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Is Drilling Worth It?

Question: Drilling has been given a bad name. The very use of the military term *drill* in place of the more neutral term *practice* implies something mindless and unpleasant that is performed in the name of discipline rather than for the student's profit. Then too, the phrase "drill and kill" has been used as a criticism of some types of instruction; the teacher drills the students, which is said to kill their innate motivation to learn. On the other side of this debate are educational traditionalists who argue that students *must* practice in order to learn some facts and skills they need at their fingertips—for example, math facts such as 5 + 7 = 12. Few teachers would argue that drilling boosts students' motivation and sense of fun. Does the cognitive benefit make it worth the potential cost to motivation?

Answer: The bottleneck in our cognitive system is the extent to which we can juggle several ideas in our mind simultaneously. For example, it's easy to multiply 19 × 6 in your head, but nearly impossible to multiply 184,930 × 34,004. The processes are the same, but in the latter case you "run out of room" in your head to keep track of the numbers. The mind has a few tricks for working around this problem. One of the most effective is practice, because it reduces the amount of "room" that mental work requires. The cognitive principle that guides this chapter is

> It is virtually impossible to become proficient at a mental task without extended practice.

You cannot become a good soccer player if as you're dribbling, you still focus on how hard to hit the ball, which surface of your foot to use, and so on. Low-level processes like this must become automatic, leaving room for more high-level concerns, such as game strategy. Similarly, you cannot become good at algebra without knowing math facts by heart. Students must practice some things. But not all material needs to be practiced. In this chapter I elaborate on why practice is so important, and I discuss which material is important enough to merit practice, and how to implement practice in a way that students find maximally useful and interesting.

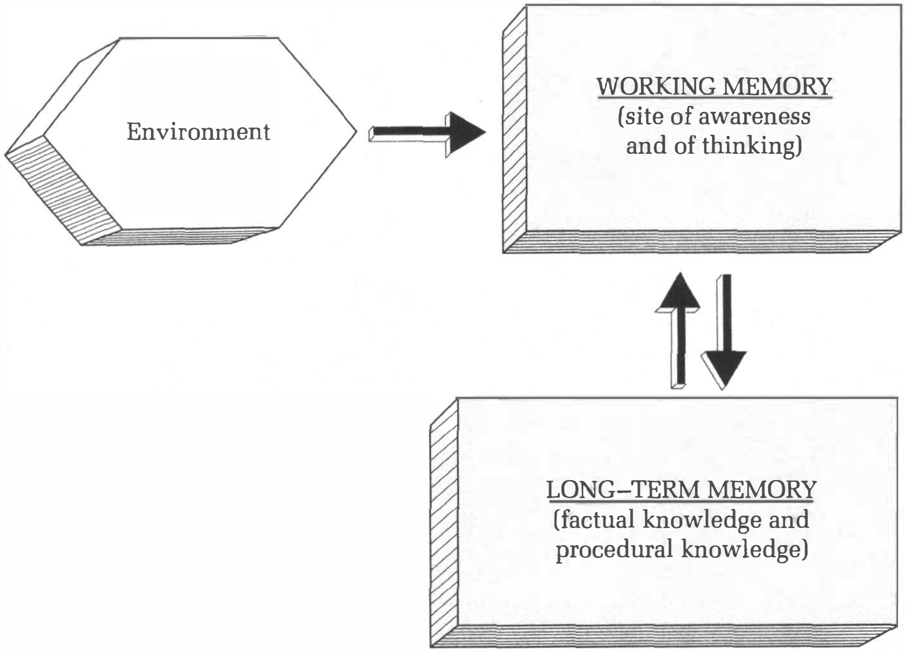

FIGURE 1: Our simple model of the mind.

Why practice? One reason is to gain a minimum level of competence. A child practices tying her shoelaces with a parent or teacher's help until she can reliably tie them without supervision. We also practice tasks that we can perform but that we'd like to improve. A professional tennis player can hit a serve into his opponent's court every time, but he nevertheless practices serving in an effort to improve the speed and placement of the ball. In an educational setting, both reasons—mastery and skill development—seem sensible. Students might practice long division until they master the process, that is, until they can reliably work long-division problems. Other skills, such as writing a persuasive essay, might be performed adequately, but even after students have the rudiments down, they should continue to practice the skill in an effort to refine and improve their abilities.

These two reasons to practice—to gain competence and to improve—are self-evident and probably are not very controversial. Less obvious are the reasons to practice skills when it appears you have mastered something and it's not obvious that practice is making you any better. Odd as it may seem, that sort of practice is essential to schooling. It yields three important benefits: it reinforces the basic skills that are required for the learning of more advanced skills, it protects against forgetting, and it improves transfer.

Practice Enables Further Learning

To understand why practice is so important to students' progress, let me remind you of two facts about how thinking works.

Figure 1 (which you also saw in Chapter One) shows that working memory is the site of thinking. Thinking occurs when you combine information in new ways. That information might be drawn from the environment or from your long-term memory or from both. For example, when you're trying to answer a question like "How are a butterfly and a dragonfly alike?" your thoughts about the characteristics of each insect reside in working memory as you try to find points of comparison that seem important to the question.

A critical feature of working memory, however, is that it has limited space. If you try to juggle too many facts or to compare them in too many ways, you lose track of what you're doing. Suppose I said, "What do a butterfly, a dragonfly, a chopstick, a pillbox, and a scarecrow have in common?"* These are simply too many items to compare simultaneously. As you're thinking about how to relate a pillbox to a chopstick, you've already forgotten what the other items are.

This lack of space in working memory is a fundamental bottleneck of human cognition. You could dream up lots of ways that your cognitive system could be improved—more accurate memory, more focused attention, sharper vision, and so on—but if a genie comes out of a lamp and offers you one way to improve your mind, ask for more working memory capacity. People with more capacity are better thinkers, at least for the type of thinking that's done in school. There is a great deal of evidence that this conclusion is true, and most of it follows a very simple logic: Take one hundred people, measure their working memory capacity, then measure their reasoning ability,† and see whether their scores on each test tend to be the same. To a surprising degree, scoring well on a working-memory test predicts scoring well on a reasoning test, and a poor working-memory score predicts a poor reasoning score (although working memory is not everything—recall that in Chapter Two I emphasized the importance of background knowledge).

Well, you're not going to get more working-memory capacity from a genie. And because this chapter is about practice, you might think I'm going to suggest that students do exercises that will improve their working memory. Sadly, such exercises don't exist. As far as anyone knows, working memory is more or less fixed—you get what you get, and practice does not change it.

There are, however, ways to cheat this limitation. In Chapter Two I discussed at length how to keep more information in working memory by compressing the information. In a process called *chunking,* you treat several separate things as a single unit. Instead of maintaining the letters *c, o, g, n, i, t, i, o,* and *n* in working memory, you chunk them into a single unit, the word *cognition.* A whole word takes up about the same amount of room in working memory that a single letter does. But chunking letters into a word requires that you know the word. If the letters were *p, a, z, z, e, s, c,* and *o,* you could chunk them effectively if you happened to know that *pazzesco* is an Italian word meaning "crazy." But if you didn't have the word in your long-term memory, you could not chunk the letters.

Thus, the first way to cheat the limited size of your working memory is through factual knowledge. There is a second way: you can make the processes that manipulate information in working memory more efficient. In fact, you can make them so efficient that they are virtually cost free. Think about learning to tie your shoes.

FIGURE 2: This fellow has recently learned to tie his shoes. He can tie them every time, but it consumes all of his working memory to do so. With practice, however, the process will become automatic.

Initially it requires your full attention and thus absorbs all of working memory, but with practice you can tie your shoes *automatically* (Figure 2).

What used to take all of the room in working memory now takes almost no room. As an adult you can tie your shoes while holding a conversation or even while working math problems in your head (in the unlikely event that the need arises). Another standard example, as I've already mentioned, is driving a car. When you first learn to drive, doing so takes all of your working-memory capacity. As with tying your shoes, it's the stuff you're *doing* that takes up the mental space—processes like checking the mirrors, monitoring how hard you're pressing the accelerator or brake to adjust your speed, looking at the speedometer, judging how close other cars are. Note that you're not trying to keep a lot of things (like letters) in mind simultaneously; when you do that, you can gain mental space by chunking. In this example, you're trying to do a lot of things in rapid succession. Of course, an experienced driver seems to have no problem in doing all of these things, and can even do other things, such as talk to a passenger.

Mental processes can become automatized. Automatic processes require little or no working memory capacity. They also tend to be quite rapid in that you seem to know just what to do without even making a conscious decision to do it. An experienced driver glances in the mirror and checks his blind spot before switching lanes, without thinking to himself "OK, I'm about to switch lanes, so what I need to do is check my mirrors and glance at the blind spot."

For an example of an automatic process, take a look at Figure 3 and name what each of the line drawings represents. Ignore the words and name the pictures.

As you doubtless noticed, sometimes the words matched the pictures and sometimes they didn't. It probably felt more difficult to name the pictures when there was a mismatch. That's because when an experienced reader sees a printed word, it's quite difficult not to read it. Reading is automatic. Thus the printed word *pants* conflicts with the word you are trying to retrieve, *shirt*. The conflict slows your response. A child just learning to read wouldn't show this interference, because reading is not automatic for him. When faced with the letters *p, a, n, t,* and *s*, the child would need to painstakingly (and thus slowly) retrieve the sounds associated with each letter, knit them together, and recognize that the resulting combination of sounds forms the word *pants.* For the experienced reader, those processes happen in a flash and are a good example of the properties of automatic processes: (1) They happen very quickly. Experienced readers read common words in less than a quarter of a second. (2) They are prompted by a stimulus in the environment, and if that stimulus is present, the process may occur even if you wish it wouldn't. Thus you know it would be easier not to read the words in Figure 3, but you can't seem to avoid doing so. (3) You are not aware of the components of the automatic process. That is, the component processes of reading (for example, identifying letters) are never conscious. The word *pants* ends up in consciousness, but the mental processes necessary to arrive at the conclusion that the word is *pants* do not. The process is very different for a beginning reader, who is aware of each constituent step ("that's a *p*, which makes a 'puh' sound . . .").

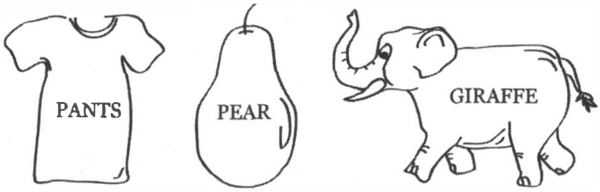

FIGURE 3: Name each picture, ignoring the text. It's hard to ignore when the text doesn't match the picture, because reading is an automatic process.

The example in Figure 3 gives a feel for how an automatic process operates, but it's an unusual example because the automatic process interferes with what you're trying to do. Most of the time automatic processes help rather than hinder. They help because they make room in working memory. Processes that formerly occupied working memory now take up very little space, so there is space for *other* processes. In the case of reading, those "other" processes would include thinking about what the words actually mean. Beginning readers slowly and painstakingly sound out each letter and then combine the sounds into words, so there is no room left in working memory to think about meaning (Figure 4). The same thing can happen even to experienced readers. A high school teacher asked a friend of mine to read a poem out loud. When he had finished reading, she asked what he thought the poem meant. He looked blank for a moment and then admitted he had been so focused on reading without mistakes that he hadn't really noticed what the poem was about. Like a first grader, his mind had focused on word pronunciation, not on meaning. Predictably, the class laughed, but what happened was understandable, if unfortunate.

The same considerations are at play in mathematics. When students are first introduced to arithmetic, they often solve problems by using counting strategies. For example, they solve $5 + 4$ by beginning with 5 and counting up four more numbers to yield the answer 9. This strategy suffices to solve simple problems, but you can see what happens as problems become more complex. For example, in a multidigit problem like $97 + 89$, a counting strategy becomes much less effective. The problem is that this more complex problem demands that more processes be carried out in working memory. The student might add 7 and 9 by counting and get 16 as the result. Now the student must remember to write down the 6, then solve $9 + 8$ by counting, while remembering to add the carried 1 to the result.

The problem is much simpler if the student has memorized the fact that $7 + 9 = 16$, because she arrives at the correct answer for that subcomponent of the problem at a much lower cost to working memory. Finding a fact in long-term memory and putting it into working memory places almost no demands on working memory. It

FIGURE 4: This sentence is written in a simple code: 1 = A, 2 = B, 3 = C, and so on, with a new line denoting a new word. The efforts of a beginning reader are a bit like your efforts to decode this sentence, because the value of each letter must be figured out. If you make the effort to decode the sentence, try doing it without writing down the solution; like the beginning reader, you will likely forget the beginning of the sentence by the time you are decoding the end of the sentence.‡

1
12 15 14 7 19 20 1 14 4 9 14 7
7 15 1 12
15 6
8 21 13 1 14
5 21 13 1 14
5 14 17 21 9 18 25
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20 15
21 14 4 5 18 19 20 1 14 4
15 21 18 19 5 12 22 5 19

is no wonder that students who have memorized math facts do better in all sorts of math tasks than students whose knowledge of math facts is absent or uncertain. And it's been shown that practicing math facts helps low-achieving students do better on more advanced mathematics.

I've given two examples of facts that students often need to retrieve: which sounds go with which letters when reading, and math facts such as 9 + 7 = 16. In both cases, the automatization comes about through memory retrieval—that is, given the right stimulus in the environment, a useful fact pops into working memory. There are other sorts of automatization that entail other processes. Notable examples are handwriting and keyboarding. Initially, forming or keyboarding letters is laborious and consumes all of working memory. It's hard to think of the content of what you're trying to write because you have to focus on getting the letters right; but with practice, you are able to focus on the content. In fact, it's likely that other processes in writing become automatized as well. For more advanced students, rules of grammar and usage are second nature. They don't need to think about the agreement of a sentence's subject and verb, or about refraining from ending a sentence with a preposition.

To review, I've said that working memory is the place in the mind where thinking happens—where we bring together ideas and transform them into something new. The difficulty is that there is only so much room in working memory, and if we try to put too much stuff in there, we get mixed up and lose the thread of the problem we were trying to solve, or the story we were trying to follow, or the factors we were trying to weigh in making a complex decision. People with larger working-memory capacities are better at these thinking tasks. Although we can't make our working memory larger, we *can,* as I have said, make the contents of working memory smaller in two ways: by making facts take up less room through chunking, which requires knowledge in long-term memory and is discussed in Chapter Two; and by shrinking the processes we use to bring information into working memory or to manipulate it once it is there.

So now we get to the payoff: What is required to make these processes shrink, that is, to get them to become automatized? You know the answer: practice. There may be a workaround, a cheat, whereby you can reap the benefits of automaticity without paying the price of practicing. There may be one, but if there is, neither science nor the collected wisdom of the world's cultures has revealed it. As far as anyone knows, the only way to develop mental facility is to repeat the target process again and again and again.

You can see why I said that practice enables further learning. You may have "mastered" reading in the sense that you know which sounds go with which letters, and you can reliably string together sounds into words. So why keep practicing if you know the letters? You practice not just to get faster. What's important is getting so good at recognizing letters that retrieving the sound becomes automatic. If it's automatic, you have freed working-memory space that used to be devoted to retrieving the sounds from long-term memory—space that can now be devoted to thinking about meaning.

What's true of reading is true of most or all school subjects, and of the skills we want our students to have. They are hierarchical. There are basic processes (like retrieving math facts or using deductive logic in science) that initially are demanding of working memory but with practice become automatic. Those processes must become automatic in order for students to advance their thinking to the next level. The great philosopher Alfred North Whitehead captured this phenomenon in this comment: "It is a profoundly erroneous truism, repeated by all copybooks and by eminent people when they are making speeches, that we should cultivate the habit of thinking of what we are doing. The precise opposite is the case. Civilization advances by extending the number of important operations which we can perform without thinking about them."[1]

Practice Makes Memory Long Lasting

Several years ago I had an experience that I'll bet you've had. I happened on some papers from my high school geometry class. I don't think I could tell you three things about geometry today, yet here were problem sets, quizzes, and tests, all in my handwriting, and all showing detailed problem solutions and evidence of factual knowledge.

This sort of experience can make a teacher despair. The knowledge and skills that my high school geometry teacher painstakingly helped me gain have vanished, which lends credence to the occasional student complaint, "We're never gonna *use* this stuff." So if what we teach students is simply going to vanish, what in the heck are we teachers doing?

Well, the truth is that I remember a *little* geometry. Certainly I know much less now than I did right after I finished the class—but I do know more than I did before I took it. Researchers have examined student memory more formally and