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CAROLINE: Hi, everyone. You're listening to the "Talks at Google" podcast, where great minds meet. I'm Caroline, your host for this week's episode with Professor Barbara Oakley. "Talks at Google" brings the world's most influential thinkers, creators, makers, and doers the all to one place. Every episode of this podcast taken from a video that can be seated at youtube.com/talksatgoogle. Dr. Barbara Oakley, a professor of engineering at Oakland University in Rochester, Michigan, has received many awards for her teaching, including the coveted National Science Foundation New Century Scholar award. She also knows firsthand how it feels to struggle with math. She flunked her way through high school math and science courses before enlisting in the Army immediately after graduation.

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When she saw how her lack of mathematical and technical savvy severely limited her options both to rise in the military and to explore other careers, she returned to school with the newfound determination to retool her brain to master the very subjects that had given her so much trouble throughout her entire life. In this episode, Dr. Oakley discusses her book "A Mind for Numbers," which lets us in on secrets to effectively learning math and science, secrets that even dedicated and successful students wish they'd known earlier. And now, here is Dr. Barbara Oakley, "Learning How to Learn." BARBARA OAKLEY: It's such a pleasure to be here, and I'd like to begin by telling you a little story--another one. And this story is about--well, I think all of us love to watch other people to some greater or lesser extent.

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And I love people-watching. And so I have to tell you about this one guy who was one of the most interesting people I have ever watched. And this was when I was working down in Antarctica at McMurdo Station. And this guy's name was Neil. Neil was this thin, wispy little guy was kind of a high-pitched voice, and he had a big head, so he looked like this sort of upside down exclamation point. And what Neil used to like to do is he liked to pick up the phone and answer it with a perfect imitation of the 6'8" gorilla of a station manager, Art Brown. So, one day, the phone rings. Neil picks it up, as usual. "Hello, this is Art Brown speaking". And it was Art Brown on the other end of the line. So Art says, "Who the heck is this?"

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Or more unprintable words to that effect, and Neil says, "Why, Art, this is you. I'm so glad you've finally gotten in touch with yourself." And so that's actually what we're going to do here today is to help you to get more in touch with yourself and what you're doing when you're doing one of the most important things you can do as a human being. And that is to learn new things. Now, to start, I have to tell you a little bit about my background and growing up. I grew up moving all over the place. By the time I'd hit tenth grade, I'd lived in ten different places. Now, moving around a lot like this has some benefits, but it also has some drawbacks or potential drawbacks. And one of the things for me was math is a very sequential topic, and, if you miss it anywhere along the line—

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somebody's a little bit further ahead, and you're from a school where it was a little behind--all of a sudden, you can actually fall off the bandwagon, and then you've fallen off. It's hard to get back on. And that's what happened to me early on. I fell off the math bandwagon. I just said, "I can't do this. I hate it. I really want nothing to do with it at all." Science is the same way, and so I basically flunked my way through elementary, middle, and high school math and science. And it's really funny thinking back on it now because I'm a professor of engineering. And I publish well in some of the top journals, so I do very well as an engineer. But, one day, one of my students found out about my sordid past as a math flunky, and he asked me. He said, "How'd you do it? How'd you change your brain?"

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And I thought, "You know, how did I do it?" I mean, looking back on it, I was just a little kid, and I loved animals, and I liked fluffy, furry things. I liked to knit, and I loved language and studying language. And, at that time, it wasn't-- weren't college loans that were relatively straightforward to get. And, so, I really wanted to learn a language. And I couldn't afford to go to school, so how could I study language in that kind of situation? And there was one way I could do it. I could actually go and learn a language and get paid for it while I was doing it. And that was to join the Army. And, so, that's what I did. I joined the army, and there you see me looking incredibly nervous about to throw a hand grenade, and I did learn a language. I learned Russian, and I ended up working out on Russian trawlers, Soviet trawlers up in the Bering Sea.

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And that's me standing on a bunch of fish there. I can still swear quite well in Russian, although the rest of the Russian is a little rusty. But I loved having adventures and gaining new perspectives, and so I also ended up at the South pole station in Antarctica, and that's where I met my husband. So I always say, "I had to go to the end of the earth to meet that man." And I did. So the thing is, though, what was going on was I began to realize that, you know, I was always interested in these new perspectives, but they were always sort of perspectives that I was kind of comfortable with somehow. You know, and having adventures, that's sort of comfortable thing, but I wasn't actually stretching myself to really have a totally new perspective.

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I thought back on the engineers that I had worked with, west Point engineers, who were in the military, and I realized that their problem-solving skills were, in many ways, exceptional. They could think in a way that I couldn't think. And I thought, "You know, what if I could read these kinds of equations like they could read equations? What if I could, in some sense, learn the language that they were able to speak? Could I actually change my brain to learn in that way, to learn what these people knew?" And, so, as I began to try to answer that student's question, "How did you change your brain?" I started working on a book to kind of describe what some of these key ideas were.
And, while I was working on this book, I did things like I went to ratemyprofessor.com.

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Probably a few of you, if you've been in schools, realize that that's a pretty good website. And I looked to see who were the top professors worldwide teaching subjects like engineering, math, chemistry, physics, economics--a lot of really difficult subjects and a lot of very relevant subjects as well, like psychology, even English--how did they teach so people could learn, and how did they learn themselves? And I also reached out to top cognitive psychologists and neuroscientists, and my own background also informed this. I've taught for several decades as an engineering professor, done active research in active learning. And, so, all of these things kind of combined together. And what I found that I thought was very interesting was, when I reached out to all these professors, a lot of the ones in the STEM disciplines, in particular--science, technology, engineering, and math—

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use these
approaches that might involve things like metaphor or analogy, but they were very embarrassed to say that because other professors would kind of be like, "Oh, you're dumbing things down." But it was actually something that all of these top professors used to more easily communicate the ideas. It was like this shared handshake. They all knew how to do it, but they didn't realize these other top professors were using the same approaches. So what I'm going to tell you now is I'm going to give you some insight. These are the key ideas related to learning that all of these people have discovered. So, first off, we know that the brain is really complicated. So what we're going to do is simplify it.

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And you can simplify the brain's operation into two fundamentally different modes. The first one is what I call focus mode. In the second is what I'll call the diffuse mode. And this is actually--it relates to the default mode network and other related--there are some 24 or 25, so far, neural resting states that have been detected. And, so, all of these states altogether I'll just call the diffuse mode. And what can happen--I mean our best way to really understand these two different modes is to use a metaphor, and the metaphor we are going to use is that of a pinball machine. And a pinball machine, you all know how it works. You just take a pinball, and you pull back on the rubber--or on the plunger, and a ball goes boinking around on the rubber bumpers, and I that's how you get points.

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And what we're gonna do is we're going to take that pinball machine, and we're gonna superimpose it on the brain. And you see the brain right here. Here's the little ears, and there's the nose right there. And what we're gonna do, we're gonna take that pinball machine, and we're gonna to put it right on the brain. And there you go. There's the pinball machine on the brain. And you can see how you can pull back on the plunger there and you've got all these little pinball's, and they're very--or the rubber bumpers--and they're all very close together. So what happens is, in focus mode-type thinking, like what I'm showing right here, we've got these close-together bumpers, and you often have patterns that are

already there. For example, if you've already learned how to multiply, and you're trying to do a multiplication problem, you would sit in focus mode, and you've got these patterns that are already there. And you think a thought, and it takes off, and it moves roughly around the rubber bumpers

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along the pathways it's already been in before, that you've developed as a consequence of previous learning. But what if the pattern you're trying to think is something new? What if you already know about multiplication, but you've never encountered division before? So you're trying to understand this idea with the concept of the limits in calculus. How do you go at a completely new idea that you've never encountered before? Well, that's where this other way of the brain works in diffuse mode thinking, can actually be a benefit. Now, take a look. Here's the diffuse--the representative of the diffuse mode, and it's just an analogy, but it's a very good one that helps us understand. Look at how far apart those rubber bumpers are. When you think a thought in diffuse mode, the thoughts can range much more widely.

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Now, you can't think in a tight-going fashion to actually solve the particulars of a problem, but you can at least get to a new sort of way of thinking about things that you couldn't have gotten if you were just in the focus mode. In fact, sometimes, when you're trying to solve a really difficult problem, the worst thing you can do is just keep sitting there and focusing and focusing on it. Because you can be up on that part of the brain, so to speak, and yet you need to be in a completely different place. So the best thing to do when you're really stuck and frustrated on a problem is not to keep focusing on it. You actually need to get in a very different mode of thinking. And that's what--that's what's represented here. And, so, what this means, practically, for you is, you're sitting there, you're working. Hey, get out. Go for a run. Go down and have a--go take a shower, if you need to.

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Do something that really gets your mind totally off it because, when you're in this mode, as long as your attention is focused on that problem, you're still in this mode, and you can't get to this way of solving things. So how can this play out for people? If you look at this guy right here, he was Salvador Dali, one of the most brilliant of the surrealist painters of the 20th century. He's shown here with his pet ocelot, Babu. And what Dali used to do is this. He'd sit in a chair when he had an intractable problem with his paintings to solve. He'd sit and he'd relax, and he'd relax away, and, just as he'd relaxed so much, kind of letting his mind run free, he'd have a key in his hand. And just as he'd relax so much that he'd fall asleep, the key would fall from his hand, the clatter would wake him up.

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And off he would go with this new idea from the diffuse mode, taking it back to the focus mode, where he could refine and really use them. So you might think, "Well that's just great for artists, but what if you're an engineer?" If you look at this guy right here, this was Thomas Edison.

Edison used to do, at least according to legend, was he'd sit in a chair with ball bearings in his hand. And he'd relax and relax, and then, finally, when he'd fall asleep, the ball bearings would fall from his hand. And whatever he had, in his very relaxed way, been thinking about, he'd be able to take some those ideas from that mode and bring them back with him to the focus mode, where he could refine and analyze and come up with some of those brilliant inventions. So the lesson for us out of all of this is this.

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I'm giving some exemplary innovators in various fields, but, whenever you're solving a problem, even if it's a problem that thousands or even millions of other people have solved before, for you, it's the very first time that you've solved that problem, and you need to use some of these same creative approaches that these other brilliant thinkers have used. And what you want to do--be aware of is that you can be in focus mode or you can be in diffuse mode, but you can't really, as far as we know, unless you're an exceptionally well-trained monk, be in both modes at the same time. So focused or diffuse. And you want to develop both modes. Diffuse thinking is often not conscious, but it is also learning, and, so, that's why that relaxation process can also be very important.

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Now, I just want to give you a quick image here. This shows some of the brilliant connectivity of the default mode network. See all these connections here between various aspects of the brain? This is a web for one mode of working, but focus mode has a very different web. So, if you're only focusing, you're not making access or getting access to a lot of the different connections that are available for you. That's why going back and forth between modes can be so very important. Now, it takes time to do this. You can't--that's why you can't just sit down and solve a difficult problem immediately. You often have to go back and forth between the modes. And, in some sense, you can almost think of it like this is a weightlifter.

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And a weightlifter doesn't cram the night before a big meet and build muscles like that. It takes time to develop those muscles. In the same way, it takes time to develop the neural scaffold that is involved in learning and in new thinking processes. But I know what you're really thinking. You may be thinking "I'm a procrastinator. I wait. Sometimes I don't have time to do stuff." Right? So let's talk a little bit about procrastination. Sometimes you can be a really effective human being but still procrastinate about some things. And, so, in that sense, there are things to learn to help improve your productivity and your effectiveness in what you do. So procrastination arises in a very interesting way.

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Studies have shown that, if you look at something you don't like, the pain centers of your brain actually activate. So, if you look at a book for a subject you don't like, you can actually feel a twinge, and we can see it in the brain if you're being imaged. So what do you do when you

feel pain? I mean, it's the same pain as when you hammer your thumb with a hammer. Well, you have two different ways of handling it. The first way is you can work through it.
In 20 minutes or so, and the pain will gradually disappear. But, if you're like most people, what you will do is you'll just kind of turn your attention away to something pleasant, and guess what? You'll feel better immediately, right? And, so, in some sense, procrastination can actually be a little bit like an addiction. You do it once, you do it twice. It's not that big a deal.

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You do it a lot of times, though, and it actually can be very, very detrimental for your life. So I'm an engineer. I believe in a totally practical, useful things. So what I'm gonna do is cut right to the chase and say, "Here's the most effective way to help you deal with procrastination." And it is simply to use the Pomodoro Technique. And this is a technique that was developed by Francesco Cirillo in the 1980s, and it involves--he called it the Pomodoro Technique because he had a tomato-shaped timer, and "pomodoro" is Italian for "tomato." And what he would do is he would--he recommends you set a timer for 25 minutes--actually, you can have different times. Different time lengths are useful for different people--but you set it, in general, for 25 minutes, and then you turn off everything else. So no alarms, no instant messages.

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Anything that can disturb your concentration, you turn that off. And then you work with as careful and focused attention as you can for those 25 minutes. Now, sometimes, I'll be working way and I'll think, "Am I really focusing as hard as I can?" And then I think, "Well, obviously not because I just got distracted, and I'm wondering whether I'm focusing instead of actually working." And so--but I let that thought just drift by, and then I get back to my work. And that's what you are doing in this technique. You want to just keep your mind on your work. And what happens is, because you're are only focusing on the task and the time and not the pain of "I must complete this task," it somehow makes it so much easier to do. I mean, virtually anybody can sit for 25 minutes and work. And then, when you're done, you reward yourself.

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And that reward is actually very important because what you're doing is you're focusing during the focus mode, but then you want to train yourself to relax and enjoy and do something different. Surf the web, go off--whatever floats your boat, you go off and do that. And this actually is important because we know that some aspects of learning take place during this relaxed process. So your tendency is to think, "I'm not working when I'm not focusing," but you actually are. So it kind of gives you a little bit a feeling of relief and accomplishment that it is okay to relax. So a couple of little pointers. First, don't sit down and do a Pomodoro and say, "You know, I'm gonna finish off my work." Don't focus on the task. Only focus on the time. And that's the trick to this Technique

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because it gets you past that pain in the brain and allows you to just relax comfortably and get into the flow of the task. The other thing is don't say, "Okay, I'm gonna to do 20 Pomodoros today," and think that you're gonna to beat yourself into more productivity that way. You want to just gradually start getting used to this technique, and you'll see that it works very, very well. Now, another aspect that's really important related to learning is we've often been told, "Hey, sleep's really important before big test," or something like that. Actually, sleep is important in a lot of different ways, and I'm going to talk to you--just mention a little bit of one of the primary important reasons that sleep's important for learning. We've found that, if you look at the cells--these little circles here represent cells and neurons in the brain. And what happens when you go to sleep is this.

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When you're awake--first when you're awake, these metabolites will come out, and they'll go in between the junctions, and they kind of sit out there, and they're essentially toxins in your brain. So, when you're awake, these toxins are gradually accumulating your brain, and they affect your judgment. That's why, when you stay awake a longer and longer time, it's more and more difficult to think clearly. So, when you go to sleep, though, here's what happens. Now, watch very carefully to what happens to those cells. You go to sleep, they shrink. I'll do it again because I just have so much fun doing this. See? They shrink when you go to sleep. And, because they shrink, what that does is that allows fluids to wash by the cells and wash these metabolites out. So a very important part of sleep is just the housekeeping, the cleaning that takes place, that allows your brain to function so much more effectively.

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Now, another very important aspect of learning or of sleep relates to neural synaptic growth. In this wonderful paper by Guang Yang--she's out of Langone--if you look at the top picture, you can see here what's going on. This is the same neuron at the top and the bottom. The top neuron before learning and before sleep, the bottom neuron is after learning and after sleep. All of these little triangles are new synaptic connections. And so, when you learn something, and you go to sleep, that's when the new synaptic connections are forming. And this is what's going on when you're learning. So that's why it's very important when you're learning something new.

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Again, you don't want to cram at the last minute. You want to have many short learning periods. Sleep, learning, sleep. And that's helping you build that neural scaffold that helps you learn so much better. So there's another aspect of learning, and people often think--this is so completely disconnected from real learning that they even are taking away recess from kids because they're like, "Oh, that doesn't help them learn. Only when they're sitting in front of us, learning from us, that's when they really learn." But that's not true at all. We're now finding how incredibly important exercise is to the learning process. Now, if you

look here, this study was of a mouse, and they were training this mouse to differentiate between two different symbols.

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And, if you look in the background, what's happening is all of these blue blobs are old neurons. Now, we used to think you are born with all the neurons that you have, and that's what you got for the rest of your life. Well, of course, now we know that's not true, but it was received wisdom for many decades. And what they found was--see these red lines here? Those are actually the new neurons that are being born every day in all of us, as well as in this mouse, in the hippocampus, and that is how--those are absolutely essential to our ability to learn and remember new information. There's two ways to allow these new neurons to grow and survive. One is you get exposed to new environments. That's why travel can be so good.

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That's why learning can be effective. And these kinds of things can help those new neurons survive. But the other way of helping those new neurons survive that's just as powerful as learning is simply to exercise. So exercise is profoundly important. And I'm not talking, "Hey, I've got to be an Olympic weight lifter or be a marathon runner." Even simple walking be very, very effective in helping. And I'm sure you will have the experience. You're all muzzy-brained, and then you go out for walk, and it clears up your way of thinking. But even a few days of an exercise program is doing much more than that. It's actually enhancing the ability of your neurons to grow and survive. Now, if you look, there's a name right here, Terrence Sejnowski. He was on one of the original papers doing this original research. He's the Francis Crick Professor at the Salk Institute.

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And he's also my colleague in doing the massive open online course that's based on the book. And Terry is a remarkable guy, and it was really a lot of fun making the massive open online course with him. So we went, and we did some filming together. And then I asked him. I said, "Well, Terry, you're talking all this stuff about the importance of exercise. Do you exercise? What do you do?" And he was like, "Do I exercise?" And what he does is he goes and--every day, or every few days, he goes down--he's like a mountain goat. The guy's 65, and he climbs down. I'm scrambling after him. And he goes running on the beach, just like you see here, and this is how he gets his exercise. I love how he finishes here. Watch this. Look at that. So he is a legend in neuroscience.

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And I'm convinced that part of it is because he uses some of these ideas that he found in his research to help and really keep his edge intellectually. Now, let's just talk a little bit about something called working memory. Working memory is how you keep a brief thought in mind. It used to be thought that you had seven slots in working memory, and that's why you could hold the phone number of seven members. But now we're kind of realizing it's more like maybe there's four slots in working memory, so--maybe for me it's like to slots. But, anyway, you have four slots. And it's in your pre--you can kind of think of it as--

you're working memory, you're holding things in your prefrontal cortex. So I've got it kind of symbolized right there as your four slots of working memory. So, when you are remembering something or thinking about something with working memory,

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you can think of it symbolically, at least, as something like an octopus, the octopus of attention that reaches through those thoughts of working and makes connections between different ideas. And that's why you can't hold too many ideas at once in your brain before you get all confused. But what happens if you're multitasking? What happens if you kind of got a little bit of an eye out here on some--am I getting an instant message? In some sense, that's like taking one of those tentacles away of your working memory. And you don't have a lot of tentacles. So it really is actually kind of making--whatever intellectual heft you have, you're losing some of it. You're getting a little stupider when you're multitasking, so that's why careful focused attention is so incredibly important, especially when you're working on something that's rather difficult.

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Now, I'd just like to contrast this with the diffuse mode. The diffuse mode is--it's a lot of connections, but they're much more random in how they take place. So, how do you take something from working memory into long-term memory, which is more distributed around in your brain? Well, the best way is through practice. Practice makes, in some sense, permanent. The more you practice, the more--the broader that little neural pathway becomes, and the more deeply-embedded becomes. So, if you're learning something and you practice, those patterns get deeper and deeper, and that's how you can learn something and draw it from working memory--or from long-term memory into working memory. If you don't practice, what's going to happen is you've got those neurons, and it's almost like you've got these little metabolic vampires that just come, and they suck those patterns away before they can get deepened.

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And, so, that's why sometimes you can learn something from a professor. You even understand it. You've had that great stroke of insight. You walk away. You don't look at it for a few days, and those little metabolic vampires just suck that pattern away, and you can't really remember or understand what you had learned previously. So the best way to get patterns well-embedded in your long-term memory is to practice through spaced repetition. So you might practice Monday, Tuesday, Wednesday, maybe again on Friday. And, by spacing things out, you realize now that you're getting those new synaptic connections growing every time you learn a little, and then you sleep on it. What you don't want to do is this kind of thing, where you're just kind of cramming like crazy, and then, look, that metabolic vampire and just kind of sucks it out all away, and you are left with very little.

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It's hard to remember what you were learning. A good way to think about it is just the analogy of a wall. If you're building a brick wall and you give yourself time between layers of mortar, it can set, and you can

build a solid, sturdy wall. But, if you don't, it's all kind of a jumble, and it doesn't turn into a really good structure that you can actually use. So let's go back again, and we're going to talk a little bit more, quickly, about attention and how it affects--and the relationship with working memory. Now, if you look here, you can see you've got one slot in your working memory that's filled. When you have one slot filled, you can put other things in your working memory.

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But here's the trick. How do you get things into just one slot? It turns out that, if you create a chunk, one chunk of the material, it's easy to pull into working memory. So here's what I mean by that. If you look here, here's a raw pattern of information. It's a puzzle. It's hard to figure out. It looks like a mad scramble, but once--and look what's going on in your working memory. It's kind of going a little crazy trying to figure things out. In fact, recent research at Stanford has shown children who are trying to learn math facts, their little prefrontal cortexes is are going crazy as they try to assimilate and master the material, but once they've got those math facts down, this relaxes. What's actually happening is this.

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They've got the essential idea, and what that essential idea is like is one smooth, single ribbon they can easily pull into working memory when they need to in order to understand and make connections with other problems that they're trying to solve. Now, if you just memorize, and you're not understanding what you're memorizing, it's like creating that little circle there. You can see it. You've got it. It really is a chunk, but you can't fit it very well with other chunks. So there's another important idea about chunking, and that's this. Once you've compressed an idea, that's--one of the most brilliant mathematicians was mentioning, one of the great aspects of math is simply that idea that you can compress it. You grapple, grapple, grapple, and all, and all of a sudden, it clicks, and you've got it compressed. Once you've got it compressed in a chunk, there's, actually, you can make that chunk bigger.

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Just like learning a little piece of song, you can actually learn another peace and join them together, and you got a bigger chunk. Or you can also learn similar chunks of other disciplines. It's very, very helpful. That's an idea of transfer. But what you're really doing when you're learning and mastering a topic is you are, in some sense, creating a library of chunks, and you can draw on that library and make connections between things, and that's how great creativity arises is making connections with those chunks. So true experts often have enormous libraries of chunks that they've developed. Now, when you're learning, there is sort of a--you can think of it as--there's a top-down approach. So if you're learning a new topic,

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you can almost think of it like, "There's a chunk there that's that tire, and here's a chunk that's the man's face, and another tire." So you're learning all these chunks, and, when you get them all learned, it forms the big picture of the material. Even if you're missing a few pieces here

and there, you've still got that big picture. But, if you don't practice and repeat and really master your chunks, it's like this. It's like you're trying to put together the big picture with chunks that are faint. And it's much harder to put together the big picture with that in mind. So, again, as I was saying, you've got one ribbon of thought. That's a chunk. Here is another chunk in another field, but it's of a similar shape. And that's the idea of transfer. So, if you're a physicist, you may be able to learn economics more easily because some of the chunks are really similar in their shape.

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If you are a language learner, and you're learning math and science, there are meta-chunks available. For example, that idea of practice and repetition for language also applies in learning math and science. So let's go to some other aspect that I think relates to learning. Some of you may say--some of you may have wonderful memories here, but some of you may wish you had better memories. Well, let me kind of give you a little awareness. What you think may be a negative attribute actually can be a very, very positive attribute. It turns out that, when you have a poor working memory, what that really means is you can't hold things in mind very well, right? So you're looking at your colleague who can remember all this different stuff.

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They can hold it in their working memory, turn somersaults with it, and come up with new ideas real quickly, and you're lucky to remember what they were even talking about. But here's the thing. Research has shown that, if you have a poor working memory, your four slots are pretty weak, other stuff is always slipping in. That's why you can't hold ideas very well in your mind. But, because the other stuff is slipping in, you're actually more creative. And research has shown that, if you have attention deficit disorder or your attention wanders--oh, shiny! Then, what that means is you have much more potential for being creative. Do you have to work harder than some other people in order to make up for that? Yeah, you do. But that comes with the trade-off that you are highly creative.

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So you can be very, very valuable in your job even though you may have to work harder sometimes to have that achievement. Now, you may say, "Well, that's all well and good, but I'm actually a slow thinker. I see these other people, and they've got a super race car brain. They can pick up these ideas so fast, and I kind of move along
more slowly." Well, one of my heroes in the history of science is the Nobel Prize winner Santiago Ramon y Cajal, who is known as the father of modern neuroscience. Ramon y Cajal was not a genius, and he said so himself. Part of what he did was he worked hard and was persistent, but he said these people with race car brains, which he was not, often race along and then jump to conclusions that he didn't miss.

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He would see them, and he was more flexible in his thinking. When he would see a mistake, he would go, "wait a minute," whereas the race car driver is so used to being right and being fast that they're much less

able to be persistent and to flexibly change in the light of contradictory data. So, if you have a slow brain, think of it like this. There's the person with the race car brain. Great. But you're the hiker, and your experience is completely different. You walk along. You can see the little rabbit trails that they've missed. You can reach out and touch the pine needles. You can smell the pine forest. All of this is missed by the race car driver. So your way of thinking can be exceptionally valuable as well. In fact, Maryam Mirzakhani, she won the Fields Medal,

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which is the top award in mathematics, the equivalent in mathematics of the Nobel Prize. And she was told as a young person, "You think too slowly to be a mathematician." Well, guess what? She's one of the most creative mathematicians alive. So, if you think slowly, more power to you. You're doing good. Now, I also want to bring up another aspect, and that is the aspect of the imposter syndrome. This is so important, and so common. And what it is is a feeling like that you're the fake in the room, right? "I'm working here. I'm working at Google, and I'm really not as good as they say that I am, and I'm kind of an imposter here." And people feel this all over the world no matter what they're doing. Your a professor? "Oh, wait a minute. They're going to find it with the real truth is!" "I took a test, and I did well, but, next time, I'm going to fail it because I know they'll find out what the real truth is."

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Really, really common feeling. And the best way to address the imposter syndrome is to just be aware of how common it is. So next time you have a thought like, "I'm really not as good as they say I am." Remember, that's the imposter
syndrome talking. And probably one of the most important things that I could bring up--that's what I'm doing it towards the end here--is this idea of the illusions of competence in learning. Now, let's say that, suddenly, for some reason, a bear came hurtling out this screen and rampaging through the room. Would you feel a surge of adrenaline and nervous energy? I mean, suddenly, your body would react physiologically to this feeling of intense fear as you realized the bear was actually in front of you.

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But, in the thing is, when you think about learning situations, we often say--students will come up and say, "You know, I have test anxiety. That's why I didn't do well on this test." But, for a lot of students, sadly, sitting down and looking at a test is like there's a bear there. They just realized at that moment that they really didn't know the material even though they thought they did. So students and people can fool themselves they're learning something when they're actually not learning something. So, I'll give you some of the best ways for truly learning something. First off, tests are the best. Test yourself on everything all the time. The same hour spent testing as opposed to that hour spent studying, you will learn far more by taking a test.

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And use flash cards. Flash cards are not just language learners. Why let them have all the fun? Flash cards are for ordinary--for learning in math and science, for example. If you talk to great poets, what great poets will tell you is memorize the poem because you'll feel the passion and the power of the poem much more deeply. Why should mathematicians not be able to share in this fun? How about engineers? When we have equations, if you memorize the equation and really look at what does it mean while you are doing that, it actually can bring out the richness of what you're learning. And another thing is when you're having homework. Homework--a lot of times people make the mistake of thinking "Hey, I did my homework problem." And it's like saying, "I'm learning the piano, and I played this piano piece one time, and so I've got it."

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Nobody does that when they're learning a musical instrument. And, in the same way, when you're studying, you don't want to do a homework problem once. You don't have time to do all of them and kind of repeat them. Pick some of the key ones, and see if you can do it again. Practice it and maybe do it in your mind. Can you step through all the steps? If you can, play it almost like a song in your mind. You've really got it. You've got it down as a chunk, and that can help build things. Build your knowledge of the material. Now, probably the most valuable technique when you're trying to really understand something difficult is simple recall. When you're reading material on a page, you read away, and your tendency is to "Well, I'm going to underline it." Because, when your hand is on the page, you think it's moving it into your brain somehow, but it actually is not.

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So resist the urge. You can do a little bit of underlining, but it's better to write it because you're helping to neurally encode these ideas. And, then, when you read the page, simply look away, and see what you can recall. That, as it turns out, is very powerful in building your understanding of the material in a way that other techniques, including mind mapping and rereading, they're not nearly as good as recall. So another very important aspect is simply to study judiciously with other people or talk about what you're trying to understand with other people. Now, this has to be done judiciously. Obviously, all learning does not take place in a cooperative fashion. Sometimes you have to go off.

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But when you're learning something sort of in focus mode, there's a part and parcel of that focus mode, and that is a feeling that what you've just learned is correct, this sort of rightness feeling. And the only way you can really disabuse yourself, sometimes, is to go off and bounce your ideas off of other people, and they can almost serve like a greater kind of diffuse mode to help disabuse you when you do make mistakes. So judicious studying with friends and conversation with colleagues can be incredibly helpful. Also, explain in a way that a 10-year-old can understand. So, frequently, we explain electricity, the flow of electricity, as water, the flow of water. It's an analogy. It breaks down. All analogies break down. But Richard Feynman, the Nobel Prize-winning physicist used to go around and challenge top mathematicians in

the world to explain in a simple way--a way that their grandmothers could understand--what they were doing.

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And you know what? They could. So this means that, no matter how difficult the problem is that you're working on, if you find a way to explain it simply, you will be able to understand it much more deeply. One thing to do is insert yourself into whatever the problem is. Like here I am in a copper matrix. If Barbara McClintock, the Nobel Prize-winning geneticist, use to kind of imagine herself down at a genetic level so she could understand and see how the genes might actually be operating. So that's a trick that's often used by some of the greatest thinkers. Try to find a way to get yourself into, almost like a play, whatever you're trying to understand. If you want some more information about what I've talked about here, there's much more in the book, "A Mind for Numbers."

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And there is a lot more--and it's all free--in the massive open online course for Coursera through UC San Diego, "Learning How to Learn." And that is the key, except for one thing. I would like to leave you with this last thought. We are often told that "follow your passion." That is the key to everything. Just follow your passion, and your life will really be a better place for it. We're told that. But some things--your passion develops about what you're really good at, and some things take much longer to get good at, so don't just follow your passions. Broaden your passions, and your lives will be greatly enriched. Thank you very much.

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PERSON: Thanks, Barb, for the fantastic talk. Now, we will open it up for a few questions for Barb. Please raise your hand if you have a question, and I'll bring the mic over to you. PERSON: So one of the questions I had was that I've--whenever learning things and tackling tough problems, people always say, "Well break it down into smaller parts that you know how to do." And, so, I wondered how that fits into the focus and diffuse mode, because that seems kind of like breaking a diffuse problem into a bunch of focus problems. BARBARA OAKLEY: It actually--what that really relates to is the idea of chunks. So remember you've got four slots in working memory. The more you can understand one simple part of it and make it into a junk. And then another little aspect of it, make that into a chunk, and then another one.

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And then--so you're focusing to do that. And then, in diffuse mode, you're reaching up above and making the connection randomly, when you're sleeping, out for a walk, taking a shower, all of these kinds of things. So they all are related, but, actually, that's great advice. If you try to learn it all at once, it's so overwhelming. It's like your little prefrontal cortex is scrambling madly, but it's overwhelmed. So you want to just get a piece of it so you can draw that up as a ribbon. Very good question. PERSON: A chunk requires understanding? So, when there is a chunk, that means there was an experience of understanding that lead to that? BARBARA OAKLEY: Not necessarily. You can learn a word in a language

and you can not know what that word means, and you can learn a lot of words in a language but not know what that means.

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But, if you do know what they mean, it actually can make it easier to remember that word and easier to chunk that word and easier to use those chunks to put together sentences. So, for the most part, we always want to chunking to involve understanding as well. But, technically, no. You don't have to have understanding. It's just that understanding helps to kind of knit things together so that you can remember them more easily. For example, if I'm trying to learn the word "duck" is "pato" in Spanish. If I'm just going "pato," I'm trying to remember that word. I don't have any understanding of what that means. It's kind of harder to remember. But if I know that "pato" means "duck," I can say, "What if I'm trying to remember it by having a little "pato" that my duck is floating in." And that can help--that understanding helps serve as a bridge to get it into my mind.

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So that's a really good question because people often think, "Oh, you build the chunk. Is automatic that you understand it." Not necessarily, but it's a very good thing to have for the most part. PERSON: I wanted to ask. You mentioned that people who've mastered one area can find it easier to learn another area because there are related chunks, right? BARBARA OAKLEY: Depending on how close the area is. If you learn Icelandic, you're probably gonna be able to learn German more easily, but it may help a little bit with some of the metacognitive skills as far as when you're learning Chinese, but they're so very different that it's only those metacognitive sort of things that might help with learning. There's still a little bit of an aspect of fundamental "how do you structure language" that I think is common to all languages.

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So it depends on how close things are, but what I think is fascinating is that you never know. That's why it's so important to have people coming from one field to a very different field. Right, you're a deep-sea diver, you go into a nursing, and you actually can bring some really good ideas, and the best ideas are often developed by two different types of people. One is someone who is very young, so they haven't been sort of indoctrinated into "this is how you think." But the other is outsiders, people who are trained in a different discipline, who come and take an initial look and have fresh eyes at what they're seeing. So good questions. PERSON: Maybe a more practical thing. I'm curious about your opinion, if you're familiar with it, with the everyday math curriculum, which a lot of schools are teaching now, which, for example, my kids take.

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For example, when they teach math, they emphasize getting a sort of almost number theory feel. They learn four different ways to must multiply instead of one like we learned. For example, with my kids, they're incredibly confused by this. I'm just wondering if you're familiar with it. How does it fit into this, and if you think that's a--have opinions. BARBARA OAKLEY: It's different in different parts of the

country. And, so, I'm out in Michigan. We have different techniques. It depends. I think it depends on the kids. For some kids, it's great to learn all these different techniques. For other kids, you know, just get one method down really well, and then you can climb up from there. My own personal opinion is one of the best math supplement programs is simply Kumon mathematics. And I'm not a paid spokesperson for Kumon mathematics,

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but what they do is they have simple methods of practice and repetition that help build mastery in your learning of mathematics. And they don't give you a bunch of different methods. They just make sure you know how to multiply. You know how to divide. And you really know how to do these things. So, I guess, in my gut sense--and I haven't really encountered that question before--I think I'd prefer to see someone really learn it well using one technique. When you're older, you can see other ways, but if you got that one way really good, you got it, and you can move up. But, if your learning too many, it can be quite confusing. I suppose it would be the equivalent of you're growing up learning eight languages at once. You know, some kids can handle it, but, for a lot of kids, it might be a little bit confusing to have too much going on at one time.

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Especially about one thing. PERSON: I Have a question around reading. Not like math or something, but if I'm reading say, a philosophy book by Nietzsche or Heidegger, for example, which is 400 pages long, and I'm a slow reader. I'm assuming I'm a very focused reader because I do grasp and retain what I have read pretty well, but I'm incredibly slow. Do you have any methods to figure out how to be a fast reader but, at the same time, be able to retain and deeply grasp what I'm reading? BARBARA OAKLEY: The short answer is no. Research has lately shown that techniques for speed reading are actually--they're a little bit, it seems, somewhat spurious. To read anything difficult more deeply simply takes time. I always think in the back my mind STEM disciplines, Science, Technology, Engineering, and Math, is really difficult for a lot of people, but then there's philosophy.

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That's, I think, one of the hardest things in general for people to really grasp. It's incredibly important, but it's difficult. And I think just having a little understanding and compassion for yourself that you're actually tackling among humankind's most difficult topics and, if it's slow, well you're doing fantastic because I would be the same way. And I think a lot of people are really the same way. There are some probably superfast, Maserati-brain thinkers who could buzz right through that stuff, but they would miss things that you would see. PERSON: I've been wondering how your techniques apply more generally to kids. And you briefly touched, actually, in a previous question practice and repetition, practice and repetition. But, more concretely, how do you get actually kids interested in mathematics so that they keep on practicing? BARBARA OAKLEY: The way that we've been teaching kids is like,

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"Let's get them introduced to the fun stuff. We're gonna have them hands-on, and we're gonna have them dropping eggs and doing all of this

exciting stuff." And then they get to college, and they hit calculus, and it's like the death march. They start dropping like flies because they're not used to it. Everything's always been fun, right? So we don't do that when we're teaching things like music. We don't do that when we're teaching foreign languages, but students fall in love with those subjects because they can gain the expertise, in part through some dredging, through practice and repetition. So, I think, part of the reason that we have so many kids in this country fall off the bandwagon is we try to make everything really exciting and really fun, and we forget the lessons that language learners and musicians and sportspeople in sports, dance instructors--they all know that practice and repetition is part of gaining expertise.

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And, when we get that incorporated back into the curriculum, it's there, but it's not nearly as sound as it is in many other countries, which is why I think we see so many people coming to this country with a love and a mastery of learning in science and in mathematics that is not growing organically because we're not introducing kids in the United States to some of these ideas of--also the supplemental importance of practice and repetition. So those are my thoughts. We do do a little bit of it, but, really, not enough because, for a long time, sadly, there's been this feeling that too much practice and repetition in mathematics will kill your creativity instead of the reality, which is every great expert has to have practice and repetition with what they're learning. So those are my thoughts on that.

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PERSON: Thank you. PERSON: So understanding is important, and contact is important, so there can be like a top-down approach and bottom-up approach. So what do you think is better? Is it better to understand the big picture and then try to study a subject? Or is it better to study the small chunks and build this understanding from? Or maybe we have to mix it? BARBARA OAKLEY: You've got it. Exactly right. You don't want to be just doing small things all the time, and you don't want to be perched overhead all the time. You want to be--it's hard to get what is the big picture when you learn one little chunk, and you learn another little chunk, but you want to start piecing that into the big picture as much as you can, and so you want to be kind of going back and forth. One of the techniques that I didn't talk about that's very important is that of interleaving.

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And, a lot of times, when you're learning, for example, some new technique in calculus, you will do ten problems of pretty much the same--learning that technique in calculus, but you don't want to do that. You want to do one or two problems using that technique, flip to another section of the book. Do that problem. Kind of compare. "Wait a minute. Why am I using this technique here, and that technique here? Why are those different?" Flip back, do another one of the first technique. Then flip to a different--we're not straining people. We don't even have our books set up to interleave, and we need to start doing that because that's what actually--it's practice and repetition, but mixed with interleaving that builds flexibility. So those are my thoughts on that.

Good question. PERSON: When I was in high school and college and taking math, I was perfectly fine. You know, I did well on the test.

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But my problem was always trying to apply it outside that environment, trying to use it practically or in everyday life or whatever. Whatever it was that I needed certain math skills were, I just could never do it, and I was wondering if you had any sort of technique or strategy or ideas about how there's a way to take math from the school and sort of be able to apply it in regular life or just outside of school. BARBARA OAKLEY: That's a very good
question. One of the things that people do when they're--they look at math and they say, "How am I ever going to use this?" In fact, I remember when I was called into the principal's office in eighth grade because I wasn't doing my math. I was actually reading a book, and, so, I remonstrated with the principal, saying that there was no real use for it. I would never use it, and they gave up on me at that point. But it's kind of like this.

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When you're at the gym, and you're lifting a specific type of weight, are you ever gonna go into the outside world and lift that kind of weight? Of course not. But you're actually using muscles that you might use related muscles when you're lifting up your luggage to get in and put in the airline compartment. So what you're doing when you're learning something in math and science is you're developing sort of neural pathways. You may not use exactly that one, but, in surprising ways, they can shape how you're thinking about things. So an example is this. They did a study and they found--you know there's some kids who go through all the way through college and you can kind of take courses that have almost no math really involved. You know, "math for poets" or these kinds of courses. And you go all the way through.

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But people who have this kind of background where they've had very little exposure, when you control for all aspects of what's going on that you can reasonably control for, the ones who have no real background in math are far more likely to default on their home mortgages. So think about that. But it's actually--you're able to think more intelligently. Now, what about you're really concerned about the environment. So someone comes up and says, "Well, we've gotta have electric cars." Sounds really good, right? But if you're trained, you've got some kind of background, you can go, "Yeah, but wait a minute. What about the effect of batteries on the environment? Do they actually make more pollution? In fact, does that transfer of energy create more harm for the environment than a regular gasoline engine?"

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If you're taught to think a little bit more rationally and carefully about things, you can actually--you're using those intellectual muscles in ways that you haven't really--you don't really realize how important that actually is. So one way, though, just reflecting, just a little bit of a different word because your question's very deep. When you're learning a language, one of the things you do is you're learning you're

practicing, and it can be really tough to actually go and meet somebody and talk with them, right? Who speaks that language. But that real-life experience is what brings the language alive and what nourishes the desire to learn it. So, I think, finding ways when you're walking around, and you're thinking about something you've just learned mathematically, look around and try and bring it into the environment you're in. And try to think about it in those ways.

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That's such a great question because it helps us be aware of the richness of life around us. And, so, I think trying to bring some of these ideas you're learning into the life around us in the brilliant thing to do and a great attitude to have. So I thank you so very much for having me here. PERSON: Fantastic talk. Great answers. Thank you so much, Barb. Thank you. CAROLINE: Thanks for listening. If you have any feedback about this or any other episode, we'd love to hear from you. You can visit g.co/talksatgoogle/podcastfeedba ck to leave your comments. To discover more great content, you can always find us online at youtube.com/talksatgoogle or by our twitter handle @GoogleTalks. Talk soon.