Recent Advances in the Neurosciences: Implications for Visitor Studies

John H. Falk
Science Learning, inc. (SLi)
Annapolis, Maryland

Introduction

Within the last half dozen years, major breakthroughs have occurred in the study of the human mind. Most important has been the actual ability, through the use of new technologies, to "see" inside the brain. Utilizing advanced imaging techniques, such as positron-emission tomography and magnetic resonance imaging, coupled with powerful computers, scientists have been able to capture real-time images of the physiology associated with thought processes, observing specific regions of the brain "lighting up" when activities such as reading or dancing are performed. These images are demonstrating for the first time how neurons and their elaborate cast of supporting cells organize and coordinate their tasks (cf. Raichle, 1994). The result has been the beginning of an ability to understand brain functioning based on direct "observation" of the various parts of the brain in conjunction with more traditional studies of human behavior. Neuroscience research, in combination with cognitive psychology research, is leading to a radical rethinking of the learning process. This paper provides a brief overview of brain (and a sprinkling of cognitive science) research and suggests implications for the museum field in terms of how we define and measure learning. For a more thorough discussion see Falk and Dierking (1997).

Background

The Brain

The brain is at once exceedingly simple and overwhelmingly complex. It is a large, very wet and seemingly undifferentiated mass of hundreds of billions of cells — comparable to the number of stars in the known universe. Although abundant in number, for the most part, this mass of cells is composed of only two types: glial cells and neurons.

The most numerous type of cells in the brain is the glial cells. Although still poorly understood, glial cells play key roles in a large number of important areas of brain development and maintenance (Kimmelberg & Norenberg, 1989).

Neurons are primarily responsible for the phenomenon referred to as thinking. The brain contains tens of billions of these highly interconnected cells. Although they come in a variety of sizes and shapes, each neuron is composed of the same basic parts and functions in a similar manner. In addition to the cell body which contains the basic structures necessary for maintaining cellular function, each neuron also has two other parts, axons and dendrites. Because the main function of a neuron is to transmit and receive chemical messages, it comes equipped with a transmitting end, an axon, and a receiving end, dendrites. Most neurons have a single axon extension that sends its chemical message to the other neurons in its circuit. Some axons are huge, extending for several feet, but most are relatively short. At its end, an axon may divide into branches, thus communicating its message, in the form of released neurotransmitter chemicals, to numerous other neurons. Messages only flow in one direction along the axon — away from the cell body.

A typical neuron has many short, finger-like, tubular extensions called dendrites that reach out towards other neurons in their vicinity. These projections contain receptors designed to pick up chemical signals from the axons of other neurons. Depending on a host of factors, such as the recency of the last electrical impulse (referred to as "firing"), and the chemical threshold and the receptivity of the dendrite, if the "right" type of chemical signal is received, the dendrite initiates an electrical signal that is relayed through the cell to the axon where it is once again translated into a chemical signal.

In large part, "learning" appears to be related to changes in the dendrites. For example, during memory formation, spines have been observed developing on dendrites, which increases the number of available receptors and therefore the amount of neurotransmitter information that can enter the neuron at one time. These billions of neurons and glial cells are arranged throughout the brain in clusters or columns, that in turn, are arrayed in layers, that in turn, are organized into distinct areas such as the frontal, occipital, temporal and parietal lobes as well as unique structures such as the amygdala, hippocampus and hypothalamus. It has long been suspected that the complexity of the brain emerges from the unique spatial arrangement of its constituent parts. Recent research suggests that this is both true and not true.

The localized, in current parlance "modular" nature of the brain is never more evident than in cases of selective brain damage. Neuroscience has gained tremendous insight into the nature of brain organization by observing those unfortunate individuals who happen to have impaired one, and just one, small part of the brain. Through this process it has been learned, for example, that the mental processing of things seen and the verbalization about what has been seen, through words, are located in different regions of the brain. It is through observations of hundreds of such cases that it has been determined that our ability to transfer the visual world into mental constructs and communicate these constructs in words involves literally dozens of different sites. For example, walking through a science center and seeing a group of children playing with a new interactive exhibit. The interactive is being moved by the actions of the children at a relatively slow speed as judged by the movement of the blade against the background of the other exhibits in the area): the color (the interactive is blue) is processed separately from high-resolution form perception (it looks like a large propeller); movement and stereoscopic depth ("Why are they moving the blade? Perhaps it has something to do with thrust?") are processed separately from who is moving the exhibit (my neighbor's daughter); and name recognition (it's Mary) is processed in still another area (Restak, 1994). But to us, looking at the children playing with the interactive, all this modularization seems strange since we experience this event as a seamless whole.

The brain may have distinct regions, but these distinct areas constantly communicate with each other through an elaborate network of interconnections. No matter where you look in the brain, particularly the cerebral cortex (where most higher order thinking presumably occurs), all brain cells and collections of brain cells communicate with other cells (Restak, 1994). Thus, traditional notions of brain regionality and specialization are being revealed to be, at best, only partially true. Research is revealing that memories, whether of an object like a science exhibit or an idea like "thrust," not only do not reside in a single location but, at some level, do not actually exist. Contrary to long-held views, memories are neither permanently resident in an area of the brain nor actually permanent at all (Edelman, 1987). All learning, all memory, represents a continual ongoing process of mental "construction." Pieces of past experiences are assembled *internally*, under the influence of *external* stimuli. Brain functioning, it appears, is distributed throughout different parts of the brain, with various areas contributing different aspects to a memory or function on demand. Perceptually, we perceive ideas and memories as a single undifferentiated whole, but they are not.

The human brain evolved to permit the long-term survival of the individual. To be successful meant acquiring vast amounts of information in the present and utilizing that information to solve life problems, some in the immediate future, as well as many that only occur in the distant future. Thus the brain evolved the capacity for carrying out two very important and related functions. It evolved the ability to acquire and store information in a usable (i.e. retrievable) manner; and it evolved the ability to reuse (i.e. remember) stored information to solve and act upon problems. In other words, the human brain is a highly evolved device for <u>learning</u>. For convenience, we can divide learning into two large "steps". The first involves the active acquisition of information (creating memory) and is what we usually think of as the "process" of learning. The second involves the utilization of stored information to solve problems (using memory), and is the type of learning usually measured as an outcome of an experience that can be thought of as the "product" of learning.

The Process of Learning

Each individual is attuned to receiving and processing a vast array of information, both from the external world and from inside the body. How do humans acquire information? The answer normally given in psychology textbooks is through our sense organs. In fact, brain research has shown that in addition to acquiring information through our sense organs, the brain also acquires a steady stream of information from the internal organs of the body and from other regions of the brain. Constructivist theory has suggested that each individual uniquely acquires and processes information. Brain research supports this view; the "information" we acquire and process in any given learning situation is as much a function of what's going on <u>inside</u> of us as it is a function of what is going on <u>outside</u> of us (Restak, 1994).

Our brain independently and simultaneously processes information coming in from our eyes, ears, nose, skin, internal organs, skeletal muscles and other regions of the brain. Although vast quantities of information may flood into a dozen or more receptor areas of the brain simultaneously, we are rarely conscious of this welter of data. Our brain is capable of separating what information to attend to from what information to ignore. Much of the information coming into our brain occurs below the level of consciousness, nonetheless, within the realm of awareness. Although we may not be consciously aware of all that is occurring around us, much of it is still being processed. Consequently, when we later reflect upon an event, like a museum visit, we are more likely to "reconstruct" what we saw or did, rather than actually "remember" it. In fact, "perception" is rarely complete. Typically "realities" are pieced together from bits and pieces of information, a "constructed" reality that we accept as reality (Rosenfield, 1988).

Through an equally complex process, our brain determines what to attend to in the environment. Deciding what to attend to involves a number of considerations, including an assessment of current relevance to our survival and well-being, as well as an assessment of prospects for long-term relevance, what Silverman (1995) has called "meaning-making." A large part of this decision making involves brain activity in the frontal cortices which contain past memories of similar or related experiences. Prior personally "meaningful" experiences, even experiences seemingly not directly related to the museum, will be utilized in processing the information. This is why an individual standing in front of a painting of a sunset is as likely to tell his friend how this painting reminds him of the time he and his brother were visiting Hawaii as he is to talk about the significance of the sunset within the painting. For that individual, images of Hawaiian sunsets are perhaps more meaningful than are schools of late 19th century British artists.

Equally important for mental processing, though, is the information being provided chemically and electronically about our emotional and bodily state. For example, if people visit a museum, even an interesting museum, but are stressed because of events in their personal lives, their body will be releasing high levels of the peptide cortisol. These peptides will interact with the hippocampus and disrupt the transfer into long-term memory of what might otherwise be a memorable experience.

In order for learning to occur, experiences must be encoded and transferred into long-term memory. The process by which this occurs involves the collection of experiences and sensations from throughout the various regions of the brain, which are then routed through the hippocampus (Hilts, 1995).

Once through the hippocampus, the memories are redistributed back to dozens, perhaps hundreds, of locations within the brain. Sometimes the redistributed memories are sent back to similar locations from whence they originated, sometimes they are sent to new locations in the brain. As memories move through the hippocampus, the disparate types of "memories" are "bundled" together. In the process, every memory is provided with an emotion, time and location "stamp" before being stored (Restak, 1994). This is why asking someone to describe what they learned in a museum will always be framed within the context of what an individual saw or did, as well as how they felt (e.g., Falk, 1988; Stevenson, 1991; Falk & Dierking 1992; McManus, 1993). Learning is always "situated," in other words, contextually bound by place, social situation and emotion (Falk & Dierking, 1992; Ceci & Roazzi, 1992).

The Product of Learning

There is good evidence that we process different types of memories in different parts of the brain. For example, there appear to be two major types of long-term memory, procedural and declarative (Baddeley, 1990; Restak, 1994). Procedural long-term memory, which involves primarily the amygdala, cerebellum and autonomic nervous system, is the memory we use to walk, drive a car or touch type. These memories do not rely on conscious verbal recall, except to initiate, monitor and stop the extended movement sequence. Declarative long-term memory, which involves primarily the hippocampus and the cortex, are factual label-and-location type memories.

Psychologists have distinguished two types of declarative memory — episodic and semantic — and it appears that these, too, are processed in different regions of the brain. Episodic declarative memories are very personal, tied to specific episodes in one's life, such as the first trip to a museum. Semantic declarative memories are more abstract and symbolic, and usually are associated with language. Consequently, different parts of the brain are involved in monitoring and regulating such tasks as judging the beauty of a picture, reading an exhibit label and manipulating a track ball on a computer interactive. However, despite the fact that these functions can be shown to occur in separate parts of the brain, in real life they rarely function separately. Most of the time, multiple parts of the brain are working together, in parallel. Under normal circumstances, your brain integrates information from all its components into a single, perceptually seamless, process (Restak, 1994).

One of the great paradoxes of current brain research is that reductionist methods have resulted in the identification of different types of memory systems occurring in different regions of brain, but these methods have yielded little useful insight into how memories are formed (Rosenfield, 1988). The parceling out of brain activities may be nothing more than an adaptive strategy to minimize risks through redundancy and distribution of "resources." Or it may be just another interesting example of specialized, but highly integrated systems, of which the body has many examples. A case in point is the human circulatory and respiratory systems. Traditional textbook presentations treat these two systems separately when, in fact, they are but a single integrated system; totally interdependent and intertwined.

The integrated nature of brain functioning has been strongly reinforced by recent investigations of brain activity patterns. It is not just the higher cortical areas of the brain that are involved in solving problems or decision making. For example, all parts, including the "primitive" emotion-laden brain stem areas, are essential ingredients. Some of the most compelling evidence for the integration of brain functions in decision making and problem solving again come from studies of brain-damaged individuals. In one of the most celebrated cases, an individual with all his "higher faculties" intact, but severe damage to the part of his brain necessary for emotions, could "pass" every kind of intelligence test administered but, in the absence of emotions, was incapable of making important life decisions, including even the most basic decisions required in his job as an accountant (Damasio, 1994). In fact, all higher intellectual functioning, including analyzing objects in a museum, involves emotion (Rosenfield, 1988; Damasio, 1994; Restak, 1994). Brain research confirms what many museum researchers have long suspected: cognition and affect are not separable, but an integrated whole.

Research into brain activity has also provided important insights into how memories are preserved; how they are reinforced over time and thus available for utilization. Social interactions, in particular conversation, turn out to be important vehicles for consolidating and stimulating memories. Some neuroscientists have even argued that the primary purpose of conversation is the reinforcement of memories (Sylwester, 1995). In this context, the social nature of museums emerges as more than a "nicety." Social interaction in museums plays a fundamental role in learning.

Implications

As this brief review has attempted to suggest, learning is an exceedingly complex phenomenon. Brain-based research is revealing that much of the "conventional wisdom" about learning no longer seems valid. Shattered are many of the conceptions about learning that we carry from our school days. For years psychologists and educators treated learning as a linear and predictable accumulation of knowledge (cf., Roschell, 1995). This model, often characterized as the factory model of learning, operated as if learning was a process of filling up identically empty minds as they moved past on the educational assembly line. Within museums, this model takes the form of visitors moving through an "expertly designed" exhibition with requisite stops at each element — the assumption being that the message of the exhibition will be incrementally built up in visitors' minds as they move through the exhibition. Stop by stop, visitors will accumulate more and more information until they reach a critical threshold of information and then the exhibition's "big ideas" will be understood and "learned."

Brain research shows that this model is erroneous. Learning is revealed to be a uniquely personal, contextual experience, constructed from both internal (head and body) and external (physical world and social contacts) experience. Consequently, learning is rarely linear and is always highly idiosyncratic. What a visitor learns in an exhibition is determined first and foremost by the individual's prior experiences. Which prior experiences are called forth, though, are determined by a complex of factors which includes the content and presentation of the exhibition, but also the conversations that occur between the visitor and his/her companions and whatever may have been on the individual's mind when he/she walked into the museum that day. Learning can even be influenced by what an individual had for breakfast that day or whether or not he/she has a cold.

Although it is clear that exhibitions that require "most" visitors to "stop" at each element can be designed, brain research confirms what many have already appreciate. This activity, in and of itself, is no guarantee that information is being incrementally assimilated and accommodated. Even when outwardly behaving in an "appropriate" fashion, different visitors, depending upon their prior interests and knowledge,z social companions and physiological state, will exit the exhibition with vastly different "learning."

Also problematic is the prevailing reductionist model of learning, which not only distinguishes but treats as separate phenomenon, processes such as cognition and affect, or memory systems such as semantic and episodic memory. Some psychologists even treat learning and memory as separate phenomenon. As brain research makes clear, these categories may be distinguishable but they are fundamentally inseparable. Learning does involve many independently functioning information processes, including information coming in from the senses, from internal organs and from different regions of the brain. However, brain processing results in these independent bits of information being integrated into a set of highly interconnected memory traces — so interconnected that it is exceedingly difficult to disentangle the separate bits of sensory, emotional and cognitive information once processed.

In a similar way, learning involves many different types of memory systems, including declarative and procedural memory as well as semantic and episodic memory. These systems appear to operate in concert, not separately. Consequently, memories are an amalgam of what we did, what we thought and who we were with. In a similar way, feelings and thoughts, words and experiences combine in the brain to form the basis of what we call learning. Learning is the whole package, not just the pieces. Learning is translating experience into stored memories which become the substrate upon which future learning can be built. The result is that efforts to understand visitor learning, by necessity, need to deal with the complex, multidimensional nature of learning and memory. Learning does include affect and cognition, semantic and episodic constituents. Attempting to separate these constituents or even worse, factor out certain constituents, is in the long run counter productive and misleading. Understanding museum learning requires a holistic, not reductionist, approach.

Brain research also reveals the ephemeral, constructed nature of learning. In other words, memories are not really permanent stores but constantly (re)constructed versions of past experience. Memories are constantly being created, destroyed, and then again recreated by the brain. What we "learned" yesterday only is learned to the extent that we can form new associations between the elements of that memory and new experiences. It means, as has been found by Dierking, Falk and Abrams (1996), that visitors to a museum may exhibit different "learning" at different times. Something ostensibly "learned" immediately following a visit may not be there three months later but, equally interesting, something ostensibly "not learned" immediately after a visit may subsequently emerge as "learned."

Finally, brain research is helping reframe questions of human learning and behavior within an evolutionary context. Humans go to museums and learn there for reasons more profound than merely "filling up time." Although these reasons may be poorly understood, understanding museum learning will require knowing how museum visitation relates to human biological and cultural evolution. In other words, not only should we attempt to understand museum learning as a piece of an individual's whole life rather than just as an isolated one- or two-hour event, but so too must we strive to frame the museum experience within an even larger evolutionary context. How do museum experiences enhance human biological/cultural survival, as played out in the context of late 20th century America? How, as Silverman (1995) has argued, do museum experiences help people make meaning in their lives? These are questions rarely asked when designing exhibits or programs and equally rarely considered when assessing museum learning.

The findings from brain research should have impact on how we, in the museum field, go about defining and measuring learning. They raise particular questions about what we should use as evidence of learning and they question the distinctions many researchers currently make between types of learning (e.g. cognitive versus affective, or semantic versus episodic memory). They raise the issue of when we should assess learning; in other words, how long after the museum experience should we be looking for evidence of learning? Finally, they suggest that we need to take a much broader view of museum experiences in general, and museum learning in particular, before we can reasonably hope to understand why people go to museums, what they do there and what they take away with them from those experiences.

References

Baddeley, A. (1990). *Human memory: Theory and practice.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Ceci, S. J. & Roazzi, A. (1992). The effects of context on cognition: Postcards from Brazil. In. R. Sternberg & R. Wagner (Eds.), *Mind in Context.* Cambridge: Cambridge University Press.

Damasio, A. R. (1994). *Descartes' error: Emotion, reason and the human brain.* New York: Avon Books.

Dierking, L. D., Falk, J. H. & Abrams, C. (1996). Long-term museum learning: A pilot study. *Current Trends in Audience Research and Evaluation, 10.* Papers presented at a poster session of the 1996 American Association of Museums annual meeting, Minneapolis, MN: AAM Committee on Audience Research and Evaluation.

Edelman, G. (1987). *Neural darwinism: The theory of neuronal group selection.* New York: Basic Books.

Falk, J. H. (1988). Museum recollection. In. S. Bitgood, S. Roper & A. Benefield (Eds.), *Visitor Studies: Theory, Research, and Practice, Proceedings of the First Annual Visitor Studies Conference.* Jacksonville, AL: The Center for Social Design.

Falk, J. H. & Dierking, L. D. (1992) *The museum experience.* Washington, DC: Whalesback Books.

Falk, J. H. & Dierking, L. D. (1997). *How people learn when they don't need to.* Manuscript in preparation.

Hilts, P. J. (1995). *Memory's ghost: The strange tale of Mr. M and the nature of memory.* New York: Simon & Schuster.

Kimmelberg, H. & Norenberg, M. (1989). Astrocytes. *Scientific American. 260(4)*, 66-76.

McManus, P. (1993). A study of visitors' memories of Gallery 33. In J.P. Jones (Ed.), *Gallery 33: A Visitor Study.* Birmingham, UK: Birmingham City Council.

Raichle M. E. (1994).Visualizing the mind. *Scientific American. 270(4)*, 57-64.

Restak, R. M. (1994). *The modular brain.* New York: Simon & Schuster.

Roschell, J. (1995). Learning in interactive environments: Prior knowledge and new experience. In J. Falk & L. Dierking (Eds.), *Public Institutions for Personal Learning.* Washington, DC: American Association for Museums.

Rosenfield, I. (1988). *The invention of memory: A new view of the brain.* New York: Basic Books.

Silverman, L. (1995). Visitor meaning-making in museums for a new age. *Curator 38(3),* 161-70.

Stevenson, J. (1991). The long-term impact of interactive exhibits. *International Journal of Science Education. 13(5),* 521-31.

Sylwester, R. (1995). *A celebration of neurons: An educator's guide to the human brain.* Alexandria, VA: Association for Supervision and Curriculum Development.