuits among preexisting structures. This allows babies to come into the world with eyes that are almost ready to fire and that are exceptional examples of design and precision. Soon after birth, each neuron in the eye's retina begins to correspond to a specific set of cells in the occipital lobes. Because of this design feature in our visual system, called retinotopic organization, every line, diagonal, circle, or arc seen by the retina in the eye activates a specific, specialized location in the occipital lobes in a split second (Figure 1-2).

This quality of the visual system is somewhat different from why our Cro-Magnon ancestors could identify animals on the distant horizon, why many of us can identify the model of a car a quarter-mile away, and why bird-watchers can identify a tern other people may not even see. Dehaene suggests that the visual areas in our ancestors' brains responsible for object recognition

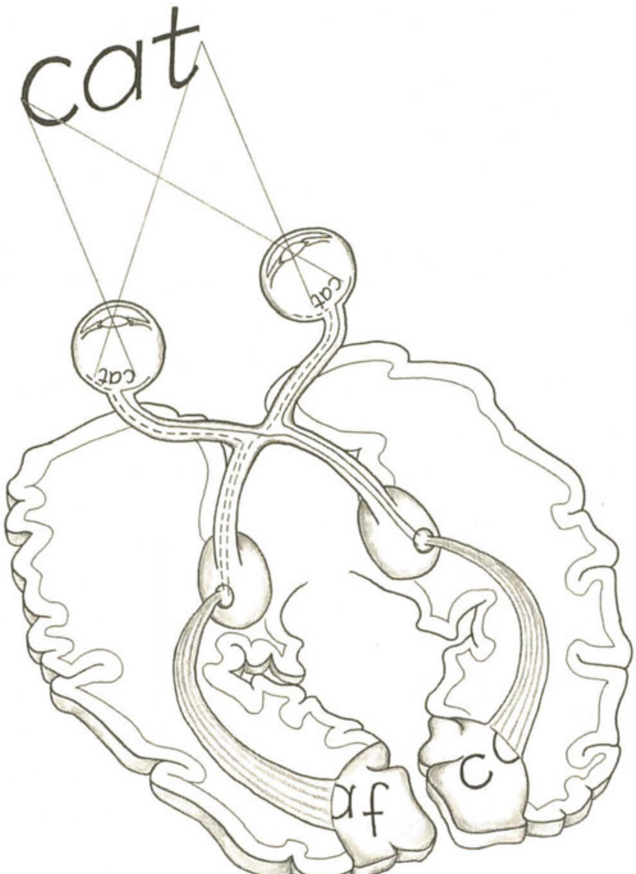

Figure 1-2: Visual Systems

were used to decipher the first symbols and letters of written language by adapting their built-in system for recognition. Critically, the combination of several innate capacities—for adaptation, for specialization, and for making new connections—allowed our brain to make new pathways between visual areas and those areas serving the cognitive and linguistic processes that are essential to written language.

The third principle exploited by reading—the capacity of the neuronal circuits to become virtually automatic—incorporates the other two. This is what allowed you to fly across Proust's passage and understand what you read. Becoming virtually automatic does not happen overnight and is not a characteristic of either a novice bird-watcher or a young novice reader. These circuits and pathways are created through hundreds or, in the case of some children with reading disabilities like dyslexia, thousands of exposures to letters and words. The neuronal pathways for recognizing letters, letter patterns, and words become automatic thanks to retinotopic organization, object recognition capacities, and to one other extremely important dimension of brain organization: our ability to *represent* highly learned patterns of information in our specialized regions. For example, as the networks of cells responsible for recognizing letters and letter patterns learn to "fire together," they create representations of their visual information that are far more rapidly retrieved.

Fascinatingly, networks of cells that have learned to work together over a long time produce representations of visual information, even when this information isn't in front of us. In an illuminating experiment by Harvard cognitive scientist Stephen Kosslyn, adult readers in a brain scanner were asked to close their eyes and imagine certain letters. When they were asked about capital letters, discrete regions responsible for one part of the visual field in the visual cortex responded; lowercase letters triggered other discrete areas. Thus merely imagining letters results in activation of particular neurons in our visual cortex. For the expert reading brain, as information enters through the retina, all the physical properties of the letters are processed by an array of specialized neurons that feed their information automatically deeper and deeper into other visual processing areas. They are part and parcel of the virtual automaticity of the reading brain, in which all its representations and indeed all its individual processes—not just visual ones—become rapid-fire and effortless.

What happens between our first exposure to letters and expert reading is very important to scientists because it offers a unique opportunity to watch the orderly development of a cognitive process. The various features that characterize the visual system—enlisting older genetically programmed structures, recognizing patterns, creating discrete working groups of specialized neurons for particular representations, making circuit connections with great versatility, and achieving fluency through practice—are similar in all the other major cognitive and linguistic systems involved in reading. I will elaborate on this later, but first I want to highlight a marvelous (and hardly coincidental) analogue between what happens in the brain and what happens in the internal thoughts of every reader.

In much the way reading reflects the brain's capacity for going beyond the original design of its structures, it also reflects the reader's capacity to go beyond what is given by the text and the author. As your brain's systems integrated all the visual, auditory, semantic, syntactic, and inferential information from Proust's passage about a single day in childhood with a beloved book, you, the reader, automatically began to connect what Proust wrote with your own thinking and personal insights.

I cannot, of course, describe where your thoughts went, but I can describe mine. Because I had just visited an exhibit at the Boston Museum of Fine Arts on Monet and impressionism, I found myself connecting how Proust wrote about a single day in his childhood with how Monet painted *Impression: Sunrise*. Both Proust and Monet used pieces of information to render a composite that made a more vivid impression than if they had created a perfect reproduction. In so doing, both artist and novelist are examples of Emily Dickinson's enigmatic charge to "tell all the Truth, but tell it slant—/Success in Circuit lies."

Emily Dickinson never envisioned neuronal circuits when she wrote those lines, but it turns out that she was as astute physiologically as she was poetically. By using indirect approaches, Proust and Monet force their readers and viewers to contribute actively to the constructions themselves, and in the process to experience them more directly. Reading is a neuronally and intellectually circuitous act, enriched as much by the unpredictable indirections of a reader's inferences and thoughts, as by the direct message to the eye from the text.

This unique aspect of reading has begun to trouble me considerably as I consider the Google universe of my children. Will the constructive component at the heart of reading begin to change and potentially atrophy as we shift to computer-presented text, in which massive amounts of information appear instantaneously? In other words, when seemingly complete visual information is given almost simultaneously, as it is in many digital presentations, is there either sufficient time or sufficient motivation to process the information more inferentially, analytically, and critically? Is the act of reading dramatically different in such contexts? The basic visual and linguistic processes might be identical, but would the more time-demanding, probative, analytical, and creative aspects of comprehension be foreshortened? Or does the potential added information from hyperlinked text contribute to the development of children's thinking? Can we preserve the constructive dimension of reading in our children alongside their growing abilities to perform multiple tasks and to integrate ever-expanding amounts of information? Should we begin to provide explicit instruction for reading multiple modalities of text presentation to ensure that our children learn multiple ways of processing information?

I stray with these questions. But indeed we stray often when we read. Far from being negative, this associative dimension is part of the generative quality at the heart of reading. One hundred fifty years ago Charles Darwin saw in creation a similar principle, whereby "endless" forms evolve from finite principles: "From so simple a beginning, endless forms most beautiful and most wonderful have been, and are being evolved." So it is with written language. Biologically and intellectually, reading allows the species to go "beyond the information given" to create endless thoughts most beautiful and wonderful. We must not lose this essential quality in our present moment of historical transition to new ways of acquiring, processing, and comprehending information.

To be sure, the relationship between readers and text differs across cultures and across history. Thousands of lives have been altered or lost depending on whether a sacred text like the Bible is read in a concrete, literal way or in a generative, interpretative way. Martin Luther's act of translating the Latin Bible into the German language, which permitted ordinary people to read and interpret it for themselves, significantly influenced the history of religion. Indeed, as some historians observe, the changing relationship of readers to text over time can be seen as one index of the history of thought.

The thrust of this book, however, will be more biological and cognitive than cultural-historical. Within that context, the generative capacity of reading parallels the fundamental plasticity in the circuit wiring of our brains: both permit us to go beyond the particulars of the given. The rich associations, inferences, and insights emerging from this capacity allow, and indeed invite, us to reach beyond the specific content of what we read to form new thoughts. In this sense reading both reflects and reenacts the brain's capacity for cognitive breakthroughs.

Proust said most of this, if more obliquely, in a powerful description of the ability of reading to elicit our own thinking.

> We feel quite truly that our wisdom begins where that of the author ends, and we would like to have him give us answers, while all he can do is give us desires. And these desires he can arouse in us only by making us contemplate the supreme beauty which the last effort of his art has permitted him to reach. But by . . . a law which perhaps signifies that we can receive the truth from nobody, and that we must create it ourselves, that which is the end of their wisdom appears to us as but the beginning of ours.

Proust's understanding of the generative nature of reading contains a paradox: the goal of reading is to go beyond the author's ideas to thoughts that are increasingly autonomous, transformative, and ultimately independent of the written text. From the child's first, halting attempts to decipher letters, the experience of reading is not so much an end in itself as it is our best vehicle to a transformed mind, and, literally and figuratively, to a changed brain.

Ultimately, the biological and intellectual transformations brought about by reading provide a remarkable petri dish for examining how we think. Such an examination requires multiple perspectives—ancient and modern linguistics, archaeology, history, literature, education, psychology, and neuroscience. The goal of this book is to integrate these disciplines to present new perspectives on three aspects of written language: the evolution of the reading brain (how the human brain learned to read); its development (how the young brain learns to read and how reading changes us); and its variations (when the brain can't learn to read).

How the Brain Learned to Read

We will begin in Sumer, Egypt, and Crete, where the still mysterious beginnings of written language can be found among Sumerian cuneiform, Egyptian hieroglyphs, and some recently discovered proto-alphabetic scripts. Each major type of writing invented by our ancestors demanded something a little different from the brain, and this may explain why more than 2,000 years elapsed between these earliest known writing systems and the remarkable, almost perfect alphabet developed by the ancient Greeks. At its root the alphabetic principle represents the profound insight that each word in spoken language consists of a finite group of individual sounds that can be represented by a finite group of individual letters. This seemingly innocent-sounding principle was totally revolutionary when it emerged over time, for it created the capacity for every spoken word in every language to be translated into writing.

Why Socrates directed all his legendary rhetorical skills against the Greek alphabet and the acquisition of literacy is one of the great, largely untold stories in the history of reading. In words unerringly prescient today, Socrates described what would be lost to human beings in the transition from oral to written culture. Socrates' protests—and the silent rebellion of Plato as he recorded every word—are notably relevant today as we and our children negotiate our own transition from a written culture to one that is increasingly driven by visual images and massive streams of digital information.

How the Young Brain Learns to Read and How We Are Changed over the Life Span

Several thought-provoking links connect the history of writing in the species to the development of reading in the child. The first is the fact that although it took our species roughly 2,000 years to make the cognitive breakthroughs necessary to learn to read with an alphabet, today our children have to reach those same insights about print in roughly 2,000 days. The second concerns the evolutionary and educational implications of having a "rearranged" brain for learning to read. If there are no genes specific only to reading, and if our brain has to connect older structures for vision and language to learn this new skill, every child in every generation has to do a lot of work. As the cognitive scientist Steven Pinker eloquently remarked, "Children are wired for sound, but print is an optional accessory that must be painstakingly bolted on." To acquire this unnatural process, children need instructional environments that support all the circuit parts that need bolting for the brain to read. Such a perspective departs from current teaching methods that focus largely on only one or two major components of reading.

Understanding the period in development stretching from infancy to young adulthood necessitates an understanding of the full range of circuit parts in the reading brain and their development. It also involves a tale of two children, both of whom must acquire hundreds upon hundreds of words, thousands of concepts, and tens of thousands of auditory and visual perceptions. These are the raw materials for developing the major components of reading. Owing largely to their environments, however, one child will acquire these essentials, and the other will not. Through no fault of their own, the needs of thousands of children go unmet every day.

Learning to read begins the first time an infant is held and read a story. How often this happens, or fails to happen, in the first five years of childhood turns out to be one of the best predictors of later reading. A little-discussed class system invisibly divides our society, with those families that provide their children environments rich in oral and written language opportunities gradually set apart from those who do not, or cannot. A prominent study found that by kindergarten, a gap of 32 million words already separates some children in linguistically impoverished homes from their more stimulated peers. In other words, in some environments the average young middle-class child hears 32 million more spoken words than the young underprivileged child by age five.

Children who begin kindergarten having heard and used thousands of words, whose meanings are already understood, classified, and stored away in their young brains, have the advantage on the playing field of education. Children who never have a story read to them, who never hear words that rhyme, who never imagine fighting with dragons or marrying a prince, have the odds overwhelmingly against them.

Knowledge about the precursors of reading can help change that situation. Thanks to remarkable new technologies, we can now see what happens if all goes right in the acquisition of reading, as a child moves from decoding a word like "cat" to the fluent, seemingly effortless comprehension of "a feline creature named Mephistopheles." We find a series of predictable phases that a human passes through across the life span, illustrating just how different the circuits and requirements of a new reader's brain are from those of an expert reader, who navigates the tangled worlds of *Moby-Dick, War and Peace*, and texts on economics. Our growing knowledge about how the brain learns to read over time can help predict, ameliorate, and prevent some forms of unnecessary reading failure. Today, we possess sufficient knowledge about the components of reading to be able not only to diagnose almost every child in kindergarten at risk of a learning difficulty, but also to teach most children to read. This same knowledge underscores what we do not wish to lose in the achievement of the reading brain, just as the digital epoch begins to make new and different demands on that brain.

When the Brain Can't Learn to Read

Knowledge about reading failure provides a different angle on this knowledge base, with some surprises for anyone who looks there. From the viewpoint of science, dyslexia is a bit like studying a young squid that can't swim very fast. This squid's different wiring can teach us both about what is necessary for swimming and about the unique gifts this squid must have to be able to survive and flourish without swimming like every other squid. My colleagues and I use a variety of tools, from naming letters to brain imaging, to understand why so many children with dyslexia, including my own firstborn son, have difficulty not only with reading but also with seemingly simple linguistic behaviors like discriminating individual sounds or phonemes within words, or quickly retrieving the name of a color. By tracking activity in the brain as it performs these various behaviors in normal development and in dyslexia, we are constructing living maps of the neuronal landscape.

The surprises on this landscape increase daily. Recent advances in neuroimaging research begin to paint a different picture of the brain of a person with dyslexia that may have enormous implications for future research, and particularly for intervention. Understanding these advances can make the difference between having a huge number of our future citizens poised to contribute to society and having a huge number who cannot contribute what they could otherwise. Connecting what we know about the typical child's development to what we know about impediments in reading can help us reclaim the lost potential of millions of children, many of whom have strengths that could light up our lives.

For we are also in the exciting early stages of understanding the little-studied benefits that accompany the brain development of some persons with dyslexia. It is no longer reducible to coincidence that so many inventors, artists, architects, computer designers, radiologists, and financiers have a childhood history of dyslexia. The inventors Thomas Edison and Alexander Graham Bell, the business entrepreneurs Charles Schwab and David Neeleman, the artists Leonardo da Vinci and Auguste Rodin, and the Nobel prize–winning scientist Baruj Benacerraf are all extraordinarily successful individuals with a history of dyslexia or related reading disorders. What is it about the dyslexic brain that seems linked in some people to unparalleled creativity in their professions, which often involve design, spatial skills, and the recognition of patterns? Was the differently organized brain of a person with dyslexia better suited for the demands of the preliterate past, with its emphasis on building and exploring? Will individuals with dyslexia be even better suited to the visual, technology-dominated future? Is the most current imaging and genetic research giving us the outlines of a very unusual brain organization in some persons with dyslexia that may ultimately explain both their known weaknesses and our steadily growing understanding of their strengths?

Questions about the brain of a person with dyslexia lead us to look both backward to our evolutionary past and forward to the future of our symbolic development. What is being lost and what is being gained for so many young people who have largely replaced books with the multidimensioned "continuous partial attention" culture of the Internet? What are the implications of seemingly limitless information for the evolution of the reading brain and for us as a species? Does the rapid, almost instantaneous presentation of expansive information threaten the more time-demanding formation of in-depth knowledge? Recently, Edward Tenner, who writes about technology, asked whether Google promotes a form of information illiteracy and whether there may be unintended negative consequences of such a mode of learning: "It would be a shame if brilliant technology were to end up threatening the kind of intellect that produced it."

Reflecting on such questions underscores the value of intellectual skills facilitated through literacy that we don't wish to lose, just when we appear potentially poised to replace them with other skills. This book is two parts science, one part personal observation, and as much truth as I can find to tell about how fiercely we must work as a society to preserve the development of particular aspects of reading, both for this generation and for generations to come. I will argue that unlike Plato, who with deep ambivalence straddled oral language and literacy, we do not need to choose between two modes of communication; rather, we must be vigilant not to lose the profound generativity of the reading brain, as we add new dimensions to our intellectual repertoire.

Like Proust, however, I can lead the viewer only so far in the realm of established or given knowledge. My final chapter goes beyond the information that we know, into areas where we have only intuition and extrapolation to guide us. By the end of this exploration of the reading brain, what we know of the profound cognitive miracle that takes place every time a human being learns to read will be the reader's to preserve and to go beyond.