phrasing something can make your mind look at the problem from a different angle and spark understanding.

3. I think most clearly when I'm driving. Sometimes I'll just take a break and drive around—this helps a lot. I have to be somewhat occupied because if I just sit down and think I end up getting bored or distracted and can't concentrate.

{ 3 }

learning is creating:

Lessons from Thomas Edison's Frying Pan

Thomas Edison was one of the most prolific inventors in history, with more than one thousand patents to his name. *Nothing* got in the way of his creativity. Even as his lab was burning to the ground in a horrific accidental fire, Edison was excitedly sketching up plans for a new lab, even bigger and better than before. How could Edison be so phenomenally creative? The answer, as you'll see, relates to his unusual tricks for shifting his mode of thinking.

Shifting between the Focused and Diffuse Modes

For most people, shifting from focused to diffuse mode happens naturally if you distract yourself and then allow a little time to pass. You can go for a walk, take a nap, or go to the gym. Or you can work on something that occupies other parts of your brain: listening to music, conjugating Spanish verbs, or cleaning your gerbil cage.[1] *The*

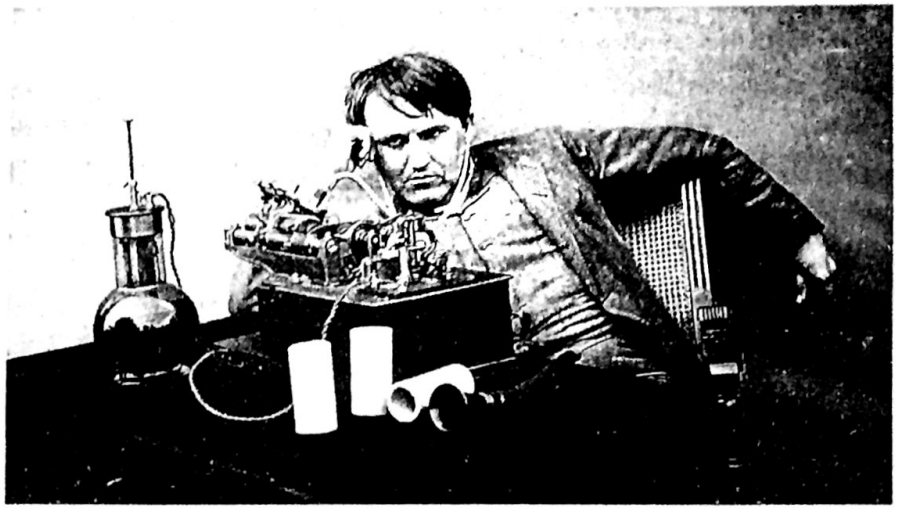
key is to do something else until your brain is consciously free of any thought of the problem. Unless other tricks are brought into play, this generally takes several hours. You may say, "I don't have that kind of time." You do, however, if you simply switch your focus to other things you need to do, and mix in a little relaxing break time.

Creativity expert Howard Gruber has suggested that one of the three *B*'s usually seems to do the trick: the bed, the bath, or the bus.[2] One remarkably inventive chemist of the mid-1800s, Alexander Williamson, observed that a solitary walk was worth a week in the laboratory in helping him progress in his work.[3] (Lucky for him there were no smartphones then.) Walking spurs creativity in many fields; a number of famous writers, such as Jane Austen, Carl Sandburg, and Charles Dickens, found inspiration during their frequent long walks.

Once you are distracted from the problem at hand, the diffuse mode has access and can begin pinging about in its big-picture way to settle on a solution.[4] After your break, when you return to the problem at hand, you will often be surprised at how easily the solution pops into place. Even if the solution doesn't appear, you will often be further along in your understanding. It can take a lot of hard focused-mode work beforehand, but the sudden, unexpected solution that emerges from the diffuse mode can make it feel almost like the "aha!" mode.

That whispered, intuitive solution to whatever puzzle you are attempting to deal with is one of the most elusively cool feelings of math and science—and art, literature, and anything else creative, for that matter! And yes, as you'll see, *math and science are deeply creative forms of thinking even when you are just learning them in school.*

That twilight, disconnected feeling one experiences while drifting off to sleep was, it seems, part of the magic behind Edison's extraordinary creativity. When faced with a difficult problem, instead of focusing intently on it, Edison, according to legend, took a



Brilliant inventor Thomas Edison *(above)* is thought to have used a clever trick to switch from focused to diffuse mode. This was the same trick used by famed surrealist painter Salvador Dalí *(below)* for his artistic creations.

nap. But he did so while sitting in a lounge chair, holding a ball bearing in his hand above a plate on the floor. As he relaxed, his thoughts moved toward free and open diffuse-mode thinking. (This is a reminder that falling asleep is a good way to get the brain thinking loosely about a problem you want to solve, or anything you are working on creatively.) When Edison fell asleep, the ball bearing fell from his hands. The clatter woke him so he could grasp the fragments of his diffuse-mode thinking to create new approaches.[5]

Creativity Is about Harnessing and Extending Your Abilities

There is a deep connection between technical, scientific, and artistic creativity. Wild surrealist painter Salvador Dalí, like Thomas Edison, also used a nap and the clatter of an object falling from his hand to tap into *his* diffuse-mode creative perspectives. (Dalí called this "sleeping without sleeping."[6]) **Enlisting the diffuse mode helps you learn at a deep and creative level.** There is much creativity underlying math and science problem solving. Many people think that there's only one way to do a problem, but there are often a number of different solutions, if you have the creativity to see them. For example, there are more than *three hundred* different known proofs of the Pythagorean theorem. As we will soon learn, technical problems and their solutions may be considered a form of poetry.

Creativity, however, is more than simply having a developed set of scientific or artistic capabilities. It is about harnessing and extending your abilities. Many people think they are not creative, when that is simply untrue. We *all* have the ability to make new neural connections and pull from memory something that was never put there in the first place—what creativity researchers Liane Gabora and Apara Ranjan refer to as "the magic of creativity."[7] Understanding how your mind works helps you better understand the creative nature of some of your thoughts.

NOW YOU TRY!

From Focused to Diffuse

Read the following sentence and identify how many errors it contains:

Thiss sentence contains threee errors.

The first two errors are easily discovered using a focused-mode approach. The third, paradoxical error becomes obvious only when you change perspectives and adopt a more diffuse approach.[8] (Remember, the solution is in the endnote.)

Working Back and Forth between Modes to Master Material

Edison's story reminds us of something else. *We learn a great deal from our failures in math and science.*[9] Know that you are making progress with each mistake you catch when trying to solve a problem—finding errors should give you a sense of satisfaction. Edison himself is said to have noted "I have not failed. I've just found 10,000 ways that won't work."[10]

Mistakes are inevitable. To work past them, start early on your assignments and, unless you are really enjoying what you are doing, *keep your working sessions short.* Remember, when you take breaks, your diffuse mode is still working away in the background. It's the best deal around—you continue to learn while you are taking it easy. Some people think they never enter diffuse mode, but that's simply not true. Every time you relax and think of nothing in par-

ticular, your brain enters into a natural default mode that's a form of diffuse thinking. Everybody does this.[11]

Sleep is probably the most effective and important factor in allowing your diffuse mode to tackle a difficult problem. But don't be fooled by the diffuse mode's seemingly easygoing, sometimes sleepy nature. One way to think of the diffuse mode is as a base station when you are mountain climbing. Base stations are essential resting spots in the long journey to difficult mountaintops. You use them to pause, reflect, check your gear, and make sure you've got the right route picked out. But you would never confuse resting at a base station with the hard work of getting to the top of a mountain. **In other words, just using your diffuse mode doesn't mean you can lollygag around and expect to get anywhere.** As the days and weeks pass, it's the distributed practice—the back and forth between focused-mode attention and diffuse-mode relaxation—that does the trick.[12]

Enlisting the focused mode, which is often what you need to do to first get a problem into your brain, requires your full attention. Studies have shown that we have only so much mental energy—willpower—for this type of thinking.[13] When your energy flags, sometimes you can take a break by jumping to other focused-type tasks, such as switching from studying math to studying French vocabulary. But the longer you spend in focused mode, the more mental resources you use. It's like a concentrated, extended set of mental weight lifting. That's why brief interludes that involve movement or talking with friends, where you don't have to concentrate intently, can be so refreshing.

You may want your learning to progress more quickly—to somehow command your diffuse mode to assimilate new ideas faster. But compare it to exercise. Constantly lifting weights won't make your muscles any bigger—your muscles need time to rest and grow before you use them again. Taking time off between weight sessions helps build strong muscles in the long run. Consistency over time is key!

USE THESE DIFFUSE-MODE TOOLS AS REWARDS AFTER FIRM FOCUSED-MODE WORK[14]

General Diffuse-Mode Activators

- Go to the gym
- Play a sport like soccer or basketball
- Jog, walk, or swim
- Dance
- Go for a drive (or tag along for the ride)
- Draw or paint
- Take a bath or shower
- Listen to music, especially without words
- Play songs you know well on a musical instrument
- Meditate or pray
- Sleep (the ultimate diffuse mode!)

The following diffuse-mode activators are best used briefly, as rewards. (These activities may pull you into a more focused mode than the preceding activities.)

- Play video games
- Surf the web
- Talk to friends
- Volunteer to help someone with a simple task
- Read a relaxing book
- Text friends
- Go to a movie or play
- Television (dropping a remote if you fall asleep doesn't count)

Don't Worry about Keeping Up with the Intellectual Joneses

Students who are beginning to struggle in math and science often look at others who are intellectual racehorses and tell themselves they *have* to keep up. Then they don't give themselves the extra time they need to truly master the material, and they fall still further behind. As a result of this uncomfortable and discouraging situation, students end up unnecessarily dropping out of math and science.

Take a step back and look dispassionately at your strengths and weaknesses. If you need more time to learn math and science, that's simply the reality. If you're in high school, try to arrange your schedule to give yourself the time you need to focus on the more difficult materials, and limit these materials to manageable proportions. If you're in college, try to avoid a full load of heavy courses, especially if you are working on the side. A lighter load of math and science courses can, for many, be the equivalent of a heavy load of other types of courses. Especially in the early stages of college, avoid the temptation to keep up with your peers.

You may be surprised to discover that learning slowly can mean you learn more deeply than your fast-thinking classmates. One of the most important tricks that helped me retool my brain was learning to avoid the temptation to take too many math and science classes at once.

Avoid *Einstellung* (Getting Stuck)

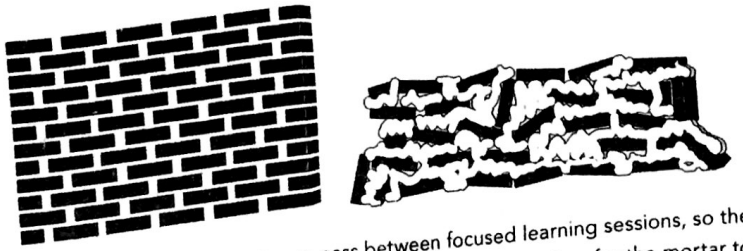
Remember, accepting the first idea that comes to mind when you are working on an assignment or test problem can prevent you from finding a better solution. Chess players who experience *Einstellung* truly believe they are scanning the board for a different solution. But careful study of where their eyes are moving shows that they are keeping their focus on the original solution. *Not only their eyes, but their mind itself can't move away enough to see a new approach to the problem.*[15]

According to recent research, *blinking is a vital activity that provides another means of reevaluating a situation.* Closing our eyes seems to provide a micropause that momentarily deactivates our attention and allows us, for the briefest of moments, to refresh and renew our consciousness and perspective.[16] So blinking may momentarily disconnect us from our focused-mode perspective. But on the other hand, deliberately closing our eyes may help us focus more deeply—people often look away or close or cover their eyes to avoid distractions as they concentrate on thinking of an answer.[17]

Now we can begin to understand Magnus Carlsen and his genius for appreciating the importance of seemingly trivial distractions. When Carlsen stood and turned his glance—and his attention—toward other chess boards, he may have been helping his mind leap momentarily out of focused mode. Turning his eyes and attention elsewhere likely was critical in allowing his diffuse intuition to go to work on his game with Kasparov. How was Carlsen able to switch modes so quickly to gain his sudden insights? His expertise in chess probably played a role, along with his own intuitive practice skills. This is a hint that you, too, may be able to develop ways to quickly toggle between the focused and diffuse modes as you develop your expertise in a subject.

Incidentally, Carlsen probably also knew his bouncing from his chair would distract Kasparov. Even slight distractions at that level of play can be disconcerting—a reminder for you that deep focused attention is an important resource that you don't want to get pulled out of. (Unless, that is, it's time to purposefully take a step back and let the diffuse mode take over.)

Figuring out a difficult problem or learning a new concept almost always requires one or more periods when you aren't consciously working on the problem. Each interlude in which you are not directly focused on the problem allows your diffuse mode to look at it in a fresh way. When you turn your focused attention back to the problem, you consolidate new ideas and patterns that the diffuse mode has delivered.



Learning well means allowing time to pass between focused learning sessions, so the neural patterns have time to solidify properly. It's like allowing time for the mortar to dry when you are building a brick wall, as shown on the left. Trying to learn everything in a few cram sessions doesn't allow time for neural structures to become consolidated in your long-term memory—the result is a jumbled pile of bricks like those on the right.

ALTERNATING FOCUSED AND DIFFUSE THINKING

"As a piano player for a decade and a half, I sometimes found myself facing a particularly difficult run. I just couldn't get it, so I would force my fingers to do it over and over again (albeit very slowly or incorrectly), and then I'd take a break. The next day when I tried it again, I would be able to play it perfectly, as if by magic.

"I tried taking a break today with a calculus problem that was tricky and was starting to infuriate me. In the car on the way to the Renaissance festival, it came to me and I had to write it on a napkin before I forgot! (Always have napkins in your car. You never know.)"

—Trevor Drozd, junior, computer science

The resting times between your focused-mode efforts should be long enough to get your conscious mind completely off the problem you're working on. Usually a few hours is long enough for the diffuse mode to make significant progress but not so long that its insights fade away before being passed on to the focused mode. A good rule of thumb, when you are first learning new concepts, is not to let things go untouched for longer than a day.

The diffuse mode not only allows you to look at the material in new ways but also appears to allow you to synthesize and incorporate the new ideas in relation to what you already know. This idea of looking from fresh perspectives also gives us insight on why "sleeping on it" before making major decisions is generally a good idea,[18] and why taking vacations is important.

The tension between the focused and diffuse modes of learning takes time for your brain to resolve as you work your way through learning new concepts and solving new problems. Working in the focused mode is like providing the bricks, while working in the diffuse mode is like gradually joining the bricks together with mortar. The patient ability to keep working away, a little bit at a time, is important. This is why, if procrastination is an issue for you, it will be critical to learn some of the upcoming neural tricks to effectively address it.

NOW YOU TRY!

Observe Yourself

Next time you find yourself becoming frustrated at something or someone, try taking a mental step back and observing your reaction. Anger and frustration can occasionally have their place in motivating us to succeed, but they can also shut down key areas of the brain that we need in order to learn. Rising frustration is usually a good time-out signal for you, signaling that you need to shift to diffuse mode.

What to Do When You're *Really* Stumped

People with strong self-control can have the most difficulty in getting themselves to *turn off* their focused mode so that the diffuse mode can begin its work. After all, they've been successful because sometimes they could keep going when others flagged. If you often find yourself in this situation, you can use another trick. Make it a rule to listen to study partners, friends, or loved ones who can sense when you are becoming dangerously frustrated. Sometimes it's easier to listen to someone else than to yourself. (When my husband or children, for example, tell me to stop working with a buggy piece of software, I follow this rule myself, albeit always begrudgingly at the time.)

Speaking of talking to other people, when you're genuinely stuck, nothing is more helpful than getting insight from classmates, peers, or the instructor. Ask someone else for a different perspective on how to solve the problem or a different analogy to understand the concept; however, it's best that you first wrestle with the problem yourself *before* you talk to anyone else, because it can embed the basic concepts deeply enough that you become receptive to the explanation. Learning often means making sense of what we've ingested, and for that, we need to have ingested something. (I remember belligerently staring at my science teachers in high school, blaming them for my lack of understanding, without realizing that I was the one who needed to take the initial steps.) And don't wait until the week before midterms or final exams for this assistance. Go early and often. The teacher can often rephrase or explain in a different way that allows you to grasp the topic.

FAILURE CAN BE A GREAT TEACHER

"When I was in tenth grade I decided to take an AP computer science class. I ended up failing the AP exam. But I would not accept the failure, so I took the class and the test again the following year. Somehow, staying away from programming for nearly a year and then coming back to it made me realize how much I truly enjoyed it. I passed the test easily on the second try. If I had been too afraid of failure to take the computer science class the first time, and then a second time, I would certainly not be what I am today, a passionate and happy computer scientist."

—Cassandra Gordon, sophomore, computer science

NOW YOU TRY!

Understand the Paradoxes of Learning

Learning is often paradoxical. The very thing we need in order to learn impedes our ability to learn. We need to focus intently to be able to solve problems—yet that focus can also block us from accessing the fresh approach we may need. Success is important, but critically, so is failure. Persistence is key—but misplaced persistence causes needless frustration.

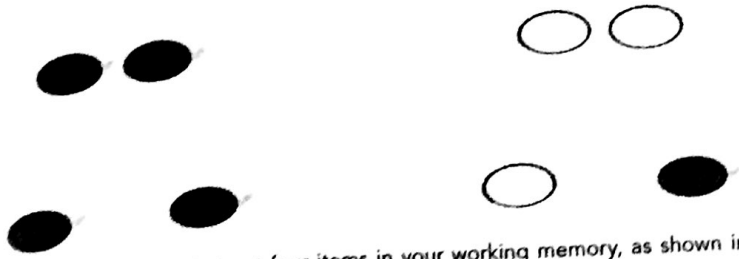
Throughout this book, you will encounter many paradoxes of learning. Can you anticipate what some of them might be?

Introduction to Working and Long-Term Memory

At this point, it's helpful to touch on some of the basics of memory. For our purposes, we're going to talk about only two major memory systems: *working memory* and *long-term memory*.[19]

Working memory is the part of memory that has to do with what you are immediately and consciously processing in your mind. It used to be thought that our working memory could hold around seven items, or "chunks," but it's now widely believed that the working memory holds only about four chunks of information. (We tend to automatically group memory items into chunks, so it seems our working memory is bigger than it actually is.[20])

You can think of working memory as the mental equivalent of a juggler. The four items only stay in the air—or in working memory—because you keep adding a little energy. This energy is needed so your metabolic vampires—natural dissipating processes—don't suck the memories away. In other words, you need to maintain these memories actively; otherwise, your body will divert your energy elsewhere, and you'll forget the information you've taken in.



Generally, you can hold about four items in your working memory, as shown in the four-item memory on the left. When you master a technique or concept in math or science, it occupies less space in your working memory. This frees your mental thinking space so that it can more easily grapple with other ideas, as shown on the right.

Your working memory is important in learning math and science because it's like your own private mental blackboard where you can jot down a few ideas that you are considering or trying to understand.

How do you keep things in working memory? Often it's through rehearsal; for example, you can repeat a phone number to yourself

until you have a chance to write it down. You may find yourself shutting your eyes to keep any other items from intruding into the limited slots of your working memory as you concentrate.

In contrast, **long-term memory might be thought of as a storage warehouse.** Once items are in there, they generally stay put. The warehouse is large, with room for billions of items, and it can be easy for stored parcels to get buried so deeply that it's difficult to retrieve them. Research has shown that when your brain first puts an item of information in long-term memory, you need to revisit it a few times to increase the chances you'll later be able to find it when you need it.[21] (Techie types sometimes equate short-term memory to random-access memory [RAM], and long-term memory to hard drive space.)

Long-term memory is important for learning math and science because it is where you store the fundamental concepts and techniques that you need to use in problem solving. It takes time to move information from working memory to long-term memory. To help with this process, use a technique called *spaced repetition*. As you may have guessed, this technique involves repeating what you are trying to retain, like a new vocabulary word or a new problem-solving technique, but spacing this repetition out over a number of days.

Putting a day between bouts of repetition—extending your practice over a number of days—does make a difference. Research has shown that if you try to glue things into your memory by repeating something twenty times in one evening, for example, it won't stick nearly as well as it will if you practice it the same number of times over several days or weeks.[22] This is similar to building the brick wall we saw earlier. If you don't leave time for the mortar to dry (time for the synaptic connections to form and strengthen), you won't have a very good structure.

NOW YOU TRY!

Let Your Mind Work in the Background

The next time you are tackling a tough problem, work on it for a few minutes. When you get stuck, move on to another problem. Your diffuse mode can continue working on the tougher problem in the background. When you later return to the tougher problem, you will often be pleasantly surprised by the progress you've made.

ADVICE ON SLEEPING

"Many people will tell you that they can't nap. The one thing I learned from a single yoga class I took many years ago was to slow down my breathing. I just keep breathing slowly in and out and don't think *I must fall asleep.* Instead, I think things like, *Sleepytime!* and just focus on my breathing. I also make sure it's dark in the room, or I cover my eyes with one of those airplane sleep masks. Also, I set my phone alarm for twenty-one minutes because turning a short power nap into a longer sleep can leave you groggy. This amount of time gives me what's basically a cognitive reboot."

—Amy Alkon, syndicated columnist and catnap queen

The Importance of Sleep in Learning

You may be surprised to learn that simply being awake creates toxic products in your brain. During sleep, your cells shrink, causing a striking increase in the space *between* your cells. This is equivalent to turning on a faucet—it allows fluid to wash past and push the toxins out.[23] This nightly housecleaning is part of what keeps your brain healthy. When you get too little sleep, the buildup of these toxic products is believed to explain why you can't think very clearly. (Too little sleep is affiliated with conditions ranging from Alzheimer's to depression—prolonged sleeplessness is lethal.)

Studies have shown that sleep is a vital part of memory and learning.[24] Part of what this special sleep-time tidying does is erase trivial aspects of memories and simultaneously strengthen areas of importance. During sleep, your brain also rehearses some of the tougher parts of whatever you are trying to learn—going over and over neural patterns to deepen and strengthen them.[25]

Finally, sleep has been shown to make a remarkable difference in people's ability to figure out difficult problems and to find meaning and understanding in what they are learning. It's as if the complete deactivation of the conscious "you" in the prefrontal cortex helps other areas of the brain start talking more easily to one another, allowing them to put together the neural solution to your problem as you sleep.[26] (Of course, you must plant the seed for your diffuse mode by first doing focused-mode work.) It seems that if you go over the material right before taking a nap or going to sleep for the evening, you have an increased chance of dreaming about it. If you go even further and set it in mind that you *want* to dream about the material, it seems to improve your chances of dreaming about it still further.[27] Dreaming about what you are studying can substantially enhance your ability to understand—it somehow consolidates your memories into easier-to-grasp chunks.[28]

If you're tired, it's often best to just go to sleep and get up a little earlier the next day, so your reading is done with a better-rested brain. Experienced learners will attest to the fact that reading for one hour with a well-rested brain is better than reading for three hours with a tired brain. A sleep-deprived brain simply can't make

the usual connections you make during normal thinking processes. Going without sleep the night before an examination can mean that even if you are perfectly prepared, your mind is simply unable to function properly, so you do poorly on the test.

A METHOD FOR MANY DISCIPLINES

Focused and diffuse approaches are valuable for all sorts of fields and disciplines, not just math and science. As Paul Schwalbe, a senior majoring in English, notes:

"If I have trouble working on a problem, I lie down in my bed with an open notebook and pen and just write out thoughts about the problem as I fall asleep, as well as sometimes right after waking up. Some of what I write makes no sense, but sometimes I gain a totally new way of looking at my problem."

SUMMING IT UP

- Use the focused mode to first start grappling with concepts and problems in math and science.
- After you've done your first hard focused work, allow the diffuse mode to take over. Relax and do something different!
- When frustration arises, it's time to switch your attention to allow the diffuse mode to begin working in the background.
- It's best to work at math and science in small doses—a little every day. This gives both the focused and diffuse modes the time they need to do their thing so you can understand what you are learning. That's how solid neural structures are built.

- If procrastination is an issue, try setting a timer for twenty-five minutes and focusing intently on your task without allowing yourself to be drawn aside by text messages, web surfing, or other attractive distractions.
- There are two major memory systems:
  - Working memory—like a juggler who can keep only four items in the air.
  - Long-term memory—like a storage warehouse that can hold large amounts of material, but needs to be revisited occasionally to keep the memories accessible.
- Spaced repetition helps move items from working memory to long-term memory.
- Sleep is a critical part of the learning process. It helps you:
  - Make the neural connections needed for normal thinking processes—which is why sleep the night before a test is so important.
  - Figure out tough problems and find *meaning* in what you are learning.
  - Strengthen and rehearse the important parts of what you are learning and prune away trivialities.

PAUSE AND RECALL

Get up and take a little break—get a glass of water or snack, or pretend you're an electron and orbit a nearby table. As you move, check your recall of the main ideas of this chapter.

ENHANCE YOUR LEARNING

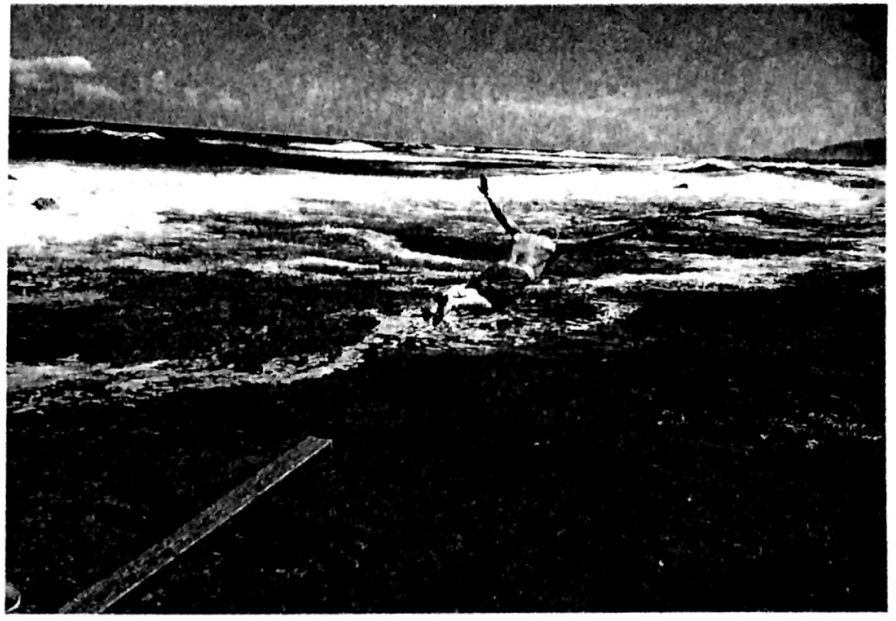
1. Name some activities you would find helpful for switching from focused to diffuse mode.

2. Sometimes you can feel *certain* you have explored new approaches to analyzing a problem, when you actually haven't. What can you do to become more actively aware of your thinking processes to help keep yourself open to other possibilities? Should you *always* keep yourself open to new possibilities?

3. Why is it important to use self-control to make yourself *stop* doing something? Can you think of times outside studying and academics when this skill might also be important?

4. When you are learning new concepts, you want to review the material within a day so that the initial changes you made in your brain don't fade away. But your mind often becomes preoccupied with other matters—it's easy to let several days or more pass before you get around to looking at the material. What kind of action plan could you develop to ensure that you review important new material in a timely fashion?

NEUROPSYCHOLOGIST ROBERT BILDER'S ADVICE ON CREATIVITY



Robert Bilder *just doing it* in Makapu'u, Hawaii

Psychiatry professor Robert Bilder is the director of UCLA's Tennenbaum Center for the Biology of Creativity and leads the "Mind Well" initiative to enhance the creative achievement and psychological well-being of students, staff, and faculty at UCLA.

Research on the biology of creativity suggests several ingredients that we all can bake into our personal recipes for success. Number one is the Nike factor: Just do it!

- *Creativity is a numbers game: The best predictor of how many creative works we produce in our lifetime is . . . the number of works we produce. I sometimes find it excruciating to pull the trigger and expose my work to other people, but every time I do, it turns out for the best.*
- *Dealing with fear: A motivational poster I received after giving a talk at Facebook headquarters reads: "What would*