1

This chapter presents a brain-based model of adult learning and connects the model to practice.

Key Aspects of How the Brain Learns

James E. Zull

Cognitive neuroscience is growing rapidly, and new discoveries appear continuously. Understanding the basic structure of the nervous system and the fundamentals of learning through change in neuron networks can give adult educators much insight. Furthermore, a foundation of basic knowledge is essential in understanding the new and evolving research. This chapter therefore focuses on fundamentals.

How Brains Are Assembled

All nervous systems have the same fundamental "bauplan." There must be sensory elements that respond to outside stimuli, motor elements that generate action, and association elements that link the sensory and the motor, sometimes simply and directly and other times through complex networks that express feedback and iterative functions.

The cortex, a complex layer of cells coating the surface of the brain, is the part of the brain associated most strongly with cognition. The region of the cortex thought to have evolved most recently, the "neocortex," has separate areas for the sensory, association, and motor functions.

Signaling, then, has directionality in the neocortex:

sensory $\rightarrow$ association $\rightarrow$ motor

The ultimate value of this arrangement is to allow living organisms to constantly sense a changing environment (sensory) and adapt to it through

New Directions for Adult and Continuing Education, no. 110, Summer 2006 © 2006 Wiley Periodicals, Inc.
Published online in Wiley InterScience (www.interscience.wiley.com) • DOI: 10.1002/ace.213

physical movement (motor), either organized and planned movement or more embedded behaviors (association).

In the human brain, the association elements constitute a major part of the neocortex. In fact, there are two large areas of association cortex, each with distinct functions. The first such area is in the back half of the neocortex. It is responsible for association of various aspects of sensory input with one another—for example, shape and color.

These associations are essential for cognitive understanding, but they do not necessarily come quickly. In fact, insight into unsolved problems is enhanced by allowing time for associations to become apparent. This often happens in periods of reflection, or even sleep, when competing sensory and motor activity is at a minimum. With time, our understandings and our associations change and grow.

The second region of association cortex occupies frontal brain regions. It is heavily engaged in conscious association and manipulation of memories and sensory experiences, functions that are necessary for problem solving and creative activity. The most basic aspect of this capability is the planning of actions designed to achieve specific purposes. Thus the frontal association neocortex sends signals to the motor regions, whose neurons are directly connected with the body's muscles, for control of movement (action).

In addition to these four regions of neocortex, there is one other fundamentally important part of the bauplan. This is the ingrowth of neurons that are not part of the sense-associate-act package; their function is to modify the signaling, making some signals more frequent and others less so, still others of longer duration, and so forth. These cells can be thought of as chemical-delivery neurons. They flood cortical neurons with chemicals that then generate the signaling changes. These changes are much slower than the normal signaling, and so the chemicals they deliver are sometimes called slow neurotransmitters. They are ancient, evolutionarily speaking, and their modern-day function is often associated with emotion: adrenaline, dopamine, and serotonin are examples.

Learning and Change in the Brain

The claim that learning is change is more than a metaphor. It is a physical statement. The brain changes physically as we learn. This change has been demonstrated at many levels in many organisms, but here I refer to the most direct study demonstrating change in the human neocortex when learning. In particular, an increase in the density of a small sensory region of neocortex, the region that senses movement, was demonstrated when people learned to juggle. The density of this region decreased when people forgot some of their juggling skills (Draganski and others, 2004): "Use it or lose it!" This and many other experiments have shown that increased signaling by cortical neurons generates the growth of more branches, which increases the density of cellular material and enhances their ability to connect with other neurons—to form more synapses.

These changes occur only in the parts of the brain that are used. They result from repeated firing of the specific neurons engaged in learning experiences, as well as from the presence of emotion chemicals around those neurons.

The Four Pillars. The nature of the change discussed here suggests that learning is powerful and long-lasting in proportion to how many neocortical regions are engaged. The more regions of the cortex used, the more change will occur. Thus, learning experiences should be designed to use the four major areas of neocortex (sensory, back-integrative, front-integrative, and motor). This leads to identification of four fundamental pillars of learning: gathering, reflecting, creating, and testing. Experienced adult educators probably recognize in the four pillars the outlines of Kolb's learning cycle (1984), which often begins with a concrete experience of "prehension" (grasping), continues through reflection and abstraction (creating a theory-in-use), and concludes with experimentation.

Gathering Data. Getting information is essential for learning. It is so fundamental that the other pillars are sometimes neglected. One demonstration of this is found in schools or other learning situations where getting information becomes the only goal. This can lead to the assumption that learning is better if courses are crammed with content.

It is important to realize that sensing (that is, gathering data) does not immediately lead to understanding. The data fed into the sensory neocortex are just that: data. A computer analogy has some value here. The data collected by the sensory neocortex are like bits that, by themselves, have no useful meaning. Learning is not equal to data collection.

But it is essential to gather data. Each sensory aspect has its own value. Vision is arguably the most powerful, giving us precise spatial input on objects in the world, and mapping those objects on the neocortex. These maps become the stuff of images that then, along with language, underlie cognition and thought. Auditory data is the core of language, which has both cognitive and emotion content. It also gives us crude mapping information about location. Touch substitutes for vision in that we can use it to create maps of anything within our reach, and it can also provide data about texture, hardness, and so forth. Smell and taste yield qualitative information that is sensed through our emotion system. Sweet, sour, fragrant, and putrid all trigger experiences in our body that we then interpret as feelings. These feelings become part of the sensory data and enrich it, engendering emotional responses.

Reflection. New data flows from the sensory neocortex toward the association regions in the back of the brain. As it flows, bits of data are merged into combinations that begin to produce a larger, more meaningful image. There is a natural hierarchy in these regions of cortex, with the lower ones providing the smaller bits that, together, become the higher ones. It is through these associations that we categorize and label objects and actions and identify the spatial relationships inherent in them. Ultimately the physical relationships are the source of relationships in general. For example, the spatial areas of back-integrative cortex are heavily engaged in estimating the relative value of objects, experiences, and people. These judgments are based on spatial relationships in a metaphoric sense (for example, which is in front?).

Associations occur between memories as well as between elements of sensory data. Thus comprehension depends on the associations between new events and past events. The more past events available to be drawn on, the more powerful the meaning. This can have positive and negative results; adults who have been traumatized by being told they “couldn’t learn” or were “bad writers” and so on may have powerful emotional barriers to learning. On the positive side, assignments that encourage students to use negative experiences as a basis for thoughtful reflection and further analysis may help students “reframe” (find new meaning in) those experiences.

Our ability to comprehend new information is also deeply based on assembly of images in the back association cortex. These images are remembered and used as tools in thought. Ultimately, physical images give us the metaphors we use in language. When we understand, we say, “I see.”

As mentioned earlier, all this assembly and association of bits of data, memories, and images might be considered the slowest part of learning. It takes time and involves rerunning our data over and over. It takes reflection. Such reflection is often missing in classrooms where “coverage” is the primary goal. Or reflection may be guided almost entirely by the instructor’s agenda, leading students to search for “right answers” (“veridical decision making” [Goldberg, 2001]) rather than make meaning (see Taylor’s Chapter Nine in this volume).

Creating. The flow of specific meanings or even bits of sensory data from the back association cortex to the front association cortex becomes the basis for conscious thought and planning. It engages what has been called working memory. A small number of relevant individual concepts, facts, or meanings are intentionally inserted into working memory. Determining “relevance” is part of the work. For example, when planning to change a tire, data about tires and cars must be used, not data about horses (or even roads). The chosen information is then manipulated such that a solution to the problem arises. Use of the tire, jack, and car must be organized in sequence. First get the jack, then lift the car, then remove the tire. However, this plan is not just a list of steps; taken as a whole it is a theory, hence an abstraction.

Such plans, theories, and abstractions consist of a combination of images and language. They are the result of intentional associations, selected and manipulated for a purpose. This is the function of the front association cortex, and it represents perhaps the most elevated aspect of learning. It involves intent, recall, feelings, decisions, and judgments. They are all required for development of deep understanding.

Testing. Testing our theories is the ultimate step in learning. The testing must be active; it must use the motor brain. Theory must be tested by action in order to complete learning—to discover how our understanding matches reality. Otherwise it remains inert, "merely received into the mind without being utilized, or tested, or thrown into fresh combinations" (Whitehead, 1929, p. 1).

Writing ideas down and talking about them are also forms of active testing. They are physical acts that produce signals from the motor brain, which the body then senses. This changes a mental idea to a physical event; it changes an abstraction once again into a concrete experience, thus continuing the learning cycle.

Emotional Foundation. As was described earlier, all regions of neocortex are enmeshed in networks of other neurons that secrete emotion chemicals. The cell bodies of these neurons are located in the most ancient parts of the brain, the brainstem, but their branches extend up into every region of neocortex. Emotion systems are ancient, but they extend their influence throughout our modern brain.

Emotion is the foundation of learning. The chemicals of emotion act by modifying the strength and contribution of each part of the learning cycle. Their impact is directly on the signaling systems in each affected neuron. For example, in the auditory cortex experimental manipulation of emotion chemicals results in extensive remodeling of responsiveness to high and low pitches (Kilgard and Merzenich, 1998).

Opening the Window of Wisdom

It is clear that there are windows for learning that close somewhat as we become adults. For example, both visual development and language area development in the brain slow down as we age. However, the neurological nature of learning strongly suggests that there is no age of finality for any learning. The promise for the adult is that the window to wisdom may actually begin to open.

This suggestion is based on the idea that learning is a process of continuous modification of what we already know. This constructivist view seems strongly confirmed by neuroscience. Change in synapses occurs whenever neurons are highly active and immersed in emotion chemicals. With experience our networks may become more complex—denser—as illustrated in the juggling research mentioned earlier. This neurological complexity can be a component of wisdom. It is the biological form of knowledge, and the more complex our knowledge is the more we are able to delineate its key elements and separate the wheat from the chaff. This may enhance our ability to make wise choices and plans. I say "may" because wisdom is difficult to define; all definitions go beyond recognizing or experiencing complexity (see Sternberg, 1990). In fact, both neuroscience and philosophical argument suggest the other side of the coin; wisdom is gained when we know what complexity to discard, and when we see basic truths in their most general and least complex form (see Sternberg, 1990, and Zull, in preparation). However, the argument here is that it may be necessary to pass through stages of experience and knowledge that are highly complex before developing the wisdom that helps us know which parts of it can be discarded.

Notes for Educators

As educators of adults, we may wish to revisit our roles and practices as we learn more about the biological basis of learning. Rather than explaining ideas or correcting errors, we may find ourselves more able to trust in learning. This means allowing learners to develop their own representations, theories, and actions instead of attempting to transfer our knowledge to them. Educators cannot give their ideas to adult learners like birthday presents.

What we can give is new experiences. Skillfully designed experiences whose purpose is to generate new ideas and theories in the learner are very powerful (Taylor, Marienau, and Fiddler, 2000). This is especially true when the learner realizes that it is up to her to interpret and explain but finds her existing neural networks inadequate for the task. Adults are most likely to change when a new experience conflicts with their existing theories. Educators can supply such new experiences and raise new questions for the learner to confront (see Taylor in this volume for a discussion of best practices).

When educators' explanations and ideas are framed as new experience, learners need not accept them carte blanche; rather, they are additional sensory data that learners must represent, abstract, and test.

The reader may note that these ideas are not necessarily new and are consistent with many of the concepts of adult learning developed by others (see Knowles, Holten, and Swanson, 2005). However, it is still of great importance to identify where neuroscience is taking us, and to examine how it fits with current concepts and theories of adult learning. Ultimately, our understanding of learning must be consistent with the biological properties of the learning organ. In fact, no matter how widely accepted they may be, all current theories will automatically be reconsidered and revisited as our knowledge about the brain continues to grow.

If this short chapter catalyzes such revisiting, it will achieve its purpose.

References

Draganski, B., Glaser, C., Busch, V., Schuierer, G., Bogdahn, U., and May, A. "Neuroplasticity: Changes in Grey Matter Induced by Training." *Nature,* 2004, *427*(22), pp. 311–312.

Goldberg, E. *The Executive Brain: Frontal Lobes and the Civilized Mind.* New York: Oxford University Press, 2001.

Kilgard, M., and Merzenich, M. "Cortical Map Reorganization Enabled by Nucleus Basilis Activity." *Science,* 1998, *279,* 1714–1718.
Knowles, M. S., Holten III, E. F., and Swanson, R. A. *The Adult Learner: The Definitive Classic in Adult Education and Human Resource Development*. Burlington, Mass.: Elsevier, 2005.
Kolb, D. A. *Experiential Learning: Experience as the Source of Learning and Development*. Upper Saddle River, N.J.: Prentice-Hall, 1984.
Sternberg, R. J. *Wisdom: Its Nature, Origins, and Development.* New York: Cambridge University Press, 1990.
Taylor, K., Marienau, C., and Fiddler, M. *Developing Adult Learners: Strategies for Teachers and Trainers.* San Francisco: Jossey-Bass, 2000.
Whitehead, A. N. *The Aims of Education and Other Essays*. New York: Macmillan, 1929.
Zull, J. E. Schools for the Natural Mind: What Ordinary Students, Teachers, Administrators, and Parents Should Demand of Their Schools. In preparation.

JAMES E. ZULL is professor of biology at Case Western Reserve University and founding director emeritus of the University Center of Innovation in Teaching and Education at Case.