LEARNING AS BIOLOGICAL BRAIN CHANGE

BY ROBERT LEAMNSON

Most of us can remember particularly striking scenes from movies we saw as children. And I suspect many experience a small shock, as I do, when they see the same film many years later. Like going back to one's old neighborhood, things are not quite the way we remember.

At one time, memory was thought to be something like boxes in the attic. We could put things there, and then with some effort and luck we could pull them out again, unchanged from the day we deposited them. But, this model is not consistent with real experiences, as the example above shows, nor is it any longer the favored scientific model.

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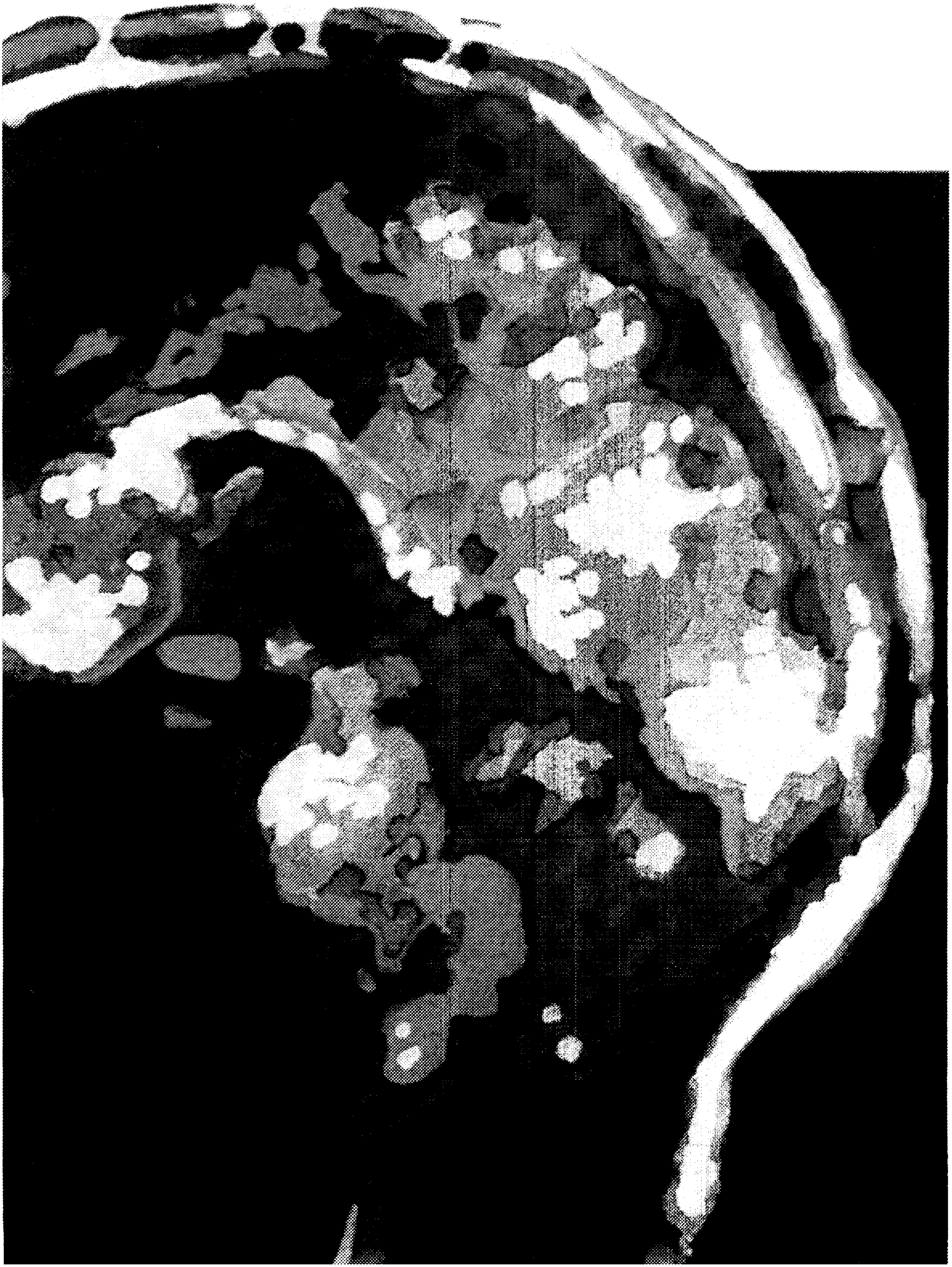


Brain and behavioral research both suggest that things we remember are "reconstructed" in the brain at the instant of remembering, and then reconstructed again at each subsequent remembering. The old model for remembering was something like taking a photograph of your uncle's farm house and keeping it. Today's newer model is more like making a pencil sketch of the scene, then losing it and re-drawing it later by trying to put all the lines and marks in the same place you did the first time. Imagine this being repeated time and again: lose the sketch and then reproduce it, lose it again and reproduce it again. It would not be surprising for each new sketch to have the essential elements from the first, but also to exhibit changes that accumulated over all the successive replications.

Because memory is an essential element in learning, teachers should have a realistic concept of it. Something that cannot be reconstructed cannot be said to have been learned in any real sense, even though many students continue to believe the opposite. I propose that teachers' approaches to teaching are— or should be— much influenced by their understanding of learning, and that it is useful to understand learning and remembering primarily as biological processes.

For some, this way of thinking might represent a real conceptual change. That is because for much of its history, the study of human learning has emphasized the psychological. Discussions of learning relied on metaphors such as Piaget's developmental stages, Bloom's Taxonomies, and Vygotsky's zone of proximal development. But for the last 20 years or so, researchers of neural structure and function have been increasingly bold in suggesting that we might get as good—or better—understanding of learning by thinking of it as an activity of the brain and therefore totally dependent on brain structure and function. The resulting models are on the dispassionate side, and will not appeal to all. They are, nonetheless, worth considering and might well, in the end, make useful contributions to pedagogy and the design of instruction.

GENETIC CONTRIBUTIONS

When all goes well, the brains of newborn human infants are remarkably similar in gross structure. As this development takes place in the uterus without sensory input having a significant role, it is the infant's endowment of structural and developmental genes that programs the building of the brain. In a normal pregnancy, all components end up where they should be, connected to one another in such a way as to prepare the infant to begin life outside the womb.

Furthermore, by birth, most neurons (the cells that carry the signals) have stopped dividing. A few neurons continue to divide, probably all our lives, but others die, so the number of neurons we're born with is probably the most we'll ever have. However, the human brain increases in mass several-fold between birth and adulthood. What accounts for this growth if the net number of neurons does not increase?

It's the functioning of the genetic program within these neurons and their support cells that accounts for much of our brain expansion. Although only a small number of neurons are undergoing cell division, *most* are anything but quiescent. They are "instructed" to increase in size, and while doing so, to send out numerous branches that can make connections with other neurons. As suggested above, some of this branching and connecting is genetically programmed to occur before birth, and—barring any trauma—will remain with us for life: one might say they are hard-wired.

But lots more of this budding, branching, and reaching out of neural extensions goes on at a remarkable pace after birth. These extensions (dendrites and axons) and their protective cellular wrappings account for most of the increase in brain size between birth and adulthood. Instructions emanating from the nucleus program the dendrites to grow out in a hairy brush around the cell, and the axon to grow "in search," so to speak, of one kind of cell, and to avoid other types. The dendrites receive signals from other cells, and the axon is the conduit for outgoing signals to still other cells. Usually a neuron has only one long axon, but it can be heavily branched toward its end, so one neuron can send signals to many others all at the same time. And because of its many dendrites, a neuron can be "signaled" from a huge variety of sources elsewhere in the brain. These multiple connections result in enormously extensive webs of interconnected neurons. The predominant thinking is that these webs or networks enable sensation, consciousness, and thought.

EPIGENETIC GROWTH

Genetics, however, plays a lesser role in postnatal neural growth and the resulting connections to other neurons. A budding neuron is programmed to grow toward one type of cell and to avoid others, but it has no specific instructions to seek out any particular cell of its target type. In postnatal growth, it is mostly a matter of chance as to which cells end up touching. These postnatal connections are therefore not genetically programmed. Genetics determines only the types of cells that get connected. The actual axonal connections are said to be "epigenetic," meaning that they are beyond, or independent of, genetic instructions.

Epigenetic growth is best understood by considering monozygotic (identical) twins. Monozygotic twins have identical genetic instructions, which explains their sometimes amazing similarity. But there are clear differences in their fingerprints, the patterns of their veins, and their brain wiring. Certain developmental processes are set in motion with only general instructions—something like "build veins as needed" with no blueprint to show just where these veins are to be placed. Axonal budding and growth follow these kinds of general instructions. There is, then, no blueprint or schematic for the wiring of the brain.

THE SYNAPSE

The connections axons make are relay stations between neurons. An isolated neuron discharging its action potential would be "trying" to send a signal, but without connections, it's just talking to itself. For one neuron to signal another neuron, or a muscle fiber, it must come in physical contact with it, but also make a specific kind of connection. These connections are called "synaptic junctions" (or sometimes just "synapses"). The nature of the synapse is not essential to these arguments, only the fact that a signal that gets to a synapse is transmitted, under appropriate conditions, to whatever cell that axon is connected to.

Learning in most cases is influenced, or stimulated, primarily by external agents. It is precisely here that teaching is critical.

Strangely, the number of synapses in the brain of a growing child exceeds that of his or her parents. The child's brain is growing rapidly, and its neurons are growing dendrites and axons at a prodigious rate. Having only minimal instructions, these extensions grow helter-skelter in all directions, making connections with any permissive cell they bump into. Jean-Pierre Changeux calls the post-natal growth of neurons "exuberant." But if we had more synapses as a child than we have now, what happened to the ones we lost?

It happens that the connections that growing axons make upon contact with a permissive cell are often temporary. There has *long* been microscopic evidence of axons degenerating or withering away (just the axons, not the cells from which they grew). It is now also known that newly formed synapses are weak, or labile, and if nothing more happens the axon usually retreats, or degenerates, and the neuron starts over with a new budding axon.

The "something" that must happen to strengthen and stabilize a synapse is simply use. The more times a synapse passes a signal, the larger it grows, and the more securely it links the two cells. The number of synaptic connections between the cells may increase as well. It is literally a case of "use it or lose it." With sufficient use, a synapse stabilizes and can then be thought of as part of our hard-wiring. We may well have it for life.

A LEARNING MODEL

Changeux combined these ideas and produced an attractive model for the process of learning, considered biologically. It is proposed, to begin with, that our thoughts and perceptions are indeed what John Searle calls an "emergent property" of our brain states. There is so much evidence for reduced mental function resulting from brain lesions that it is hard today to deny that perception and thinking are functions of the brain. Nor would many deny that this "function" is a massively complex pattern of signals going from dendrites to cell bodies to axons to dendrites and so on. And just as we will never have a blueprint of the brain's wiring, we will never know the paths that signals take to generate a memory. That there are such paths, however, is not in question.

STABILIZING SYNAPSES

If there are stable pathways of neural connections that enable us to remember something, how did we generate them? The model suggests that these webs of neurons, stably joined, are what's left of a tremendously larger number of labile synapses, most of which degenerated from lack of use. The stable circuits that enable memory are simply the ones that worked and were therefore used with greater frequency than others. This frequent use need not take a long time. Neurons can fire repeatedly at a very high rate, and sometimes a learning circuit gets burned in in a remarkably short time span. We'll see later how some other brain functions can effect rapid learning.

When John Dewey said that students learn what they do, not what we tell them, he meant, I'm sure, that they learn what they do with their brains. Physical activity that does not engage the cognitive regions of the brain might enhance motor skills, but learning takes place only when those synapses that enable understanding are used repeatedly until they stabilize. Physical activity can, as will be suggested later, enhance or facilitate cognitive processes, but it cannot by itself cause learning, beyond motor skills. Learning, as David Perkins points out, is a consequence of *thinking*—it's less the doing than the thinking, the reflecting on that doing, that counts.

PEDAGOGY

If, as the model suggests, learning is a matter of using pre-existing synapses until they are stable and hard-wired, it can then be thought of as brain change, as well as brain use. Our brains are different for having learned something; all of which would seem to put matters completely in the hands (heads) of the learner. What part does teaching play in this scheme? I have become a believer in the notion that learning is indeed a private, internal process that takes place in the head of the learner, and therefore cannot be *caused* by an external agent, human or otherwise. But I use "cause" here in a very narrow and rigorous way. To say that an external agent cannot cause learning is only to say that such an agent cannot itself stabilize the synaptic junctions needed for learning to occur. External elements can of course have a remarkable *influence* on learning. Indeed, learning in most cases is influenced, or stimulated, primarily by external agents. It is precisely here that teaching is critical.

If teaching cannot directly cause learning in another, what then are its purposes and its effects? I will condense the various aspects of teaching into two categories.

The first of these is content. The opportunity to learn, and to learn an enormous amount, is, and always has been in modern times, available to nearly everyone in developed countries. Libraries contain more than any of us will ever be able to learn. But someone who did learn primarily from books would not simply start at the first shelf in the stacks and try to go through the lot. What's central, or what's particularly worth the effort, will always be a prime question in anyone's education.

This is the first and not-to-be-denigrated function of teachers. If learning occurs when students think deeply and repeatedly about something, it is teachers' first responsibility to ensure that their students hear and see just what that *something* is. And so it follows that the first requirement for teaching is some mastery of the content.

THE ROLE OF THE EMOTIONS

While reciting—or pointing to—what's important to learn is critical, the job is nowhere near complete with those alone. To understand the teacher's second important function we need to return temporarily to the brain, and one of its more peculiar bits of organization.

When presented with a threat, a cat will arch its back, raise its hair, flatten its ears, and hiss. The cat is in an emotional state and the physiological reactions are spontaneous, but they are nevertheless the end result of the cat's brain state. Deep in our skulls, as well as the cat's, are the "ancient" parts of our brains. Psychologists and neurophysiologists lump a number of these smaller neural masses together in what they call the "limbic system"; the signals passed between the complex neural maps in this system produce what we call emotional states. All the specialized regions of our brains, however, are connected in one way or another to all the other parts. The cat's limbic system had to be in communication with its visual cortex or it would never have "known" that there was a threat.

Modules of the brain being in communication with one another means only that there are neural paths physically linking them. One such set of connections that was laid down with some precision during our embryonic development linked the limbic system to several other modules, including the frontal lobes of the neo-cortex. The frontal lobes are in turn connected to just about everything else.

Established research has clearly demonstrated that the frontal lobes play the major role in organizing the brain's activity. This region is like a monitor that keeps track of inputs from all sources, weighs them, calculates their importance, then prioritizes things so that overall the brain concerns itself with what most needs tending to.

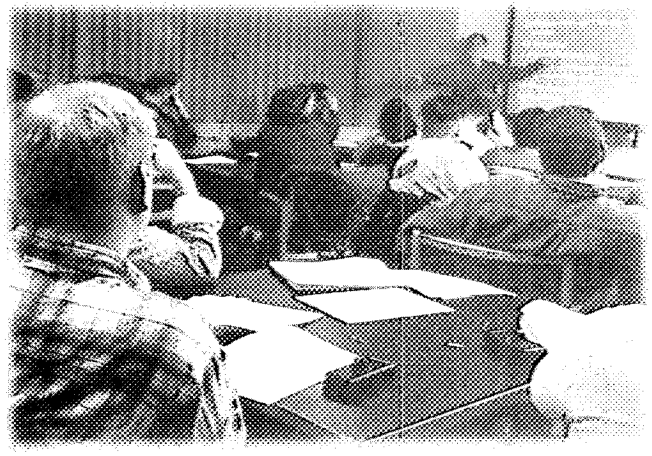
One of the ways it does this is through *gating signals*. The frontal lobes have axons that connect to other axons. Some of these connections attenuate their targets, meaning that they greatly reduce the number of signals those target axons will pass. Other gating axons have an enhancing effect on their target axons, so that those axons have a greater probability of passing neural signals on to the next cell. But it is the frontal lobes, again, that focus the brain's activity.

When we concentrate on something, we can become relatively immune to minor distractions. This is because the frontal lobes have attenuated signals emanating from sensory input such as extraneous noise or things passing in our peripheral vision, while at the same time enhancing signals being passed in the cognitive modules of the brain.

Remembering that the frontal lobes are in communication with the limbic system, we can postulate a neural explanation for the well-known phenomenon of learning being enhanced or speeded up as a result of some level of emotional involvement with content.

Fans of baseball do not have to discipline themselves to sit down for half an hour every night to study the baseball encyclopedia. Their emotional involvement with the game so focuses their attention that they are often capable of "one trial learning." Most teachers would agree that if their students were ever to become as "involved" with history, chemistry, or economics as they are in movie stars, rock musicians, and computer games, teaching would become effortless.

No matter how tempted we are to



The really difficult part of teaching is not organizing and presenting the content, but rather in doing something that inspires students to focus on that content—to become engaged.

believe otherwise, there is nothing at all wrong with the learning apparatus of our students' brains. They readily learn what captures their imagination. What's lacking where subject content is concerned is focused attention, and the limbic system is one way to get at the problem.

So it is, in my opinion, that the really difficult part of teaching is not organizing and presenting the content (by whatever technology) but rather in doing *something* that inspires students to focus on that content—to become engaged, to have some level of emotional involvement with it. This is not at all an easy thing for a teacher to accomplish. It cannot be done by force or threat. However, it becomes less daunting when we consider that the limbic system can conjure up a variety of states, at various levels of intensity. Emotional involvement is not limited to the intense levels we sometimes associate with the word "emotional." Fear, for example, is not limited to terror in the face of a life-threatening situation. Fear of embarrassment and fear of disappointing a friend are both examples of mild and potentially useful emotional states. As used here, emotion is facilitating not debilitating.

A perusal of the literature of the field leads me to believe that the goal of most educational innovations and theories— consciously or not—is to get students engaged, involved, and focused, no matter what the content or method of instruction. If it is true that the cognitive modules of our students' brains are in good working order, then getting them to fire up these modules and ignore other distractions seems like an excellent strategy.

'TWIXT CUP AND LIP

Having a strategy is one thing, bringing it off is another. The obvious problem here is that no one has control over anyone else's brain. Drugs and electrodes are out of the question, so what can one do to inspire or induce a useful emotional state in another? Well, fear is relatively easy, and teachers have always used it (inadvertently in many cases) in the form of examinations, assignments, and the like. While it's far from the noblest or most effective motivator, fear of failure often elicits some level of engagement with the content.

But most teachers would like their students to become involved with a subject for the same reasons they are—because the subject has an inner structure that is intrinsically ordered, explanatory, or even beautiful. But we must be honest here, and admit that the attractiveness of our discipline came at a price. No one is born with a cognitive interest in anything.

Some reflection on how we acquired our interest in a discipline would be time well spent. Some may have had an abiding interest in the subject for as long as they can remember but have no idea how it got started. Others, however, can remember getting "hooked" because of some event, book, or person. Some of our students might get hooked as well if exposed to similar stimuli.

To paraphrase Margaret McFarlan, we give our students who we are, and they catch that. Some emotional states certainly are contagious, as when a crowd of laughing people enhances our own sense of the ironical and facilitates our perception of humor. The same can be said of rage or fear. So long as it is not an obvious affectation, a lot of good might come from letting our own enthusiasm show while we are teaching.

KINDS OF LEARNING?

One unexpected and perhaps unwelcome result of seeing learning as a biological process is that we might begin to concentrate on the common aspects of learning in different people, not just on the differences among them. The accepted wisdom that "different people learn in different ways" is so pervasive that it has attained the status of doctrine. At one level, the idea is beyond challenge. No two people's brains are wired the same way and so each person's mental state is different from the next even when everyone perceives the same event. Yet, the synaptic stabilization model suggests that when several people all learn the same thing, they *all* fire repeatedly whatever synaptic junctions *they* have available to enable understanding. So at this very basic level we are all doing the same thing when we learn.

We all come to a learning opportunity of course, with different memories and experiences, and we will each use different combinations of hard-wired and labile pathways to burn in new circuitry. This fact provides a base-level model for the theory of multiple learning styles. But the same model suggests that *everyone's* learning style is, in fact, unique; there are as many learning styles as there are learners. This, in turn, can explain the enormous difficulty teachers have in trying to design instruction to accommodate the wide range of learning styles in any given classroom.

ACTIVE LEARNING

In the biological model, all learning is active. (As Pat Cross puts it, "passive learning is an oxymoron.") But the various pedagogical methods that are associated with "active-learning" can find reasons for both success and failure in our synaptic stabilization model.

Those of us who have been doing "hands-on" teaching for a long time, in the form of science laboratories, for example, can provide a wellspring of evidence for the fact that hands-on activity does not in any way guarantee learning. Observations can be made, measurements taken, data recorded, and calculations done all in a nearly robotic way. Some modules of the brain were certainly busy, but the final effect in many cases is simply the memory of having done all these things.

Functional Magnetic Resonance Imaging has shown that the modules of the brain that are active when engaging in novel physical activity are physically displaced from those areas involved in problem solving and other higher modes of cognition. For *both* to become engaged at once requires gating signals that link these modules and attenuate distracting stimuli.

This failure of mere activity to effect learning is consistent with our everyday experience of being able to *do* one thing while *thinking about* something totally unrelated.

Hands-on activity facilitates learning only when the "thinking" modules of the brain are in communication with the "acting" modules. Activity, then, *can* be of help in focusing attention, but it is not a sufficient cause for learning to take place. And, as the meditators among us know, it isn't even a necessary cause. Getting the limbic system involved, however, is an effective way to set off the signals that focus attention.

LEARNING LESSONS

If there is an overall lesson here for the design of instruction, it would be that such a design must include accurate information, clear presentation, but should also consider the elements of emotional involvement on the part of the learner.

There are those happy instances where emotional involvement seems almost innate. Many young people discover that learning something new and challenging tickles their brain, so to speak, and they are forever trying to repeat the experience. In the more typical case, learning is associated with schooling and that in turn with a kind of oppressive tedium. When these latter associations become hard-wired, the job of firing up a student's motivation to engage in thinking while in college becomes a real challenge.

But in terms of the brain model of learning, the task is possible because it involves only the strengthening of some pre-existing synapses through repeated use. Using weak, labile synapses, however, can cause discomfort. Designing a pedagogy that will inspire or motivate students to do the difficult is not a trivial matter. It's one of the things that makes teaching difficult. Simply getting students active or talking in groups or having fun will not alone produce learning. Students must become inspired (the best word I can think of) to associate that pleasurable, engaging activity with the content to be learned. When that happens, some wonderfully useful connections will become a permanent part of their brains' wiring.

One important set of hard-wired connections in the brain consists of those that interpret sights or sounds and signal the limbic system to establish a certain state of mind. Through learning, the word "love" has come to initiate a certain response, and "fire!" a quite different one. In quite the same way students, because of previous experiences, often go into a mild but distinctly emotional state at the sound of words like "math," "science," or "poetry." How they respond to each of these words has been wired in by prior learning, that is, by repeated or particularly dramatic experiences. New wiring, however, *can* be established through new experiences, and people's attitude or emotional stance with regard to a subject *can* change.

A particularly powerful stimulus for setting students' emotional barometers are teachers themselves. The old observation that students tend to like a subject if they like the teacher has, then, a real basis in the biology of learning. Making teaching and learning a more personal interaction between teacher and students might well be an effective first step in getting students themselves hooked on a subject.

But it should be *only* a first step. Truly effective teaching weans the student in the sense that it encourages and reinforces curiosity and other modes of emotional involvement with content. Such teaching, I believe, becomes more probable when teachers think of learning more consistently as a biological process.

RESOURCES

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