As you read this essay your eyes are in a state of almost violent motion that you probably have no awareness of and over which you exert little conscious control. If you're like most readers, you stop to look at (or fixate) about two thirds of the words in a passage. At each fixation your eyes stop for about a quarter of a second. Between fixations your eyes make rapid unguided ballistic jumps (saccades) occasionally skipping one or more words if the text is an easy read. All the while your eyes are darting about they are sending signals to many different parts of your brain which hums with electrical and chemical activity as neural signals are processed and sent on to billions of other neurons.

Despite the enormous complexity of the physiology of vision and the brain we think of this experience as something extraordinarily simple and unitary— we read. And, for fluent readers, this activity is so automatic it is virtually a compulsive act. I routinely reenact one well-known example of the power of the printed word (the Stroop effect) with students in my classes by flashing colored words on a screen. I instruct my students to respond to each image by announcing the color of the words they see. When a color word is flashed on the screen and the color of the letters differs from the word (e.g. the word “red” is depicted in blue letters), the word usually wins out. Most students quickly announce the color word rather than the color of the letters, and then, realizing their error, laugh or gasp and correct themselves. Even when students have been provided explicit directions and are anticipating a trick, their first response is usually to read the word rather than simply see it.

How is it that we experience such unity in a process that involves literally billions of neurons and the coordinated conscious and unconscious action of both muscle and mind? A great deal of recent research in cognitive science, philosophy, psychology and artificial intelligence has focused on this and other related questions concerning brains, minds, and behavior. As might be expected, the answers to these questions almost certainly will have significant implications for education. But
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what we know about children, about their development and how they learn or fail to learn may also contribute in important ways to the broader questions that cognitive scientists and philosophers are asking. The purpose of this essay is to suggest one way an educational perspective might shed light on the ongoing controversy about how minds work, which has come to be known as the “cognitive architecture debate,” and which has recently focused on two competing models of mind that have come to be known as the Classical and Connectionist architectures.

In broadest terms, the debate over cognitive architecture is about whether or not minds have a logic of their own. According to a Classical model builder, minds have both an organizational framework and rules that specify how that framework operates. Connectionist theorists, on the other hand, argue that the mind is an extraordinarily complex web of associations that only appears to be governed by a logic of rules because people tend to develop the same kinds of associations. Unlike Classical models which seek to reveal the logical structure of mind, Connectionists are attempting to establish a model patterned after anatomical and physiological characteristics of the brain.

The term “architecture” can be a bit misleading, however, since the debate doesn’t really refer either to the way the brain is put together or to any spatial characteristics whatever. One way to get a handle on the term cognitive architecture is to think about a big corporation and its central headquarters, let’s say Sears and the immense Sears Tower in Chicago. Think of the Sears Tower and everything in it (including all the people) as the brain of the Sears organization. Obviously, in order to exist as a corporation Sears needs to have an
office and workers, but it's important to note that there is more to Sears than a physical structure and a lot of people. A blueprint and a list of who is assigned to each office and work space is not enough to explain how Sears works. In order to understand how Sears works we must know something about what the people in the building do, and in order to understand what they are doing we need to know something about how all those people work together.

One way corporations describe what their workers do is by means of an organizational chart. Typically, there's a box at the top for the board of directors. We can imagine that inside that box is a description of the job responsibilities of the chairman and the board members. Immediately below the box for the board is another box for the president or chief operating officer. Since the chief operating officer reports to the board her box is immediately below and is connected to the box above. Below the chief operating officer's box are several boxes, each of which represents a vice-president with specific responsibilities (marketing, research, manufacturing, etc.). Ultimately (if you are willing to allow an enormous chart that goes into excruciating detail), every single employee of the Sears corporation could be accounted for in such an organizational chart.

Now that our analogy has been elaborated, let's put it to work for us. If you wanted to know how the Sears corporation works what kind of chart would you want? Would a blueprint of the Sears Tower tell you what you want to know? I hope you've answered "No" to my question because you can see that the blueprint is irrelevant. If Sears moved to the World Trade Center in New York it would still be Sears but the blueprint would no longer apply. It is the organizational chart that really defines Sears, not its headquarters and not even the specific individuals who work in its offices. So think of your brain as world headquarters for "Yours Truly, Inc." Anatomists are interested in the blueprints. Physiologists are interested in the way dynamic systems specified in the blueprints work (e.g. plumbing, wiring, elevators, etc.) But cognitive scientists, teachers, and psychologists are interested in the corporate structure of Yours Truly, Inc., not its physical embodiment. And it is the corporate structure that is the center of the controversy about the architecture of cognition.

I have noted two opposing camps in the debate, the Classical camp and the Connectionist camp. According to Classical theorists a mind is defined by its corporate structure, and in certain respects, the structure of mind is similar to the structure typically adopted by businesses: functional units are organized in an hierarchical pyramid-shaped pattern. According to Classical architecture, lower level processes can be automatized through the delegation of authority, but authority is viewed as flowing from higher levels to lower levels. Ultimately, the board of directors are in charge and...
Perhaps the most important implication of the cognitive architecture debate for educators is that the ability to build a predictive model of human cognition does not assure that such a theory is either appropriate or useful responsible for making major corporate decisions. Learning in Classical models consists of elaborating on the corporate structure of mind by adding new divisions or departments which can literally rewrite the job descriptions of lower level units in the corporation.

Connectionist theorists, on the other hand, adopt a much more egalitarian approach to cognition. They suggest that, in fact, there is no corporate structure that defines a flow of authority and no board of directors who specify rules for conducting business! According to Connectionist theory the free market reigns supreme even in matters of cognition. Since there is no board of directors, authority can and does shift from one department to another depending on current need. When there is a pressing need for market research, the marketing department takes charge until some other need becomes more pressing and then some other department assumes primary authority. Moreover, although one department might take charge for some time, other departments retain their authority over their own matters. If the marketing folks need an accounting analysis they don't tell the folks from accounting how to do their jobs and, when accounting goes to work, the marketing department must establish the proper balance of authority among all the departments, each of which does its own job according to its fixed job description.

What is perhaps most remarkable about Connectionist models is that, with certain domains (e.g., visual pattern recognition and associative memory), they seem to work quite well despite the anarchy they seem to imply. Connectionist models of mind suggest that our unified phenomenal experience of self (the chair of our board of directors) is an illusion, that the sense of self is nothing more than a by-product of cognition, the hum that mental machinery makes as it works. If the Connectionists are correct, of course, the problem of mind is solved since it never really existed at all! That is what some of the bolder Connectionist theorists have claimed, but there are some persistent problems that the Connectionist model builders have been unable to solve.

One problem has to do with what appears to be an essential feature of the cognitive development of children: developmental stages, which suggest a hierarchical structure where certain cognitive "departments" appear to have authority over others. Inhelder and Piaget (1958) have documented the role of these stages in cognitive development and their implications for education by means of a series of experiments that took the form of problems children were asked to solve and explain. One of the most well known involves the concept of conservation—the appreciation that the amount of matter present remains constant under a variety of deformations. In one experiment, water from a short, squat beaker is poured into a narrow tall beaker so that the level of the water rises. When asked which container has more water, children in the pre-conservation stage report that the taller beaker has more water. Children in this stage focus on only a single salient variable—the level of the water—despite watching the experimenter pour the water from one container to the second. They are oblivious to the reversibility of the operation (pouring the water) and are satisfied to trust their judgement to visually obvious (but misleading) clues. At a certain point in their development, however (at about 7 or 8), children seem to cross a threshold, suddenly acquiring the concept of conservation (read: "Office of Conservation" in the corporation of mind).

If children merely learned that water is
conserved when poured from a squat to a tall vessel, Connectionist models would work just fine. But children don't learn concepts like conservation in a narrow way. It appears that the Office of Conservation dictates how lower-level departments deal with incoming data. When children cross thresholds that bound developmental stages, they appear to completely reorganize their ways of thinking. Once the stage of conservation has been reached, children know that water in containers is conserved but they also know that pennies in a row or in a stack are conserved, as well as clay in a ball or a pancake, even if they have never seen these examples of conservation before.

The problem with Connectionist models is that, based as they are on a distributed authority that allows departments to retain their autonomy even when they're not currently in charge, they tend to be anchored to a way of doing business which doesn't allow them to undergo the radical systematic reorganization we see as children cross developmental stages. The tenacity of Connectionist models to cling to past experience is frequently cited as a strength of such systems since it tends to minimize errors when dealing with typical cases. But it also means Connectionist models are incapable of what is commonly referred to as "insight," a sudden radical reorganization of knowledge. In a Classical architecture of cognition, however, "insight" is exactly what is predicted when a higher-level Office of Conservation is established that has authority over lower-level departments. Although the lower-level departments have not been abolished, directives from a new higher-level department may radically alter the way they operate. But the only way this kind of systematic reorganization can occur is if some kind of structure exists that defines a flow of control in the system.

A second problem with Connectionist models is that, since the corporate structure defining flow of control has been denied (i.e. the board of directors, CEO, and all cross-departmental managers have all been fired), each department is an autonomous unit that only knows its own job. It's not an exaggeration to say that no one in the corporation really knows what's going on. In the free market Connectionist doctrine, the "invisible hand" of the marketplace is what drives the system. But the invisible hand isn't an explanation, it's an assumption. The explanation that Connectionist models work because they achieve the "proper balance" of authority among the units involved really doesn't explain in any meaningful way, it simply states that things seem to be working and introduces a new concept (the invisible hand of the free market mind) to account for this.

A Classical model of cognition, on the other hand, because it assumes a mental logic, begins by defining relationships between mental content and mental operations and therefore provides a natural basis for relating thought and learning (i.e., cognitive processes) to knowledge (i.e., the objects of cognition). Although there is no guarantee that instructional implications of a mental model will hold true (since the model itself may be refuted), at least a Classical model provides a way for instructional practice to connect with the theoretical apparatus. For example, at one time (late in the nineteenth century) people were thought to recognize words by recognizing, in turn, each of the letters in the word. The instructional implications drawn were that children should be taught letters before we ask them to read words and that reading of words should begin with recitation by spelling. The theory turned out to be wrong; people can and do recognize words without actually seeing each of the letters in each word but the point is not that the theory was right or wrong. The point is that the Classical approach allows instructionally relevant connections to be drawn from theory to practice and that is the essence of education as a discipline. As educators we seek to base our practice of instruction on the knowledge that is currently available about how our students can best be prepared to succeed in learning.

If the only purpose of a theory is to predict, then a Connectionist approach to cognition is fine. Connectionist models have been developed that seem to do a pretty good job of predicting what people will do in controlled experimental settings. But accounting for data is only part of the story in
an applied discipline like education. Educational theory, however, must provide a basis for rational practice and explanation. I would argue that the free market mind doesn’t provide the level of explanation we need to account for how students learn and how we should teach them. Furthermore, although the free market mind offers an adequate account for certain kinds of rote learning, I believe the limitations that have been noted exclude it from serious consideration as a model for higher-level cognitive functions such as language and reasoning.

Connectionist models of cognition (which I have been referring to as free market models of mind) present us with powerful new ways of simulating the most basic processes of mind. Such models may help us build computer simulations of automatic mental reflexes like the Stroop effect. I would argue, however, that it would be most unwise to adopt such models in explaining higher order mental functions. I have noted one empirical reason (developmental stages) for caution in extending the Connectionist framework into educational theory building. In addition, it appears that Connectionist models, by abandoning the assumption of a mental logic, seriously undercut our efforts as educators to relate what we know about the mind to a systematic logic of instructional practice.

Perhaps the most important implication of the cognitive architecture debate for educators is that the ability to build a predictive model of human cognition does not assure that such a theory is either appropriate or useful. As Geoffrey Loftus (1985) has pointed out, there is a danger that complex theory developed in the form of a computer simulation will become nothing more than a restatement of the complex behavior being simulated. Although some researchers in artificial intelligence or cognitive science might contend that their goal is to build a mind (by means of restatement in non-biological media), the role of cognitive theory in education is to help us understand the mind. An appreciation of the difference between these goals is critical to the appropriate development and application of cognitive theory in education.

References
