

The Surprising Truth About
When, Where, and Why It Happens

Benedict Carey

How We Learn

The Surprising Truth About When,
Where, and Why It Happens

Benedict Carey



RANDOM HOUSE • NEW YORK

Copyright © 2014 by Benedict Carey

All rights reserved.

Published in the United States by Random House,
an imprint and division of Random House LLC,
a Penguin Random House Company, New York.

RANDOM HOUSE and the HOUSE colophon are
registered trademarks of Random House LLC.

Interior art credits:

Pg. 162, middle left: *Orange Zest*, original oil painting
by Judy Hawkins (www.judyhawkinspaintings.com).
Courtesy of the artist.

Pg. 162, bottom left: *Spring Creek Prairie 3*, 2013,
oil painting by Philip Juras. Courtesy of the artist.

Pg. 192: Henri Matisse, *Portrait of Madame Matisse*
(*The Green Line*), 1905, 2014 Succession H. Matisse/
Artists Rights Society (ARS), New York.

Library of Congress Cataloging-in-Publication Data

Carey, Benedict.

How we learn: the surprising truth about when,
where, and why it happens/Benedict Carey.

pages cm

ISBN 978-0-8129-9388-2

eBook ISBN 978-0-8129-9389-9

1. Learning, Psychology of. 2. Learning. I. Title.

BF318.C366 2014

153.1'5—dc23

2013049850

Printed in the United States of America on acid-free paper

www.atrandom.com

9 8 7 6 5 4 3 2 1

FIRST EDITION

Illustrations by Steve Clark and Zaremba

Book design by Mary A. Wirth

Contents



<u>Introduction: Broaden the Margins</u>	ix
<u>Part One: Basic Theory</u>	
<u>1. The Story Maker</u>	3
<u>The Biology of Memory</u>	
<u>2. The Power of Forgetting</u>	21
<u>A New Theory of Learning</u>	
<u>Part Two: Retention</u>	
<u>3. Breaking Good Habits</u>	45
<u>The Effect of Context on Learning</u>	
<u>4. Spacing Out</u>	65
<u>The Advantage of Breaking Up Study Time</u>	
<u>5. The Hidden Value of Ignorance</u>	80
<u>The Many Dimensions of Testing</u>	

Part Three: Problem Solving

- | | |
|--|-------------------|
| <u>6. The Upside of Distraction</u> | <u>107</u> |
| <u>The Role of Incubation in Problem Solving</u> | |
| <u>7. Quitting Before You're Ahead</u> | <u>131</u> |
| <u>The Accumulating Gifts of Percolation</u> | |
| <u>8. Being Mixed Up</u> | <u>149</u> |
| <u>Interleaving as an Aid to Comprehension</u> | |

Part Four: Tapping the Subconscious

- | | |
|--|-------------------|
| <u>9. Learning Without Thinking</u> | <u>175</u> |
| <u>Harnessing Perceptual Discrimination</u> | |
| <u>10. You Snooze, You Win</u> | <u>195</u> |
| <u>The Consolidating Role of Sleep</u> | |
| <u>Conclusion: The Foraging Brain</u> | <u>213</u> |
|
 | |
| <u>Appendix: Eleven Essential Questions</u> | <u>223</u> |
| Acknowledgments | 229 |
| Notes | 231 |
| <u>Index</u> | <u>245</u> |

Introduction



Broaden the Margins

It was a grind.

That was the word for it back in the day: The kid who sweated the details, who made flashcards. A striver, a grade-hog, a worker bee—*that* kid—and I can see him clearly now, almost forty years later, bent over a textbook, squinting in the glow of a cheap desk lamp.

I can see him early in the morning, too, up and studying at five o'clock: sophomore year, high school, his stomach on low boil because he can't quite master—what? The quadratic formula? The terms of the Louisiana Purchase? The Lend-Lease policy, the mean value theorem, Eliot's use of irony as a metaphor for . . . some damn thing?

Never mind.

It's long gone, the entire curriculum. All that remains is the dread. Time's running out, there's too much to learn, and some of it is probably beyond reach. But there's something else in there, too, a lower-frequency signal that takes a while to pick up, like a dripping

faucet in a downstairs bathroom: doubt. The nagging sense of having strayed off the trail when the gifted students were arriving at the lodge without breaking a sweat. Like so many others, I grew up believing that learning was all self-discipline: a hard, lonely climb up the sheer rock face of knowledge to where the smart people lived. I was driven more by a fear of falling than by anything like curiosity or wonder.

That fear made for an odd species of student. To my siblings, I was Mr. Perfect, the serious older brother who got mostly As. To my classmates, I was the Invisible Man, too unsure of my grasp of the material to speak up. I don't blame my young self, my parents, or my teachers for this split personality. How could I? The only strategy any of us knew for deepening learning—drive yourself like a sled dog—works, to some extent; effort is the single most important factor in academic success.

Yet that was the strategy I was already using. I needed something more, something different—and I felt it had to exist.

The first hint that it did, for me, came in the form of other students, those two or three kids in algebra or history who had—what was it?—a cool head, an ability to do their best without that hunted-animal look. It was as if they'd been told it was okay not to understand everything right away; that it would come in time; that their doubt was itself a valuable instrument. But the real conversion experience for me came later, when applying for college. College was the mission all along, of course. And it failed; I failed. I sent out a dozen applications and got shut down. All those years laboring before the mast and, in the end, I had nothing to show for it but a handful of thin envelopes and one spot on a waiting list—to a college I attended for a year before dropping out.

What went wrong?

I had no idea. I aimed too high, I wasn't perfect enough, I choked on the SATs. No matter. I was too busy feeling rejected to think about it. No, worse than rejected. I felt like a chump. Like I'd been scammed

by some bogus self-improvement cult, paid dues to a guru who split with the money. So, after dropping out, I made an attitude adjustment. I loosened my grip. I stopped sprinting. Broadened the margins, to paraphrase Thoreau. It wasn't so much a grand strategy—I was a teenager, I couldn't see more than three feet in front of my face—as a simple instinct to pick my head up and look around.

I begged my way into the University of Colorado, sending an application along with a pleading letter. It was a simpler time then; it's a state school; and I was accepted without much back-and-forth. In Boulder, I began to live more for the day. Hiked a lot, skied a little, consumed too much of everything. I slept in when I could, napped at all hours, and studied here and there, mixing in large doses of mostly legal activities for which large colleges are justifiably known. I'm not saying that I majored in gin and tonics; I never let go of my studies—just allowed them to become *part* of my life, rather than its central purpose. And somewhere in that tangle of good living and bad, I became a student. Not just any student, either, but one who wore the burden lightly, in math and physics, and was willing to risk failure in some very difficult courses.

The change wasn't sudden or dramatic. No bells rang out, no angels sang. It happened by degrees, like these things do. For years afterward, I thought about college like I suspect many people do: I'd performed pretty well despite my scattered existence, my bad habits. I never stopped to ask whether those habits were, in fact, bad.

• • •

In the early 2000s, I began to follow the science of learning and memory as a reporter, first for the *Los Angeles Times* and then for *The New York Times*. This subject—specifically, how the brain learns most efficiently—was not central to my beat. I spent most of my time on larger fields related to behavior, like psychiatry and brain biology. But I kept coming back to learning, because the story was such an improbable one. Here were legit scientists, investigating the effect of

apparently trivial things on learning and memory. Background music. Study location, i.e., where you hit the books. Videogame breaks. Honestly, did those things matter at test time, when it came time to perform?

If so, why?

Each finding had an explanation, and each explanation seemed to say something about the brain that wasn't obvious. And the deeper I looked, the more odd results I found. Distractions can aid learning. Napping does, too. Quitting before a project is done: not all bad, as an almost done project lingers in memory far longer than one that is completed. Taking a test on a subject *before* you know anything about it improves subsequent learning. Something about these findings nagged at me. They're not quite believable at first, but they're worth trying—because they're small, easy, doable. There's no excuse for ignoring them. In the past few years, every time I have taken on some new project, for work or fun, every time I've thought about reviving a long-neglected skill, like classical guitar or speaking Spanish, the self-questioning starts:

“Isn't there a better way?”

“Shouldn't I be trying . . . ?”

And so I have. After experimenting with many of the techniques described in the studies, I began to feel a creeping familiarity, and it didn't take long to identify its source: college. My jumbled, ad-hoc approach to learning in Colorado did not precisely embody the latest principles of cognitive science—nothing in the real world is that clean. The rhythm felt similar, though, in the way the studies and techniques seeped into my daily life, into conversation, idle thoughts, even dreams.

That connection was personal, and it got me thinking about the science of learning as a whole, rather than as a list of self-help ideas. The ideas—the techniques—are each sound on their own, that much was clear. The harder part was putting them together. They must fit together somehow, and in time I saw that the only way they could

was as oddball features of the underlying system itself—the living brain in action. To say it another way, the collective findings of modern learning science provide much more than a recipe for how to learn more efficiently. They describe a way of life. Once I understood that, I was able to look back on my college experience with new eyes. I'd lightened up on my studies, all right, but in doing so I'd also allowed topics to flow into my nonacademic life in a way I hadn't before. And it's when the brain lives with studied material that it reveals its strengths and weaknesses—its limitations and immense possibilities—as a learning machine.

The brain is not like a muscle, at least not in any straightforward sense. It is something else altogether, sensitive to mood, to timing, to circadian rhythms, as well as to location, environment. It registers far more than we're conscious of and often adds previously unnoticed details when revisiting a memory or learned fact. It works hard at night, during sleep, searching for hidden links and deeper significance in the day's events. It has a strong preference for meaning over randomness, and finds nonsense offensive. It doesn't take orders so well, either, as we all know—forgetting precious facts needed for an exam while somehow remembering entire scenes from *The Godfather* or the lineup of the 1986 Boston Red Sox.

If the brain is a learning machine, then it's an eccentric one. And it performs best when its quirks are exploited.

• • •

In the past few decades, researchers have uncovered and road-tested a host of techniques that deepen learning—techniques that remain largely unknown outside scientific circles. These approaches aren't get-smarter schemes that require computer software, gadgets, or medication. Nor are they based on any grand teaching philosophy, intended to lift the performance of entire classrooms (which no one has done, reliably). On the contrary, they are all small alterations, alterations in how we study or practice that we can apply individu-

ally, in our own lives, right now. The hardest part in doing so may be trusting that they work. That requires some suspension of disbelief because this research defies everything we've been told about how best to learn.

Consider the boilerplate advice to seek out a “quiet place” and make that a dedicated study area. This seems beyond obvious. It's easier to concentrate without noise, and settling in at the same desk is a signal to the brain that says, *it's time to work*. Yet we work more effectively, scientists have found, when we continually alter our study routines and abandon any “dedicated space” in favor of varied locations. Sticking to one learning ritual, in other words, slows us down.

Another common assumption is that the best way to master a particular skill—say, long division or playing a musical scale—is by devoting a block of time to repetitively practicing just that. Wrong again. Studies find that the brain picks up patterns more efficiently when presented with a mixed bag of related tasks than when it's force-fed just one, no matter the age of the student or the subject area, whether Italian phrases or chemical bonds. I can't help thinking again of my own strained, scattered existence in college, up all hours and down napping many afternoons, in blithe defiance of any kind of schedule. I'm not going to say that such free-form living always leads to mastery. But I will argue that integrating learning into the more random demands of life can improve recall in many circumstances—and that what looks like rank procrastination or distraction often is nothing of the kind.

The science of learning—to take just one implication—casts a different light on the growing alarm over distraction and our addiction to digital media. The fear is that plugged-in Emily and Josh, pulled in ten directions at once by texts, tweets, and Facebook messages, cannot concentrate well enough to consolidate studied information. Even worse, that all this scattered thinking will, over time, somehow weaken their brains' ability to learn in the future. This is a red herring. Distractions can of course interfere with some kinds of

learning, in particular when absorption or continued attention is needed—when reading a story, say, or listening to a lecture—and if gossiping on social media steals from study time. Yet we now know that a brief distraction can help when we’re stuck on a math problem or tied up in a creative knot and need to shake free.

In short, it is not that there is a right way and wrong way to learn. It’s that there are different strategies, each uniquely suited to capturing a particular type of information. A good hunter tailors the trap to the prey.

• • •

I won’t pretend, in these pages, that the science of learning has been worked out. It hasn’t, and the field is producing a swarm of new ideas that continue to complicate the picture. Dyslexia improves pattern recognition. Bilingual kids are better learners. Math anxiety is a brain disorder. Games are the best learning tool. Music training enhances science aptitude. But much of this is background noise, a rustling of the leaves. The aim in this book is to trace the trunk of the tree, the basic theory and findings that have stood up to scrutiny—and upon which learning can be improved.

The book unfolds in four sections, and from the bottom up, so to speak. It will begin with an introduction to what scientists know about how brain cells form and hold on to new information. Having a handle on this basic biology will provide a strong physical analogy for the so-called cognitive basis of learning. Cognitive science is a step up the ladder from biology and, most important for us, it clarifies how remembering, forgetting, and learning are related. These two chapters form the theoretical foundation for all that follows.

The second section will detail techniques that strengthen our hold on facts, whether we’re trying to remember Arabic characters, the elements of the periodic table, or the major players of the Velvet Revolution. *Retention* tools. The third section will focus on *comprehension* techniques, the kind we need to solve problems in math and sci-

ence, as well as work our way through long, complex assignments, like term papers, work presentations, blueprints, and compositions. Appreciating how these approaches work, or at least how scientists think they do, will help us remember them and, more critically, decide whether they're of any practical use—today, in our daily lives. And finally, section four will explore two ways to co-opt the subconscious mind to amplify the techniques we've just described. I think of this as the “learning without thinking” part of the story, and it's a reassuring one to hear—and to tell.

The treasure at the end of this rainbow is not necessarily “brilliance.” Brilliance is a fine aspiration, and Godspeed to those who have the genes, drive, luck, and connections to win that lottery. But shooting for a goal so vague puts a person at risk of worshiping an ideal—and missing the target. No, this book is about something that is, at once, more humble and more grand: How to integrate the exotica of new subjects into daily life, in a way that makes them seep under our skin. How to make learning more a part of living and less an isolated chore. We will mine the latest science to unearth the tools necessary to pull this off, and to do so without feeling buried or oppressed. And we will show that some of what we've been taught to think of as our worst enemies—laziness, ignorance, distraction—can also work in our favor.

Part One



Basic Theory

Chapter One



The Story Maker

The Biology of Memory

The science of learning is, at bottom, a study of the mental muscle doing the work—the living brain—and how it manages the streaming sights, sounds, and scents of daily life. That it does so at all is miracle enough. That it does so routinely is beyond extraordinary.

Think of the waves of information rushing in every waking moment, the hiss of the kettle, the flicker of movement in the hall, the twinge of back pain, the tang of smoke. Then add the demands of a typical layer of multitasking—say, preparing a meal while monitoring a preschooler, periodically returning work emails, and picking up the phone to catch up with a friend.

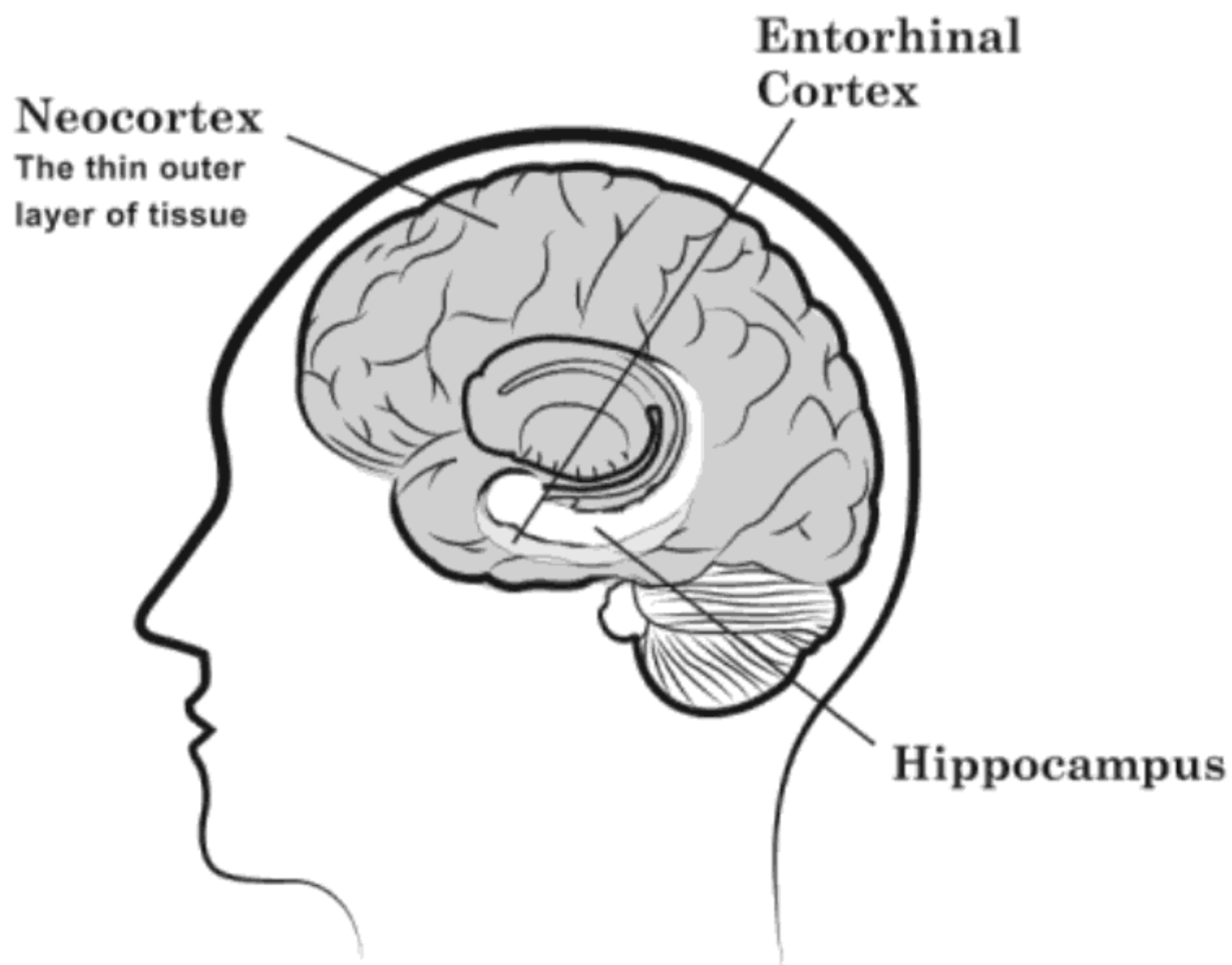
Insane.

The machine that can do all that at once is more than merely complex. It's a cauldron of activity. It's churning like a kicked beehive.

Consider several numbers. The average human brain contains 100 billion neurons, the cells that make up its gray matter. Most of these cells link to thousands of other neurons, forming a universe of

intertwining networks that communicate in a ceaseless, silent electrical storm with a storage capacity, in digital terms, of a million gigabytes. That's enough to hold three million TV shows. This biological machine hums along even when it's "at rest," staring blankly at the bird feeder or some island daydream, using about 90 percent of the energy it burns while doing a crossword puzzle. Parts of the brain are highly active during sleep, too.

The brain is a dark, mostly featureless planet, and it helps to have a map. A simple one will do, to start. The sketch below shows several areas that are central to learning: the entorhinal cortex, which acts as a kind of filter for incoming information; the hippocampus, where memory formation begins; and the neocortex, where conscious memories are stored once they're flagged as keepers.



This diagram is more than a snapshot. It hints at how the brain operates. The brain has modules, specialized components that divide the labor. The entorhinal cortex does one thing, and the hippocampus does another. The right hemisphere performs different functions from the left one. There are dedicated sensory areas, too, processing

what you see, hear, and feel. Each does its own job and together they generate a coherent whole, a continually updating record of past, present, and possible future.

In a way, the brain's modules are like specialists in a movie production crew. The cinematographer is framing shots, zooming in tight, dropping back, stockpiling footage. The sound engineer is recording, fiddling with volume, filtering background noise. There are editors and writers, a graphics person, a prop stylist, a composer working to supply tone, feeling—the emotional content—as well as someone keeping the books, tracking invoices, the facts and figures. And there's a director, deciding which pieces go where, braiding all these elements together to tell a story that holds up. Not just any story, of course, but the one that best explains the “material” pouring through the senses. The brain interprets scenes in the instants after they happen, inserting judgments, meaning, and context on the fly. It also reconstructs them later on—*what exactly did the boss mean by that comment?*²—scrutinizing the original footage to see how and where it fits into the larger movie.

It's a story of a life—our own private documentary—and the film “crew” serves as an animating metaphor for what's happening behind the scenes. How a memory forms. How it's retrieved. Why it seems to fade, change, or grow more lucid over time. And how we might manipulate each step, to make the details richer, more vivid, clearer.

Remember, the director of this documentary is not some film school graduate, or a Hollywood prince with an entourage. It's you.

• • •

Before wading into brain biology, I want to say a word about metaphors. They are imprecise, practically by definition. They obscure as much as they reveal. And they're often self-serving,* crafted to serve

*Self-serving is right.

some pet purpose—in the way that the “chemical imbalance” theory of depression supports the use of antidepressant medication. (No one knows what causes depression or why the drugs have the effects they do.)

Fair enough, all around. Our film crew metaphor is a loose one, to be sure—but then so is scientists’ understanding of the biology of memory, to put it mildly. The best we can do is dramatize what matters most to learning, and the film crew does that just fine.

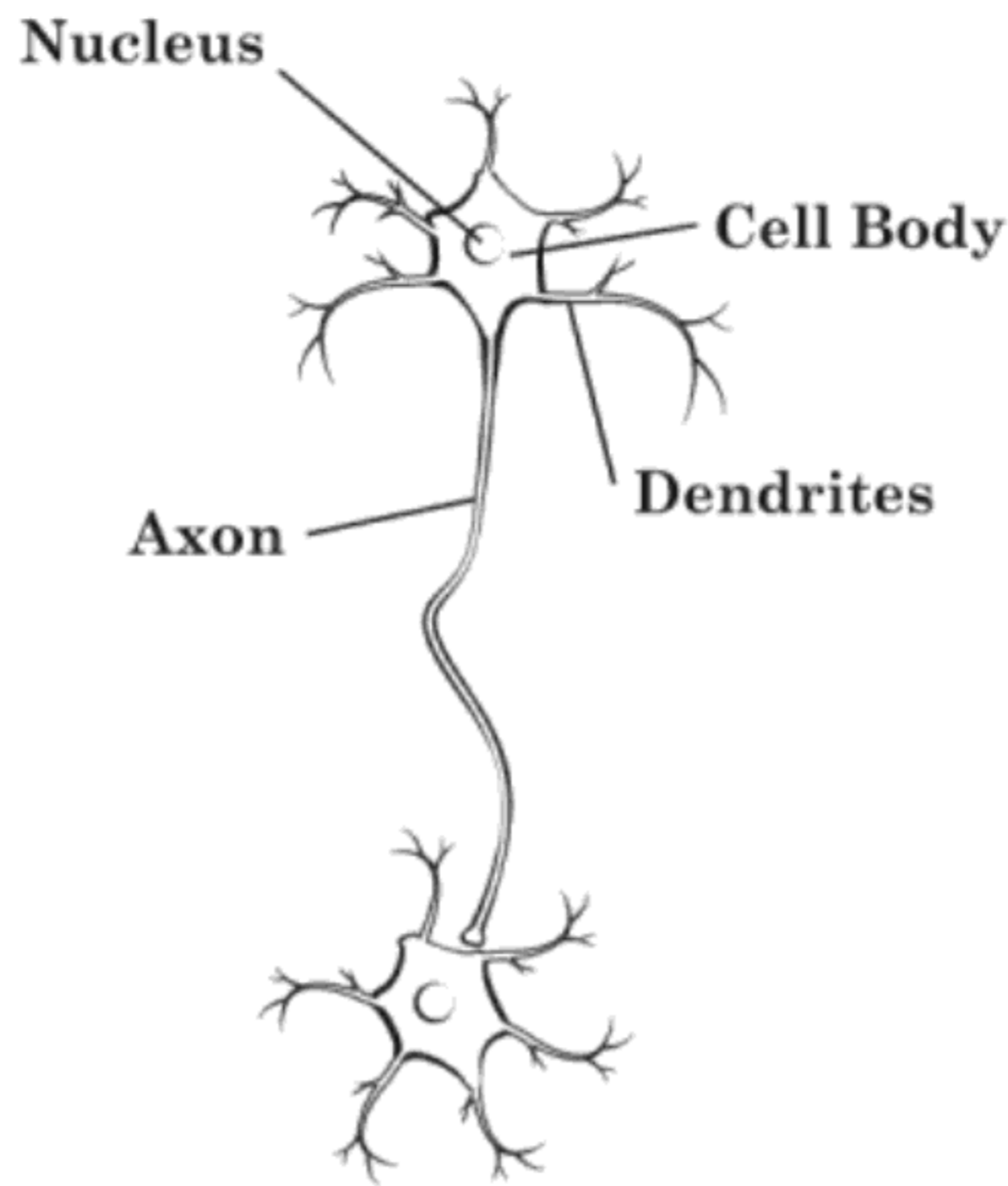
To see how, let’s track down a specific memory in our own brain.

Let’s make it an interesting one, too, not the capital of Ohio or a friend’s phone number or the name of the actor who played Frodo. No, let’s make it the first day of high school. Those tentative steps into the main hallway, the leering presence of the older kids, the gunmetal thump of slamming lockers. Everyone over age fourteen remembers some detail from that day, and usually an entire video clip.

That memory exists in the brain as a network of linked cells. Those cells activate—or “fire”—together, like a net of lights in a department store Christmas display. When the blue lights blink on, the image of a sleigh appears; when the reds come on, it’s a snowflake. In much the same way, our neural networks produce patterns that the brain reads as images, thoughts, and feelings.

The cells that link to form these networks are called neurons. A neuron is essentially a biological switch. It receives signals from one side and—when it “flips” or fires—sends a signal out the other, to the neurons to which it’s linked.

The neuron network that forms a specific memory is not a random collection. It includes many of the same cells that flared when a specific memory was first formed—when we first heard that gunmetal thump of lockers. It’s as if these cells are bound in collective witness of that experience. The connections between the cells, called synapses, thicken with repeated use, facilitating faster transmission of signals.



Intuitively, this makes some sense; many remembered experiences feel like mental reenactments. But not until 2008 did scientists capture memory formation and retrieval directly, in individual human brain cells. In an experiment, doctors at the University of California, Los Angeles, threaded filament-like electrodes deep into the brains of thirteen people with epilepsy who were awaiting surgery.

This is routine practice. Epilepsy is not well understood; the tiny hurricanes of electrical activity that cause seizures seem to come out of the blue. These squalls often originate in the same neighborhood of the brain for any one individual, yet the location varies from person to person. Surgeons can remove these small epicenters of activity but first they have to find them, by witnessing and recording a seizure. That's what the electrodes are for, pinpointing location. And it takes time. Patients may lie in the hospital with electrode implants for days on end before a seizure strikes. The UCLA team took advantage of this waiting period to answer a fundamental question.

Each patient watched a series of five- to ten-second video clips of well-known shows like *Seinfeld* and *The Simpsons*, celebrities like Elvis, or familiar landmarks. After a short break, the researchers asked each person to freely recall as many of the videos as possible, calling

them out as they came to mind. During the initial viewing of the videos, a computer had recorded the firing of about one hundred neurons. The firing pattern was different for each clip; some neurons fired furiously and others were quiet. When a patient later recalled one of the clips, say of Homer Simpson, the brain showed exactly the same pattern as it had originally, as if replaying the experience.

“It’s astounding to see this in a single trial; the phenomenon is strong, and we knew we were listening in the right place,” the senior author of the study, Itzhak Fried, a professor of neurosurgery at UCLA and Tel Aviv University, told me.

There the experiment ended, and it’s not clear what happened to the memory of those brief clips over time. If a person had seen hundreds of *Simpsons* episodes, then this five-second clip of Homer might not stand out for long. But it could. If some element of participating in the experiment was especially striking—for example, the sight of a man in a white coat fiddling with wires coming out of your exposed brain as Homer belly-laughed—then that memory could leap to mind easily, for life.

My first day of high school was in September 1974. I can still see the face of the teacher I approached in the hallway when the bell rang for the first class. I was lost, the hallway was swarmed, my head racing with the idea that I might be late, might miss something. I can still see streams of dusty morning light in that hallway, the ugly teal walls, an older kid at his locker, stashing a pack of Winstons. I swerved beside the teacher and said, “Excuse me” in a voice that was louder than I wanted. He stopped, looked down at my schedule: a kind face, wire-rimmed glasses, wispy red hair.

“You can follow me,” he said, with a half smile. “You’re in my class.”

Saved.

I have not thought about that for more than thirty-five years, and yet there it is. Not only does it come back but it does so in rich detail, and it keeps filling itself out the longer I inhabit the moment: here’s

the sensation of my backpack slipping off my shoulder as I held out my schedule; now the hesitation in my step, not wanting to walk with a teacher. I trailed a few steps behind.

This kind of time travel is what scientists call episodic, or autobiographical memory, for obvious reasons. It has some of the same sensual texture as the original experience, the same narrative structure. Not so with the capital of Ohio, or a friend's phone number: We don't remember exactly when or where we learned those things. Those are what researchers call *semantic* memories, embedded not in narrative scenes but in a web of associations. The capital of Ohio, Columbus, may bring to mind images from a visit there, the face of a friend who moved to Ohio, or the grade school riddle, "What's round on both sides and high in the middle?" This network is factual, not scenic. Yet it, too, "fills in" as the brain retrieves "Columbus" from memory.

In a universe full of wonders, this has to be on the short list: Some molecular bookmark keeps those neuron networks available for life and gives us nothing less than our history, our identity.

Scientists do not yet know how such a bookmark could work. It's nothing like a digital link on a computer screen. Neural networks are continually in flux, and the one that formed back in 1974 is far different from the one I have now. I've lost some detail and color, and I have undoubtedly done a little editing in retrospect, maybe a lot.

It's like writing about a terrifying summer camp adventure in eighth grade, the morning after it happened, and then writing about it again, six years later, in college. The second essay is much different. You have changed, so has your brain, and the biology of this change is shrouded in mystery and colored by personal experience. Still, the scene itself—the plot—is fundamentally intact, and researchers do have an idea of where that memory must live and why. It's strangely reassuring, too. If that first day of high school feels like it's right there on the top of your head, it's a nice coincidence of language. Because, in a sense, that's exactly where it is.

• • •

For much of the twentieth century scientists believed that memories were diffuse, distributed through the areas of the brain that support thinking, like pulp in an orange. Any two neurons look more or less the same, for one thing; and they either fire or they don't. No single brain area looked essential for memory formation.

Scientists had known since the nineteenth century that *some* skills, like language, are concentrated in specific brain regions. Yet those seemed to be exceptions. In the 1940s, the neuroscientist Karl Lashley showed that rats that learned to navigate a maze were largely unfazed when given surgical injuries in a variety of brain areas. If there was some single memory center, then at least one of those incisions should have caused severe deficits. Lashley concluded that virtually any area of the thinking brain was capable of supporting memory; if one area was injured, another could pick up the slack.

In the 1950s, however, this theory began to fall apart. Brain scientists began to discover, first, that developing nerve cells—baby neurons, so to speak—are coded to congregate in specific locations in the brain, as if preassigned a job. “You’re a visual cell, go to the back of the brain.” “You, over there, you’re a motor neuron, go straight to the motor area.” This discovery undermined the “interchangeable parts” hypothesis.

The knockout punch fell when an English psychologist named Brenda Milner met a Hartford, Connecticut, man named Henry Molaison. Molaison was a tinkerer and machine repairman who had trouble keeping a job because he suffered devastating seizures, as many as two or three a day, which came with little warning and often knocked him down, out cold. Life had become impossible to manage, a daily minefield. In 1953, at the age of twenty-seven, he arrived at the office of William Beecher Scoville, a neurosurgeon at Hartford Hospital, hoping for relief.

Molaison probably had a form of epilepsy, but he did not do well

The implications of Milner's research took some time to sink in. Molaison could not remember new names, faces, facts, or experiences. His brain could register the new information but, without a hippocampus, could not hold on to it. This structure and others nearby—which had been removed in the surgery—are clearly necessary to form such memories.

He could develop new physical skills, however, like tracing the star and later, in his old age, using a walker. This ability, called motor learning, is not dependent on the hippocampus. Milner's work showed that there were at least two systems in the brain to handle memory, one conscious and the other subconscious. We can track and write down what we learned today in history class, or in geometry, but not in soccer practice or gymnastics, not in anything like the same way. Those kinds of physical skills accumulate without our having to think much about them. We may be able to name the day of the week when we first rode a bike at age six, but we cannot point to the exact physical abilities that led up to that accomplishment. Those skills—the balance, the steering, the pedal motion—refined themselves and came together suddenly, without our having to track or “study” them.

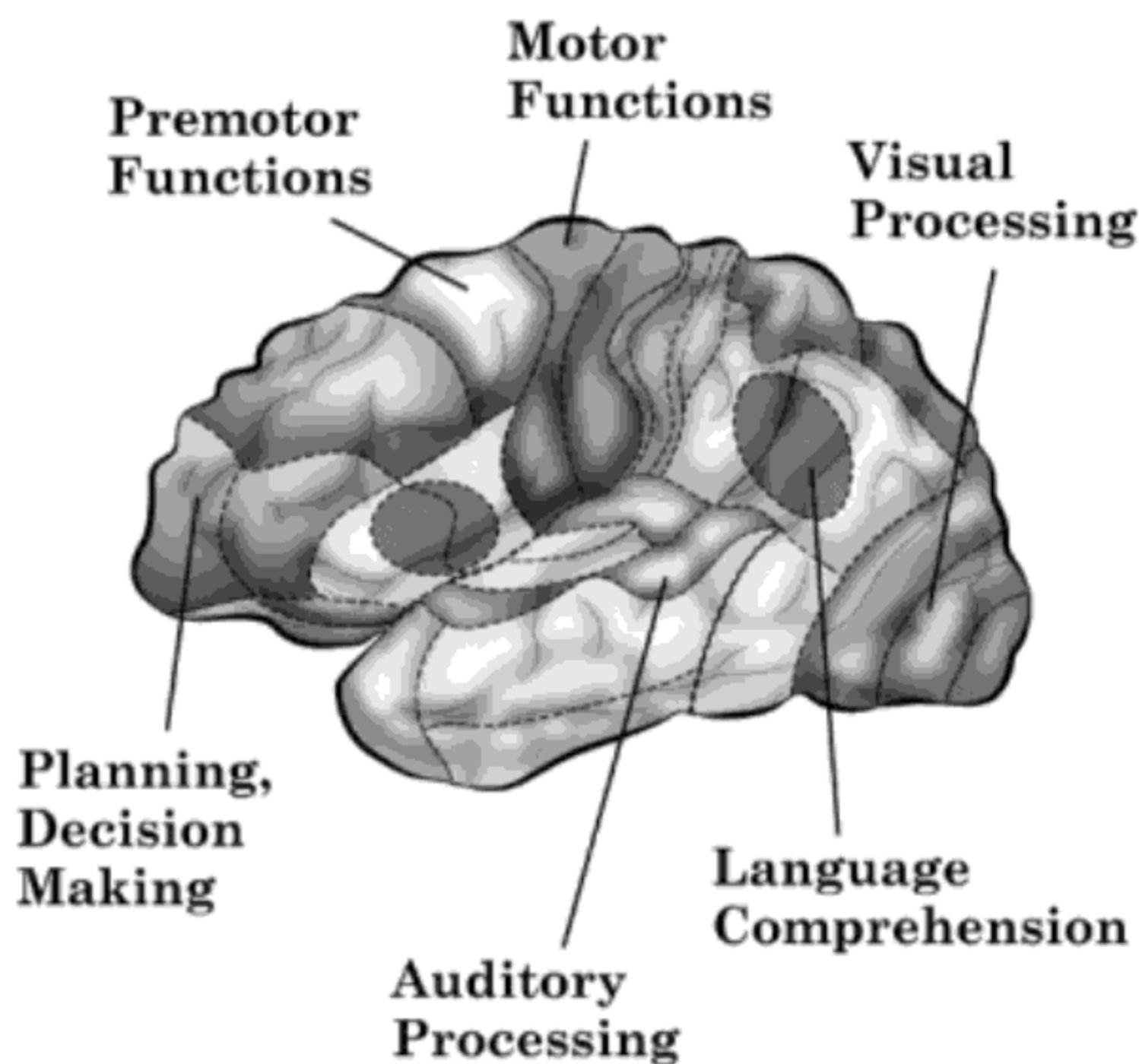
The theory that memory was uniformly distributed, then, was wrong. The brain had specific areas that handled different types of memory formation.

Henry Molaison's story didn't end there. One of Milner's students, Suzanne Corkin, later carried on the work with him at the Massachusetts Institute of Technology. In the course of hundreds of studies spanning more than forty years, she showed that he had many presurgery memories, of the war, of FDR, of the layout of his childhood house. “Gist memories, we call them,” Dr. Corkin told me. “He had the memories, but he couldn't place them in time exactly; he couldn't give you a narrative.”

Studies done in others with injuries in the same areas of the brain showed a similar before/after pattern. Without a functioning hippo-

campus, people cannot form new, conscious memories. Virtually all of the names, facts, faces, and experiences they do remember pre-date their injury. Those memories, once formed, must therefore reside elsewhere, outside the hippocampus.

The only viable candidate, scientists knew, was the brain's thin outer layer, the neocortex. The neocortex is the seat of human consciousness, an intricate quilt of tissue in which each patch has a specialized purpose. Visual patches are in the back. Motor control areas are on the side, near the ears. One patch on the left side helps interpret language; another nearby handles spoken language, as well as written.



This layer—the “top” of the brain, as it were—is the only area with the tools capable of re-creating the rich sensory texture of an autobiographical memory, or the assortment of factual associations for the word “Ohio” or the number 12. The first-day-of-high-school network (or networks; there likely are many) must be contained there, largely if not entirely. My first-day memory is predominantly visual (the red hair, the glasses, the teal walls) and auditory (the hallway noise, the slamming lockers, the teacher’s voice)—so the network has plenty of neurons in the visual and audio cortex. Yours may include

the smell of the cafeteria, the deadweight feel of your backpack, with plenty of cells in those cortical patches.

To the extent that it's possible to locate a memory in the brain, that's where it resides: in neighborhoods along the neocortex primarily, not at any single address.

That the brain can find this thing and bring it to life so fast— instantaneously, for most of us, complete with emotion, and layers of detail—defies easy explanation. No one knows how that happens. And it's this instant access that creates what to me is the brain's grandest illusion: that memories are “filed away” like video scenes that can be opened with a neural click, and snapped closed again.

The truth is stranger—and far more useful.

• • •

The risk of peering too closely inside the brain is that you can lose track of what's on the outside—i.e., the person. Not some generic human, either, but a real one. Someone who drinks milk straight from the carton, forgets friends' birthdays, and who can't find the house keys, never mind calculate the surface area of a pyramid.

Let's take a moment to review. The close-up of the brain has provided a glimpse of what cells do to form a memory. They fire together during an experience. Then they stabilize as a network through the hippocampus. Finally, they consolidate along the neocortex in a shifting array that preserves the basic plot points. Nonetheless, to grasp what people do to *retrieve* a memory—to remember—requires stepping back for a wide shot. We've zoomed in, à la Google Maps, to see cells at street level; it's time to zoom out and have a look at the larger organism: at people whose perceptions reveal the secrets of memory retrieval.

The people in question are, again, epilepsy patients (to whom brain science owes debts without end).

In some epilepsy cases, the flares of brain activity spread like a chemical fire, sweeping across wide stretches of the brain and caus-

ing the kind of full-body, blackout seizures that struck H.M. as a young man. Those seizures are so hard to live with, and often so resistant to drug treatment, that people consider brain surgery. No one has the same procedure H.M. underwent, of course, but there are other options. One of those is called split brain surgery. The surgeon severs the connections between the left and right hemispheres of the brain, so the storms of activity are confined to one side.

This quiets the seizures, all right. But at what cost? The brain's left and right halves cannot "talk" to each other at all; split brain surgery must cause serious damage, drastically altering someone's personality, or at least their perceptions. Yet it doesn't. The changes are so subtle, in fact, that the first studies of these so-called split brain patients in the 1950s found no differences in thinking or perception at all. No slip in IQ; no deficits in analytical thinking.

The changes had to be there—the brain was effectively *cut in half*—but it would take some very clever experiments to reveal them.

In the early 1960s, a trio of scientists at the California Institute of Technology finally did so, by devising a way to flash pictures to one hemisphere at a time. *Bingo*. When split brain patients saw a picture of a fork with only their right hemisphere, they couldn't say what it was. They couldn't name it. Due to the severed connection, their left hemisphere, where language is centered, received no information from the right side. And the right hemisphere—which "saw" the fork—had no language to name it.

And here was the kicker: The right hemisphere could direct the hand it controls to *draw* the fork.

The Caltech trio didn't stop there. In a series of experiments with these patients, the group showed that the right hemisphere could also identify objects by touch, correctly selecting a mug or a pair of scissors by feel after seeing the image of one.

The implications were clear. The left hemisphere was the intellectual, the wordsmith, and it could be severed from the right without

any significant loss of IQ. The right side was the artist, the visual-spatial expert. The two worked together, like copilots.

This work percolated into the common language and fast, as shorthand for types of skills and types of people: “He’s a right brain guy, she’s more left brain.” It felt right, too: Our aesthetic sensibility, open and sensual, must come from a different place than cool logic.

What does any of this have to do with memory?

It took another quarter century to find out. And it wouldn’t happen until scientists posed a more fundamental question: Why don’t we *feel* two-brained, if we have these two copilots?

“That was the question, ultimately,” said Michael Gazzaniga, who coauthored the Caltech studies with Roger Sperry and Joseph Bogen in the 1960s. “Why, if we have these separate systems, is it that the brain has a sense of unity?”

That question hung over the field, unanswered, for decades. The deeper that scientists probed, the more confounding the mystery seemed to be. The left brain/right brain differences revealed a clear, and fascinating, division of labor. Yet scientists kept finding other, more intricate, divisions. The brain has thousands, perhaps millions, of specialized modules, each performing a special skill—one calculates a change in light, for instance, another parses a voice tone, a third detects changes in facial expression. The more experiments that scientists did, the more specializing they found, and all of these mini-programs run at the same time, often across *both* hemispheres. That is, the brain sustains a sense of unity not only in the presence of its left and right copilots. It does so amid a cacophony of competing voices coming from all quarters, the neural equivalent of open outcry at the Chicago Board of Trade.

How?

The split brain surgery would again provide an answer.

In the early 1980s, Dr. Gazzaniga performed more of his signature experiments with split brain patients—this time with an added

bering. That is to say: The brain does not store facts, ideas, and experiences like a computer does, as a file that is clicked open, always displaying the identical image. It embeds them in networks of perceptions, facts, and thoughts, slightly different combinations of which bubble up each time. And that just retrieved memory does not overwrite the previous one but intertwines and overlaps with it. Nothing is completely lost, but the memory trace is altered and for good.

As scientists put it, using our memories changes our memories.

After all the discussion of neurons and cell networks; after Lashley's rats and H.M.; after the hippocampus, split brain patients, and the story maker, this seems elementary, even mundane.

It's not.

Chapter Two



The Power of Forgetting

A New Theory of Learning

Memory contests are misleading spectacles, especially in the final rounds.

At that point, there are only a handful of people left onstage and their faces reflect all varieties of exhaustion, terror, and concentration. The stakes are high, they've come a long way already, and any mistake can end it all. In a particularly tough to watch scene from the documentary *Spellbound*, about the Scripps National Spelling Bee, one twelve-year-old trips over the word “opsimath.” He appears to be familiar with the word, he's digging deep, there's a moment when he seems to have it—but then he inserts an “o” where it doesn't belong.

Clang!

A bell rings—meaning: *wrong answer*—and the boy's eyes bulge in stunned disbelief. A gasp sweeps through the crowd, followed by clapping, consolation applause for effort. He slinks offstage, numb. Variations of this scene repeat, as other well-prepped contestants miss a word. They slump at the microphone, or blink without seeing,

before being bathed in the same lukewarm applause. In contrast, those who move to the next round seem confident, locked in. The winner smiles when she hears her final word—“logorrhea”—and nails it.

These competitions tend to leave us with two impressions. One is that the contestants, and especially the winners, must be extra-human. How on earth are they doing that? Their brains must be not only bigger and faster but also *different* from the standard-issue version (i.e., ours). Maybe they even have “photographic” memories.

Not so. Yes, it’s true that some people are born with genetic advantages, in memory capacity and processing speed (though no one has yet identified an “intelligence gene” or knows with any certainty how one would function). It’s true, too, that these kinds of contests tend to draw from the higher end of the spectrum, from people who take a nerdy interest in stockpiling facts. Still, a brain is a brain is a brain, and the healthy ones all work the same way. With enough preparation and devotion, each is capable of seemingly wizardlike feats of memory. And photographic memories, as far as scientists can tell, don’t exist, at least not in the way that we imagine.

The other impression is more insidious, because it reinforces a common, self-defeating assumption: To forget is to fail. This appears self-evident. The world is so full of absentmindedness, tuned-out teenagers, misplaced keys, and fear of creeping dementia that forgetting feels dysfunctional, or ominous. If learning is building up skills and knowledge, then forgetting is losing some of what was gained. It seems like the enemy of learning.

It’s not. The truth is nearly the opposite.

Of course it can be a disaster to space out on a daughter’s birthday, to forget which trail leads back to the cabin, or to draw a blank at test time. Yet there are large upsides to forgetting, too. One is that it is nature’s most sophisticated spam filter. It’s what allows the brain to focus, enabling sought-after facts to pop to mind.

One way to dramatize this would be to parade all those spelling prodigies back onstage again for another kind of competition, a fast-paced tournament of the obvious. Quick: Name the last book you read. The last movie you saw. The local drugstore. The secretary of state. The World Series champions. And then faster still: your Gmail password, your sister's middle name, the vice president of the United States.

In this hypothetical contest, each of those highly concentrated minds would be drawing a lot of blanks. Why? Not due to mere absentmindedness or preoccupation. No, these kids are alert and highly focused. So focused, in fact, that they're blocking out trivial information.

Think about it: To hold so many obscure words in mind and keep the spellings straight, the brain must apply a filter. To say it another way, the brain must suppress—forget—competing information, so that “apathetic” doesn't leak into “apothecary,” or “penumbra” into “penultimate,” and keep any distracting trivia from bubbling to the surface, whether song lyrics, book titles, or names of movie actors.

We engage in this kind of focused forgetting all the time, without giving it much thought. To lock in a new computer password, for example, we must block the old one from coming to mind; to absorb a new language, we must hold off the corresponding words in our native tongue. When thoroughly immersed in a topic or novel or computation, it's natural to blank on even common nouns—“could you pass me the whatyoucallit, the thing you eat with?”

Fork.

As the nineteenth-century American psychologist William James observed, “If we remembered everything, we should on most occasions be as ill off as if we remembered nothing.”

The study of forgetting has, in the past few decades, forced a fundamental reconsideration of how learning works. In a way, it has also altered what the words “remember” and “forget” mean. “The rela-