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Learning Is Misunderstood

EARLY IN HIS CAREER as a pilot, Matt Brown was flying a twin-engine Cessna northeast out of Harlingen, Texas, when he noticed a drop in oil pressure in his right engine. He was alone, flying through the night at eleven thousand feet, making a hotshot freight run to a plant in Kentucky that had shut down its manufacturing line awaiting product parts for assembly.

He reduced altitude and kept an eye on the oil gauge, hoping to fly as far as a planned fuel stop in Louisiana, where he could service the plane, but the pressure kept falling. Matt has been messing around with piston engines since he was old enough to hold a wrench, and he knew he had a problem. He ran a mental checklist, figuring his options. If he let the oil pressure get too low he risked the engine's seizing up. How much further could he fly before shutting it down? What would happen when he did? He'd lose lift on the right side, but could he stay aloft? He reviewed the tolerances he'd memorized for the Cessna 401. Loaded, the best you could do on one engine was slow your descent. But he had a light load, and he'd burned through most of his fuel. So he shut down the ailing right engine, feathered the prop to reduce drag, increased power on the left, flew with opposite rudder, and limped another ten miles toward his intended stop. There, he made his approach in a wide left-hand turn, for the simple but critical reason that without power on his right side it was only from a left-hand turn that he still had the lift needed to level out for a touchdown.

While we don't need to understand each of the actions Matt took, *he* certainly needed to, and his ability to work himself out of a jam illustrates what we mean in this book when we talk about learning: we mean acquiring knowledge and skills and having them readily available from memory so you can make sense of future problems and opportunities.

There are some immutable aspects of learning that we can probably all agree on:

First, to be useful, learning requires memory, so what we've learned is still there later when we need it.

Second, we need to keep learning and remembering all our lives. We can't advance through middle school without some mastery of language arts, math, science, and social studies. Getting ahead at work takes mastery of job skills and difficult colleagues. In retirement, we pick up new interests. In our dotage, we move into simpler housing while we're still able to adapt. If you're good at learning, you have an advantage in life.

Third, learning is an acquired skill, and the most effective strategies are often counterintuitive.

Claims We Make in This Book

You may not agree with the last point, but we hope to persuade you of it. Here, more or less unadorned in list form, are some of the principal claims we make in support of our argument. We set them forth more fully in the chapters that follow.

Learning is deeper and more durable when it's *effortful*. Learning that's easy is like writing in sand, here today and gone tomorrow.

We are *poor judges* of when we are learning well and when we're not. When the going is harder and slower and it doesn't feel productive, we are drawn to strategies that feel more fruitful, unaware that the gains from these strategies are often temporary.

Rereading text and *massed practice* of a skill or new knowledge are by far the preferred study strategies of learners of all stripes, but they're also among the *least productive*. By massed practice we mean the single-minded, rapid-fire repetition of something you're trying to burn into memory, the "practice-practice-practice" of conventional wisdom. Cramming for exams is an example. Rereading and massed practice give rise to feelings of fluency that are taken to be signs of mastery, but for true mastery or durability these strategies are largely a waste of time.

Retrieval practice—recalling facts or concepts or events from memory—is a more effective learning strategy than review by rereading. Flashcards are a simple example. Retrieval strengthens the memory and interrupts forgetting. A single, simple quiz after reading a text or hearing a lecture produces better learning and remembering than rereading the text or reviewing lecture notes. While the brain is not a muscle that gets stronger with exercise, the neural pathways that make up a body of learning do get stronger, when the memory is retrieved and the learning is practiced. Periodic practice arrests forgetting, strengthens retrieval routes, and is essential for hanging onto the knowledge you want to gain.

When you *space out practice* at a task and get a little rusty between sessions, or you interleave the practice of two or more subjects, retrieval is harder and feels less productive, but the effort produces longer lasting learning and enables more versatile application of it in later settings.

Trying to solve a problem *before being taught the solution* leads to better learning, even when errors are made in the attempt.

The popular notion that you learn better when you receive instruction in a form consistent with your preferred *learning style,* for example as an auditory or visual learner, is *not supported by the empirical research*. People do have multiple forms of intelligence to bring to bear on learning, and you learn better when you "go wide," drawing on all of your aptitudes and resourcefulness, than when you limit instruction or experience to the style you find most amenable.

When you're adept at extracting the *underlying principles or "rules"* that differentiate types of problems, you're more successful at picking the right solutions in unfamiliar situations. This skill is better acquired through *interleaved and varied practice* than massed practice. For instance, interleaving practice at computing the volumes of different kinds of geometric solids makes you more skilled at picking the right solution when a later test presents a random solid. Interleaving the identification of bird types or the works of oil painters improves your ability both to learn the unifying attributes within a type and to differentiate between types, improving your skill at categorizing new specimens you encounter later.

We're all *susceptible to illusions* that can hijack our judgment of what we know and can do. Testing helps calibrate our judgments of what we've learned. A pilot who is responding to a failure of hydraulic systems in a flight simulator discovers quickly whether he's on top of the corrective procedures or not. In virtually all areas of learning, you build better mastery when you use testing as a tool to identify and bring up your areas of weakness.

All new learning requires a *foundation of prior knowledge.* You need to know how to land a twin engine plane on two engines before you can learn to land it on one. To learn trigonometry, you need to remember your algebra and geometry. To learn cabinetmaking, you need to have mastered the properties of wood and composite materials, how to join boards, cut rabbets, rout edges, and miter corners.

In a cartoon by the *Far Side* cartoonist Gary Larson, a bug-eyed school kid asks his teacher, "Mr. Osborne, can I be excused? My brain is full!" If you're just engaging in mechanical repetition, it's true, you quickly hit the limit of what you can keep in mind. However, if you practice *elaboration,* there's no known limit to how much you can learn. Elaboration is the process of giving new material meaning by expressing it in your own words and connecting it with what you already know. The more you can explain about the way your new learning relates to your prior knowledge, the stronger your grasp of the new learning will be, and the more connections you create that will help you remember it later. Warm air can hold more moisture than cold air; to know that this is true in your own experience, you can think of the drip of water from the back of an air conditioner or the way a stifling summer day turns cooler out the back side of a sudden thunderstorm. Evaporation has a cooling effect: you know this because a humid day at your uncle's in Atlanta feels hotter than a dry one at your cousin's in Phoenix, where your sweat disappears even before your skin feels damp. When you study the principles of heat transfer, you understand conduction from warming your hands around a hot cup of cocoa; radiation from the way the sun pools in the den on a wintry day; convection from the life-saving blast of A/C as your uncle squires you slowly through his favorite back alley haunts of Atlanta.

Putting new knowledge into a *larger context* helps learning. For example, the more of the unfolding story of history you know, the more of it you can learn. And the more ways you give that story meaning, say by connecting it to your understanding of human ambition and the untidiness of fate, the better the story stays with you. Likewise, if you're trying to learn an abstraction, like the principle of angular momentum, it's easier when you ground it in something concrete that you already know, like the way a figure skater's rotation speeds up as she draws her arms to her chest.

People who learn to *extract the key ideas from new material and organize them into a mental model* and connect that model to prior knowledge show an advantage in learning complex mastery. A mental model is a mental representation of some external reality.[1] Think of a baseball batter waiting for a pitch. He has less than an instant to decipher whether it's a curveball, a changeup, or something else. How does he do it? There are a few subtle signals that help: the way the pitcher winds up, the way he throws, the spin of the ball's seams. A great batter winnows out all the extraneous perceptual distractions, seeing only these variations in pitches, and through practice he forms distinct mental models based on a different set of cues for each kind of pitch. He connects these models to what he knows about batting stance, strike zone, and swinging so as to stay on top of the ball. These he connects to mental models of player positions: if he's got guys on first and second, maybe he'll sacrifice to move the runners ahead. If he's got men on first and third and there is one out, he's got to keep from hitting into a double play while still hitting to score the runner. His mental models of player positions connect to his models of the opposition (are they playing deep or shallow?) and to the signals flying around from the dugout to the base coaches to him. In a great at-bat, all these pieces come together seamlessly: the batter connects with the ball and drives it through a hole in the outfield, buying the time to get on first and advance his men. Because he has culled out all but the most important elements for identifying and responding to each kind of pitch, constructed mental models out of that learning, and connected those models to his mastery of the other essential elements of this complex game, an expert player has a better chance of scoring runs than a less experienced one who cannot make sense of the vast and changeable information he faces every time he steps up to the plate.

Many people believe that their intellectual ability is hardwired from birth, and that failure to meet a learning challenge is an indictment of their native ability. But every time you learn something new, *you change the brain*—the residue of your experiences is stored. It's true that we start life with the gift of our genes, but it's also true that we become capable through the learning and development of mental models that enable us to reason, solve, and create. In other words, the elements that shape your intellectual abilities lie to a surprising extent within your own control. Understanding that this is so enables you to see failure as a badge of effort and a source of useful information—the need to dig deeper or to try a different strategy. The need to understand that when learning is hard, you're doing important work. To understand that striving and setbacks, as in any action video game or new BMX bike stunt, are essential if you are to surpass your current level of performance toward true expertise. Making mistakes and correcting them builds the bridges to advanced learning.

Empirical Evidence versus Theory, Lore, and Intuition

Much of how we structure training and schooling is based on learning theories that have been handed down to us, and these are shaped by our own sense of what works, a sensibility drawn from our personal experiences as teachers, coaches, students, and mere humans at large on the earth. How we teach and study is largely a mix of theory, lore, and intuition. But over the last forty years and more, cognitive psychologists have been working to build a body of evidence to clarify what works and to discover the strategies that get results.

Cognitive psychology is the basic science of understanding how the mind works, conducting empirical research into how people perceive, remember, and think. Many others have their hands in the puzzle of learning as well. Developmental and educational psychologists are concerned with theories of human development and how they can be used to shape the tools of education—such as testing regimes, instructional organizers (for example topic outlines and schematic illustrations), and resources for special groups like those in remedial and gifted education. Neuroscientists, using new imaging techniques and other tools, are advancing our understanding of brain mechanisms that underlie learning, but we're still a very long way from knowing what neuroscience will tell us about how to improve education.

How is one to know whose advice to take on how best to go about learning?

It's wise to be skeptical. Advice is easy to find, only a few mouse-clicks away. Yet not all advice is grounded in research—far from it. Nor does all that passes as research meet the standards of science, such as having appropriate control conditions to assure that the results of an investigation are objective and generalizable. The best empirical studies are experimental in nature: the researcher develops a hypothesis and then tests it through a set of experiments that must meet rigorous criteria for design and objectivity. In the chapters that follow, we have distilled the findings of a large body of such studies that have stood up under review by the scientific community before being published in professional journals. We are collaborators in some of these studies, but not the lion's share. Where we're offering theory rather than scientifically validated results, we say so. To make our points we use, in addition to tested science, anecdotes from people like Matt Brown whose work requires mastery of complex knowledge and skills, stories that illustrate the underlying principles of how we learn and remember. Discussion of the research studies themselves is kept to a minimum, but you will find many of them cited in the notes at the end of the book if you care to dig further.

People Misunderstand Learning

It turns out that much of what we've been doing as teachers and students isn't serving us well, but some comparatively simple changes could make a big difference. People commonly believe that if you expose yourself to something enough times—say, a textbook passage or a set of terms from an eighth grade biology class—you can burn it into memory. Not so. Many teachers believe that if they can make learning easier and faster, the learning will be better. Much research turns this belief on its head: when learning is harder, it's stronger and lasts longer. It's widely believed by teachers, trainers, and coaches that the most effective way to master a new skill is to give it dogged, single-minded focus, practicing over and over until you've got it down. Our faith in this runs deep, because most of us see fast gains during the learning phase of massed practice. What's apparent from the research is that gains achieved during massed practice are transitory and melt away quickly.

The finding that rereading textbooks is often labor in vain ought to send a chill up the spines of educators and learners, because it's the number one study strategy of most people—including more than 80 percent of college students in some surveys—and is central in what we tell ourselves to do during the hours we dedicate to learning. Rereading has three strikes against it. It is time consuming. It doesn't result in durable memory. And it often involves a kind of unwitting self-deception, as growing familiarity with the text comes to feel like mastery of the content. The hours immersed in rereading can seem like due diligence, but the amount of study time is no measure of mastery.[2]

You needn't look far to find training systems that lean heavily on the conviction that mere exposure leads to learning. Consider Matt Brown, the pilot. When Matt was ready to advance from piston planes, he had a whole new body of knowledge to master in order to get certified for the business jet he was hired to pilot. We asked him to describe this process. His employer sent him to eighteen days of training, ten hours a day, in what Matt called the "fire hose" method of instruction. The first seven days straight were spent in the classroom being instructed in all the plane's systems: electrical, fuel, pneumatics, and so on, how these systems operated and interacted, and all their fail-safe tolerances like pressures, weights, temperatures, and speeds. Matt is required to have at his immediate command about eighty different "memory action items"—actions to take without hesitation or thought in order to stabilize the plane the moment any one of a dozen or so unexpected events occur. It might be a sudden decompression, a thrust reverser coming unlocked in flight, an engine failure, an electrical fire.

Matt and his fellow pilots gazed for hours at mind-numbing PowerPoint illustrations of their airplane's principal systems. Then something interesting happened.

"About the middle of day five," Matt said, "they flash a schematic of the fuel system on the screen, with its pressure sensors, shutoff valves, ejector pumps, bypass lines, and on and on, and you're struggling to stay focused. Then this one instructor asks us, 'Has anybody here had the fuel filter bypass light go on in flight?' This pilot across the room raises his hand. So the instructor says, 'Tell us what happened,' and suddenly you're thinking, Whoa, what if that was me?

"So, this guy was at 33,000 feet or something and he's about to lose both engines because he got fuel without antifreeze in it and his filters are clogging with ice. You hear that story and, believe me, that schematic comes to life and sticks with you. Jet fuel can commonly have a little water in it, and when it gets cold at high altitude, the water will condense out, and it can freeze and block the line. So whenever you refuel, you make good and sure to look for a sign on the fuel truck saying the fuel has Prist in it, which is an antifreeze. And if you ever see that light go on in flight, you're going to get yourself down to some warmer air in a hurry."[3] Learning is stronger when it matters, when the abstract is made concrete and personal.

Then the nature of Matt's instruction shifted. The next eleven days were spent in a mix of classroom and flight simulator training. Here, Matt described the kind of active engagement that leads to durable learning, as the pilots had to grapple with their aircraft to demonstrate mastery of standard operating procedures, respond to unexpected situations, and drill on the rhythm and physical memory of the movements that are required in the cockpit for dealing with them. A flight simulator provides retrieval practice, and the practice is spaced, interleaved, and varied and involves as far as possible the same mental processes Matt will invoke when he's at altitude. In a simulator, the abstract is made concrete and personal. A simulator is also a series of tests, in that it helps Matt and his instructors calibrate their judgment of where he needs to focus to bring up his mastery.

In some places, like Matt Brown's flight simulator, teachers and trainers have found their way to highly effective learning techniques, yet in virtually any field, these techniques tend to be the exception, and "fire hose" lectures (or their equivalent) are too often the norm.

In fact, what students are advised to do is often plain wrong. For instance, study tips published on a website at George Mason University include this advice: "The key to learning something well is repetition; the more times you go over the material the better chance you have of storing it permanently."[4] Another, from a Dartmouth College website, suggests: "If you intend to remember something, you probably will."[5] A public service piece that runs occasionally in the *St. Louis Post-Dispatch* offering study advice shows a kid with his nose buried in a book. "Concentrate," the caption reads. "Focus on one thing and one thing only. Repeat, repeat, repeat! Repeating what you have to remember can help burn it into your memory."[6] Belief in the power of rereading, intentionality, and repetition is pervasive, but the truth is you usually can't embed something in memory simply by repeating it over and over. This tactic might work when looking up a phone number and holding it in your mind while punching it into your phone, but it doesn't work for durable learning.

A simple example, reproduced on the Internet (search "penny memory test"), presents a dozen different images of a common penny, only one of which is correct. As many times as you've seen a penny, you're hard pressed to say with confidence which one it is. Similarly, a recent study asked faculty and students who worked in the Psychology Building at UCLA to identify the fire extinguisher closest to their office. Most failed the test. One professor, who had been at UCLA for twenty-five years, left his safety class and decided to look for the fire extinguisher closest to his office. He discovered that it was actually right next to his office door, just inches from the doorknob he turned every time he went into his office. Thus, in this case, even years of repetitive exposure did not result in his learning where to grab the closest extinguisher if his wastebasket caught fire.[7]

Early Evidence

The fallacy in thinking that repetitive exposure builds memory has been well established through a series of investigations going back to the mid-1960s, when the psychologist Endel Tulving at the University of Toronto began testing people on their ability to remember lists of common English nouns. In a first phase of the experiment, the participants simply read a list of paired items six times (for example, a pair on the list might be "chair—9"); they did not expect a memory test. The first item in each pair was always a noun. After reading the listed pairs six times, participants were then told that they would be getting a list of nouns that they would be asked to remember. For one group of people, the nouns were the same ones they had just read six times in the prior reading phase; for another group, the nouns to be learned were different from those they had previously read. Remarkably, Tulving found that the two groups' learning of the nouns did not differ—the learning curves were statistically indistinguishable. Intuition would suggest otherwise, but prior exposure did not aid later recall. Mere repetition did not enhance learning. Subsequent studies by many researchers have pressed further into questions of whether repeated exposure or longer periods of holding an idea in mind contribute to later recall, and these studies have confirmed and elaborated on the findings that repetition by itself does not lead to good long-term memory.[8]

These results led researchers to investigate the benefits of rereading texts. In a 2008 article in *Contemporary Educational Psychology,* Washington University scientists reported on a series of studies they conducted at their own school and at the University of New Mexico to shed light on rereading as a strategy to improve understanding and memory of prose. Like most research, these studies stood on the shoulders of earlier work by others; some showed that when the same text is read multiple times the same inferences are made and the same connections between topics are formed, and others suggested modest benefits from rereading. These benefits had been found in two different situations. In the first, some students read and immediately reread study material, whereas other students read the material only once. Both groups took an immediate test after reading, and the group who had read twice performed a bit better than the group who had read once. However, on a delayed test the benefit of immediate rereading had worn off, and the rereaders performed at the same level as the one-time readers. In the other situation, students read the material the first time and then waited some days before they reread it. This group, having done spaced readings of the text, performed better on the test than the group who did not reread the material.[9]

Subsequent experiments at Washington University, aimed at teasing apart some of the questions the earlier studies had raised, assessed the benefits of rereading among students of differing abilities, in a learning situation paralleling that faced by students in classes. A total of 148 students read five different passages taken from textbooks and *Scientific American*. The students were at two different universities; some were high-ability readers, and others were low-ability; some students read the material only once, and others read it twice in succession. Then all of them responded to questions to demonstrate what they had learned and remembered.

In these experiments, multiple readings in close succession did not prove to be a potent study method for either group, at either school, in any of the conditions tested. In fact, the researchers found no rereading benefit at all under these conditions.

What's the conclusion? It makes sense to reread a text once if there's been a meaningful lapse of time since the first reading, but doing multiple readings in close succession is a time-consuming study strategy that yields negligible benefits at the expense of much more effective strategies that take less time. Yet surveys of college students confirm what professors have long known: highlighting, underlining, and sustained poring over notes and texts are the most-used study strategies, by far.[10]

Illusions of Knowing

If rereading is largely ineffective, why do students favor it? One reason may be that they're getting bad study advice. But there's another, subtler way they're pushed toward this method of review, the phenomenon mentioned earlier: rising familiarity with a text and fluency in reading it can create an illusion of mastery. As any professor will attest, students work hard to capture the precise wording of phrases they hear in class lectures, laboring under the misapprehension that the essence of the subject lies in the syntax in which it's described. Mastering the lecture or the text is not the same as mastering the ideas behind them. However, repeated reading provides the illusion of mastery of the underlying ideas. Don't let yourself be fooled. The fact that you can repeat the phrases in a text or your lecture notes is no indication that you understand the significance of the precepts they describe, their application, or how they relate to what you already know about the subject.

Too common is the experience of a college professor answering a knock on her office door only to find a first-year student in distress, asking to discuss his low grade on the first test in introductory psychology. How is it possible? He attended all the lectures and took diligent notes on them. He read the text and highlighted the critical passages.

How did he study for the test? she asks.

Well, he'd gone back and highlighted his notes, and then reviewed the highlighted notes and his highlighted text material several times until he felt he was thoroughly familiar with all of it. How could it be that he had pulled a D on the exam?

Had he used the set of key concepts in the back of each chapter to test himself? Could he look at a concept like "conditioned stimulus," define it, and use it in a paragraph? While he was reading, had he thought of converting the main points of the text into a series of questions and then later tried to answer them while he was studying? Had he at least rephrased the main ideas in his own words as he read? Had he tried to relate them to what he already knew? Had he looked for examples outside the text? The answer was no in every case.

He sees himself as the model student, diligent to a fault, but the truth is he doesn't know how to study effectively.

The illusion of mastery is an example of poor metacognition: what we know about what we know. Being accurate in your judgment of what you know and don't know is critical for decision making. The problem was famously (and prophetically) summed up by Secretary of State Donald Rumsfeld in a 2002 press briefing about US intelligence on Iraq's possible possession of weapons of mass destruction: "There are known knowns; there are things we know that we know. There are known unknowns; that is to say, there are things that we now know we don't know. But there are also unknown unknowns—*there are things we do not know we don't know.*"

The emphasis here is ours. We make it to drive home the point that students who don't quiz themselves (and most do not) tend to overestimate how well they have mastered class material. Why? When they hear a lecture or read a text that is a paragon of clarity, the ease with which they follow the argument gives them the feeling that they already know it and don't need to study it. In other words, they tend not to know what they don't know; when put to the test, they find they cannot recall the critical ideas or apply them in a new context. Likewise, when they've reread their lecture notes and texts to the point of fluency, their fluency gives them the false sense that they're in possession of the underlying content, principles, and implications that constitute real learning, confident that they can recall them at a moment's notice. The upshot is that even the most diligent students are often hobbled by two liabilities: a failure to know the areas where their learning is weak—that is, where they need to do more work to bring up their knowledge—and a preference for study methods that create a false sense of mastery.[11]

Knowledge: Not Sufficient, but Necessary

Albert Einstein declared "creativity is more important than knowledge," and the sentiment appears to be widely shared by college students, if their choice in t-shirt proclamations is any indication. And why wouldn't they seize on the sentiment? It embodies an obvious and profound truth, for without creativity where would our scientific, social, or economic breakthroughs come from? Besides which, accumulating knowledge can feel like a grind, while creativity sounds like a lot more fun. But of course the dichotomy is false. You wouldn't want to see that t-shirt on your neurosurgeon or on the captain who's flying your plane across the Pacific. But the sentiment has gained some currency as a reaction to standardized testing, fearing that this kind of testing leads to an emphasis on memorization at the expense of high-level skills. Notwithstanding the pitfalls of standardized testing, what we really ought to ask is how to do better at building knowledge *and* creativity, for without knowledge you don't have the foundation for the higher-level skills of analysis, synthesis, and creative problem solving. As the psychologist Robert Sternberg and two colleagues put it, "one cannot apply what one knows in a practical manner if one does not know anything to apply."[12]

Mastery in any field, from cooking to chess to brain surgery, is a gradual accretion of knowledge, conceptual understanding, judgment, and skill. These are the fruits of variety in the practice of new skills, and of striving, reflection, and mental rehearsal. Memorizing facts is like stocking a construction site with the supplies to put up a house. Building the house requires not only knowledge of countless different fittings and materials but conceptual understanding, too, of aspects like the load-bearing properties of a header or roof truss system, or the principles of energy transfer and conservation that will keep the house warm but the roof deck cold so the owner doesn't call six months later with ice dam problems. Mastery requires both the possession of ready knowledge and the conceptual understanding of how to use it.

When Matt Brown had to decide whether or not to kill his right engine he was problem solving, and he needed to know from memory the procedures for flying with a dead engine and the tolerances of his plane in order to predict whether he would fall out of the air or be unable to straighten up for landing. The would-be neurosurgeon in her first year of med school has to memorize the whole nervous system, the whole skeletal system, the whole muscular system, the humeral system. If she can't, she's not going to be a neurosurgeon. Her success will depend on diligence, of course, but also on finding study strategies that will enable her to learn the sheer volume of material required in the limited hours available.

Testing: Dipstick versus Learning Tool

There are few surer ways to raise the hackles of many students and educators than talking about testing. The growing focus over recent years on standardized assessment, in particular, has turned testing into a lightning rod for frustration over how to achieve the country's education goals. Online forums and news articles are besieged by readers who charge that emphasis on testing favors memorization at the expense of a larger grasp of context or creative ability; that testing creates extra stress for students and gives a false measure of ability; and so on. But if we stop thinking of testing as a dipstick to measure learning—if we think of it as practicing retrieval of learning from memory rather than "testing," we open ourselves to another possibility: *the use of testing as a tool for learning*.

One of the most striking research findings is the power of active retrieval—testing—to strengthen memory, and that the more effortful the retrieval, the stronger the benefit. Think flight simulator versus PowerPoint lecture. Think quiz versus rereading. The act of retrieving learning from memory has two profound benefits. One, it tells you what you know and don't know, and therefore where to focus further study to improve the areas where you're weak. Two, recalling what you have learned causes your brain to reconsolidate the memory, which strengthens its connections to what you already know and makes it easier for you to recall in the future. In effect, retrieval—testing—interrupts forgetting. Consider an eighth grade science class. For the class in question, at a middle school in Columbia, Illinois, researchers arranged for part of the material covered during the course to be the subject of low-stakes quizzing (with feedback) at three points in the semester. Another part of the material was never quizzed but was studied three times in review. In a test a month later, which material was better recalled? The students averaged A- on the material that was quizzed and C+ on the material that was not quizzed but reviewed.[13]

In Matt Brown's case, even after ten years piloting the same business jet, his employer reinforces his mastery every six months in a battery of tests and flight simulations that require him to retrieve the information and maneuvers that are essential to stay in control of his plane. As Matt points out, you hardly ever have an emergency, so if you don't practice what to do, there's no way to keep it fresh.

Both of these cases—the research in the classroom and the experience of Matt Brown in updating his knowledge—point to the critical role of retrieval practice in keeping our knowledge accessible to us when we need it. The power of active retrieval is the topic of Chapter 2.[14]

The Takeaway

For the most part, we are going about learning in the wrong ways, and we are giving poor advice to those who are coming up behind us. A great deal of what we think we know about how to learn is taken on faith and based on intuition but does not hold up under empirical research. Persistent illusions of knowing lead us to labor at unproductive strategies; as recounted in Chapter 3, this is true even of people who have participated in empirical studies and seen the evidence for themselves, firsthand. Illusions are potent persuaders. One of the best habits a learner can instill in herself is regular self-quizzing to recalibrate her understanding of what she does and does not know. Second Lieutenant Kiley Hunkler, a 2013 graduate of West Point and winner of a Rhodes Scholarship, whom we write about in Chapter 8, uses the phrase "shooting an azimuth" to describe how she takes practice tests to help refocus her studying. In overland navigation, shooting an azimuth means climbing to a height, sighting an object on the horizon in the direction you're traveling, and adjusting your compass heading to make sure you're still gaining on your objective as you beat through the forest below.

The good news is that we now know of simple and practical strategies that anybody can use, at any point in life, to learn better and remember longer: various forms of retrieval practice, such as low-stakes quizzing and self-testing, spacing out practice, interleaving the practice of different but related topics or skills, trying to solve a problem before being taught the solution, distilling the underlying principles or rules that differentiate types of problems, and so on. In the chapters that follow we describe these in depth. And because learning is an iterative process that requires that you revisit what you have learned earlier and continually update it and connect it with new knowledge, we circle through these topics several times along the way. At the end, in Chapter 8, we pull it all together with specific tips and examples for putting these tools to work.