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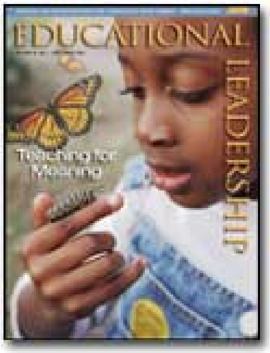

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The Art of Changing the Brain

Neurological research supports some well-known ideas about teaching, but does it suggest new—even counterintuitive—ideas?

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Let's begin with an idea that seems obvious: When we learn, we change. We do something new or better, or we may stop doing something. Learning makes a difference.

Sometimes learning is incremental, and we don't even notice the changes. At other times, learning brings about powerful changes. In the most dramatic cases, learning transforms our life.

This potential for change is what attracts many of us to teaching. We hear about teachers who influenced students' lives in important ways; we remember our own teachers and the effect they had on us; and we recognize how learning has changed our own lives. We see the opportunity to be a vehicle for change and growth in others. We see that we can make a difference.

But until recently, our ideas about *how* learning produces change have been unclear. Good teaching seems to be an art, and good teachers seem to have special, hard-to-define skills. In fact, such teachers sometimes shy away from trying to analyze their art, perhaps out of fear of losing it.

Now, however, education research and cognitive science have given us deeper insights into the process of learning. In addition, we are beginning to understand more of the fundamental neurological processes that happen in the brain when we learn and remember. This new knowledge fascinates and tantalizes teachers. Maybe we will actually find out how it all works!

My own experience as a biochemist and teacher for nearly four decades has given me the opportunity to investigate what we are learning about the brain. And to my surprise, neuroscientific research has given me new ideas that have informed my teaching.

Learning Changes the Brain

The basis for much of what I describe here is the realization that learning produces physical change in the brain. This concept represents a new way to look at both learning and neuroscience. Earlier models of the brain did not encourage us to think about change. They tended to present the brain as more fixed, with the learning wiring already in place—somewhat like an automobile, a machine that does not change when someone drives it.

In the last few decades, this fixed idea of the brain has been discarded. Instead, we talk about the brain being "plastic," meaning that the brain changes its own wiring, perhaps almost continuously. Like a piece of silly putty, the brain is molded and reshaped by the forces of life acting on it. Our wiring grows and develops depending on what we experience—even before birth. As we interact with the world, the world becomes internalized, or mapped, in our brain. The extensive plasticity of the brain continues throughout life.

Experiments have repeatedly demonstrated environment-dependent change in the brain, which happens as the connections between neurons become more extensive, become more or less active, or even extend into new parts of the brain. In one of the most recent studies of this sort, Trachtenberg and his colleagues (2002) demonstrated both physical growth and disappearance of single branches of neurons in living mice when sensory input was changed.

Until recently, all research of this nature had been conducted on laboratory animals. But Draganski and colleagues (2004) describe an experiment that, for the first time, demonstrated change in the human brain generated by learning. In this experiment, young adults were taught to juggle. The training went on for a few weeks, until they all could keep at least three balls in the air at once. MRI images of the subjects' brains before and after the experiment showed that learning to juggle generated increased density in a small part of the brain associated with vision, especially in the area that responds to movement. When the students stopped practicing juggling and their skill declined, the density of that part of the brain decreased, going back toward its original state.

Although few of us teach juggling, the fact that an action skill (juggling) produces change in the visual (sensory) part of the brain is not readily predicted, and it may presage future discoveries that will broaden and enrich our approach to education in many areas. It is worthwhile to keep our eyes open for such research.

Practice and Emotion

What causes the changes that take place in the brain when we learn? This question has two answers, both of which are essential to understanding the art of changing the brain.

Practice. Neurons, or the cells of the brain, possess biochemical pathways that make them grow and reach out to other neurons whenever they are active. When we practice something, the neurons that control and drive that action fire repeatedly. If a neuron fires frequently, it grows and extends itself out toward other neurons, much like the branches of bushes in your backyard reach out and touch one another as they grow. Particularly in the cortex, neurons that fire more frequently will also reach out more frequently.

Neurons do more than reach out, though: They actually connect. The branches of our backyard bushes don't do this. Each bush remains independent, even when many branches touch one another. But neurons can actually begin to send signals to one another if the places where they touch can transport those signals.

These signaling connections are the famous *synapses*. Synapses convert the isolated neurons into a buzzing network of neurons. The bushes begin to talk to one another. In place of individual bushes, we have an entire hedge of neurons sending signals back and forth through millions of synapses. These networks are the physical equivalent of knowledge, and the change in the connections that make up the networks is learning.

Emotion. To create and change this buzzing network, we need more than just activity—we need *emotion*. And for the brain, emotion means such emotion chemicals as adrenalin (fight or flight), dopamine (reward), or even serotonin (sleep and peace). When our network connections are awash with emotion chemicals, synapse strength is modified and the responsiveness of neuron networks can be dramatically changed (Brembs, Lorenzetti, Reys, Baxter, & Byrne, 2002).

The thinking part of our brain evolved through entanglement with older parts that we now know are involved in emotion and feelings. Emotion and thought are physically entangled—immensely so. This brings our body into the story because we feel our emotions in our body, and the way we feel always influences our brain.

In his pioneering book *Descartes' Error*, Damasio (1994) addresses this idea of the mixture of feeling and thinking. He uses the term *somatic markers* for specific body feelings that go with specific cognitive experiences. For example, when we solve a problem, we have feelings of pleasure and satisfaction. Or when we cannot understand a calculus or biochemistry text, we have feelings of frustration and despair.

This emotion connection has implications for student motivation. As part of the teacher's art, we must find ways to make learning intrinsically rewarding. Learning should feel good, and the student should become aware of those feelings. To achieve this goal, we need to make two things happen. First, classes and assignments should lead to some progress for students, some sense of mastery and success. Second, students should work on topics and activities that naturally appeal to them.

Extending the Art

Teachers have long known from experience about the importance of practice and emotional engagement in learning. But in addition to supporting what we know from education research and practical experience, we hope that neuroscience will eventually tell us something new, even counterintuitive, about how to teach. Although we should remain skeptical and put any innovative theories to the test, I find myself always looking for new ideas about teaching that are suggested by our growing understanding of the physical brain. Here are several candidates.

Don't Explain

At times in the past, I was seriously disappointed in my ability to help students learn by explaining things to them. Often I noticed that their eyes glazed over shortly after I began my explanations. Still, I believed that they did need explanations and that my job was to find better ways of explaining.

But my examination of brain research has made me think seriously about giving up on explaining as a teaching tool. When I began to understand knowledge as consisting of networks of neurons, it dawned on me—powerfully—that my students' knowledge was actually physically different from my own. Particularly in my specialty, biochemistry, our networks differed. But my networks were all that I had! When I explained biochemistry, I had to use my own networks; and for my students to understand it, they had to use theirs. Maybe the two sets of networks were just too different.

So I reduced my explanations and instead turned to demonstrations, metaphors, and stories. As much as possible I tried to show rather than explain things. And when explaining seemed inescapable, I asked other students to do it, reasoning that their networks were a better match with those of their peers.

I turned away from explanations for another reason: I realized that explaining negates the emotion needed for changing the brain. Explanation transfers the power from the learner to the teacher. But neuroscience tells us that the positive emotions in learning are generated in the parts of the brain that are used most heavily when students develop their own ideas. These areas include the frontal cortex and the pleasure centers deep in the brain that are control centers for voluntary movements. Voluntary movements, of course, are "owned," or chosen. The biochemical rewards of learning are not provided by explanations but by student ownership.

Build on Errors

As I began to explain less, I came up with more ideas that had once seemed counterintuitive. For example, rather than treating student errors as obstacles to learning, I began to welcome them. They became my raw materials for helping students build knowledge. Instead of thinking that my job was to eradicate error, I sought it out.

It was futile to imagine that I could eliminate students' existing neuronal networks with a shake of my head or a red mark with a pen. Instead I saw student errors as clues for teaching. Errors help identify gaps in student networks and provide ideas for how to build on those networks.

The now-famous video *A Private Universe* (Schneps & Sadler, 1988) provides an example. In this video, new Harvard graduates and their professors are asked to explain why summer is warm and winter is cold. Almost all of them make the error of saying that this happens because the earth is closer to the sun in summer.

In fact, I admit that this explanation also popped into my mind at first. It is the most common assumption that we find in the general population and the one that most of us developed as children. But it is wrong. The earth's orbit is nearly spherical, and the small differences in distance do not explain the seasons.

Although these childhood networks are persistent and problematic, we can also view them as a tool. Here's the learning process that might help me as a learner to build on my incomplete networks and arrive at a new understanding.

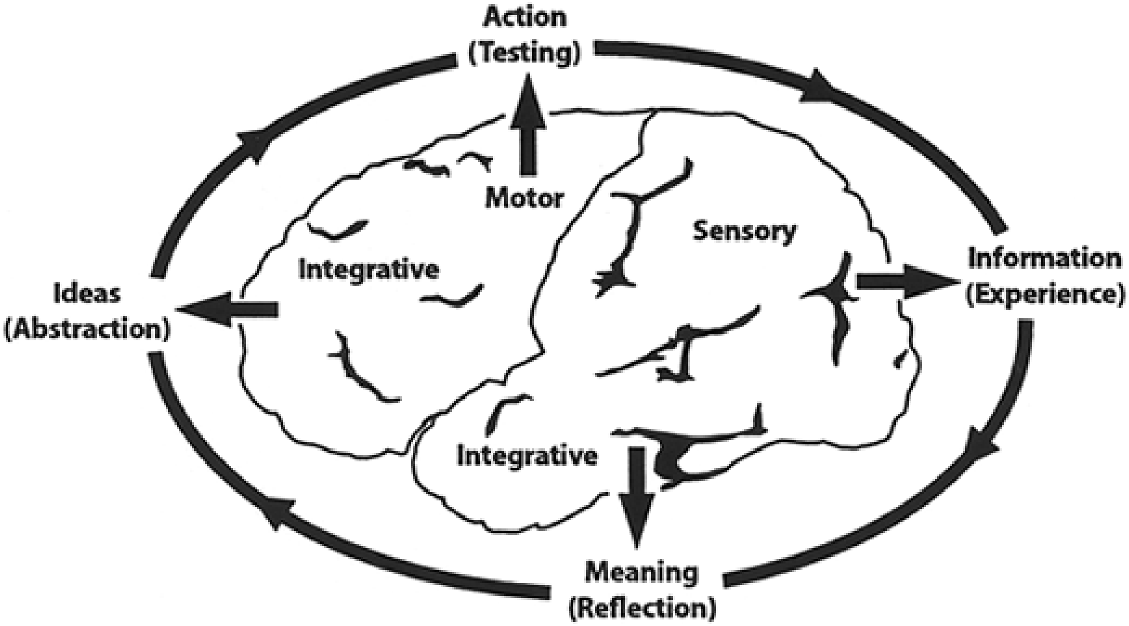
The tilt of the earth is what actually produces the seasons. (The northern hemisphere tilts toward the sun in that hemisphere's summer and away from the sun in its winter.) But my incorrect answer appears to contain some truth. After all, when the northern hemisphere tilts toward the sun, isn't it closer? But no! Again, this idea is incorrect. Rather, the *directness* of the sun's rays is what matters. And they are most direct in the northern hemisphere during summer.

So, even though my ideas were wrong, they were important. As I discover these subtleties and understand why my original ideas didn't work, I begin to take ownership of the problem. Rather than memorizing the correct answer and depending on an expert authority for it, I create my own understanding. By asking what it means to be closer to the sun, how much closer makes a difference, and why directness might matter, I build on my incomplete networks, fill in the gaps, and ultimately create a correct set of networks. I not only know the answer but also understand it.

Engage the Whole Brain

Another way we can become more artistic in our teaching is to develop ways to engage several regions of the brain in learning. In particular, let's focus on different regions of the cerebral cortex, the part of the brain most closely associated with cognitive functions. A useful, although greatly simplified, way to view the cerebral cortex is to divide it into four major regions with different functions (see fig. 1): *sensory cortex* (getting information); *integrative cortex near the sensory cortex* (making meaning of information); *integrative cortex in the front* (creating new ideas from these meanings); and *motor cortex* (acting on those ideas). If teachers provide experiences and assignments that engage all four areas of the cortex, they can expect deeper learning than if they engage fewer regions. The more brain areas we use, the more neurons fire and the more neural networks change—and thus the more learning occurs.

Figure 1. Four Major Regions of the Cerebral Cortex



Two decades ago, David Kolb (1984) proposed a cycle of learning that is compatible with these four brain regions. Kolb asserted that deep learning comes through a sequence of *experience, reflection, abstraction*, and *active testing*. If we ask our students to use these four pillars of learning, they will have a chance to use more parts of their cerebral cortex.

This perspective enables us to see how such deeper learning can happen even in a traditional classroom. For example, we might first expose students to a chemistry idea through reading or a lecture (gathering information), then ask them to think about the idea and write out its meaning in their own words (making meaning), then assign them to work in pairs to develop a theory about the idea (creating new ideas), and finally encourage them to explain their theory to the teacher or the class (actively testing ideas). The last step generates new experience (information and feedback) and the pillars can then be repeated.

Learning Is the Brain's Business

Our growing knowledge of the art of changing the brain reminds us of much we already know, but it may also produce surprises. Practice and meaning are the most important parts of this art, but of course students will not practice in a meaningful way unless they care. As teachers, we can arrange conditions and challenges that engage the learner, but still we must have faith in learning itself. Ultimately, the learner is in control.

But never fear. When our students find the right connections, they will learn. They won't be able to help themselves. Learning—changing—is simply what the brain does. And having faith in learning is part of the art of changing the brain.

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