Polanyi's Epistemology in the Light of Neuroscience

A Review Article

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ABSTRACT Key Words: Michael Polanyi, Eric Kandel, tacit knowing, implicit memory, explicit memory, habituation, sensitization, anti-Semitism, reductionism, integration, brain plasticity, selective attention.
In Search of Memory, *Eric Kandel's excellent account of the rise of neuroscience, in which his own research has a prominent place, is reviewed with special attention given to its relation to Michael Polanyi's philosophy. It is found that Polanyi's epistemological theory, although established on quite different grounds, accords well with Kandel' s description of how the brain operates. In particular, Polanyi's theory of tacit knowing seems to be both enriched and validated by Kandel's account of how memory functions.*

Eric R. Kandel. *In Search of Memory: The Emergence of a New Science of Mind.* New York: W. W. Norton & Company, 2006. Pp. xv + 510. ISBN 978-0-393-32937-7. $17.95 paperback.

How well does Polanyi's thought of half a century ago connect with the ongoing history of research in cognitive science, molecular biology, and understanding of the brain? Eric Kandel's book helps answer that question. It combines autobiography (of interest because he is a Nobel Prize winner in Physiology or Medicine) with a compelling historical account of step by step progress in understanding the brain and how it works. As a whole, his book is consistent with the general framework provided by Polanyi with respect to such issues as the tacit dimension, the epistemological centrality of integration, and emergence.

In American folk culture, when the writing of physicians is mentioned, illegible scrawl is more often the subject than graceful exposition. Kandel's work exemplifies the latter condition rather than the former suspicion. *In Search of Memory* intersperses fascinating vignettes of life history with concise, clear, and captivating accounts of key advances in neuroscience. Rare is the work that is both so well written and so informative about significant issues. In addition to outstanding prose, the book is blessed with many instructive diagrams and a helpful glossary.

Although Polanyi was born a long generation earlier than Kandel (whose date of birth is 1929), their biographical details show they share a good bit in common. They were each born into secular Jewish families in the Austro-Hungarian Empire or its remnants. Each was driven out of the German-speaking world by the incursion of the Nazis – Kandel's family escaped from Vienna just before World War II broke out. Each family emigrated to the Anglo-American world—Kandel's family to New York City. Each man earned a degree in medicine but turned professionally to other fields in scientific research. And both lived a culturally rich life in which issues of responsibility and morality came to explicit expression.

However, Kandel, unlike Polanyi, opted to reaffirm his Jewish identity by practicing its rituals in his family life. Kandel's reflections on Jewish identity bear on Polanyi's experience. Kandel, apparently relying on a distinction made by Frederick Schweitzer, distinguishes cultural anti-Semitism from racial anti-Semitism.

> Cultural anti-Semitism is based on the idea of "Jewishness" as a religious or cultural tradition that is acquired through learning, through distinctive traditions and education. . . It also holds that as long as Jewish identity is acquired through upbringing in a Jewish home, [its imputed unattractive] characteristics can be undone by education or religious conversion, in which case the Jew overcomes the Jew in himself or herself. A Jew who converts to Catholicism can, in principle, be as good as any other Catholic. (30-31)

Polanyi himself rejected provincial forms of Judaism as obscurantist and out of touch with the modern world. His rejection of rural folk Judaism and acceptance of a version of Christianity shows he understands religious identity to be a cultural option, but one with important consequences for thought and behavior. Racial anti-Semitism, on the other hand, is based on the view that Jews were the killers of Christ. Jews were seen as genetically deficient to a degree that no education or conversion could erase their imprinted deficiencies. Once Hitler entered Austria in 1938, racial anti-Semitism was imposed as official policy and the Kandels' only option if they were to survive was to escape Vienna. Similarly, Hitler's racial anti-Semitism was why Polanyi's earlier conversion to Christianity and service in World War I essentially no longer protected him, and, perceived as a racial Jew, he was best advised to leave Germany.

When one turns from life details to their approaches to science, different emphases between Polanyi and Kandel are evident. Polanyi delights in discoveries of coherence, and he regards experimentation as a tool for achieving or verifying such intellectual visions. For Kandel, however, the life of the lab is the heart of the scientific enterprise. His book elucidates, at its core, a series of illuminating experimental discoveries strung out in historical sequence like a strand of pearls. Thus Polanyi celebrates the intellectual processes whereby specific discoveries are made and provides a rather phenomenological and functional account of the mind's operations, while Kandel attends more closely to concrete , physiological details of how the brain works and provides a step by step survey of how our understanding of the brain was achieved.

Each man, however, appreciates the importance of the social context in which science is carried out, albeit again with different emphases. Kandel states that "what makes science so distinctive, particularly in an American laboratory, is not just the experiments themselves, but also the social context, the sense of equality between student and teacher, and the open, ongoing, and brutally frank exchange of ideas and criticism" (106; see also 417). Polanyi tends to stress the freedom of the mature individual scientist within the context of the authority of the scientific community (*SFS* 43ff). Indeed, the issue of freedom in science is central to each. Kandel writes, "Freedom to do research is like free speech, and we as a democratic society should, within rather broad limits, protect the freedom of scientists to carry out research wherever it takes them" (333). Polanyi would agree.

Where the scientific interests of Polanyi and Kandel most clearly overlap is in understanding the dynamics of tacit knowing. The way Polanyi situates tacit knowing in evolutionary development in Part Four of *Personal Knowledge* is affirmed in Kandel's experimental work. To understand the biological nature of the human mind, Kandel finds it profitable to begin by studying the minds of invertebrates. This is because signaling molecules found in the human brain have been conserved through millions of years of evolution; the same kind of signaling molecules are found operating in the neurons of simple animals that are found in humans (see xii-xiii). For, as the molecular geneticist Francois Jacob points out, "evolution is not an original designer that sets out to solve new problems with completely new sets of solutions. Evolution is a tinkerer. It uses the same set of genes time and again in slightly different ways" (235).

Kandel's exposition of "implicit memory" helpfully extends some of the things Polanyi, from a more intuitive perspective, said about the tacit dimension. Kandel provides details of historical cases that reveal how the brain incorporates information into knowledge and habits through different processes. Of greatest significance in this regard is the case of H.M. as studied by Brenda Milner. In 1953, H.M. sustained a serious head injury resulting in seizures and incapacitation. As a desperate measure to control his seizures, surgery was performed that removed the inner surface of his medial temporal lobe and hippocampus. His seizures were cured, but he suffered devastating loss of long-term memory. Kandel's account of what Milner discovered through observing H.M. is so helpful it is worth recounting in some detail. First, H.M.

> had perfectly good short-term memory, lasting for minutes. He could readily remember a multidigit number or a visual image for a short period after learning it, and he could carry on a normal conversation, provided it did not last too long or move among too many topics. This short-term memory function was later called working memory and shown to involve an area known as the prefrontal cortex, which had not been removed from H.M. Second, H.M. had perfectly good long-term memory for events that had occurred before his surgery. He could remember the English language, his IQ was good, and he recalled vividly many events from his childhood.
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> What H.M. lacked, and lacked to the most profound degree, was the ability to convert new short-term memory into new long-term memory. . . He could retain new information as long as his attention was not diverted from it, but a minute or two after his attention was diverted to something else, he could not remember the previous subject or any thing he thought about it.(127-128)

Milner showed that memory is a distinct mental function quite different from other perceptual, motor, and cognitive processes. The surgery demonstrated that the medial temporal lobe and the hippocampus are processing and transforming sites rather than storage sites. It was further shown that the long-term storage areas for people, objects, places, facts, and events are the parts of the prefrontal cortex that were originally the sites where their short-term memory experience occurred. The hippocampus is needed to convert short-term to long-term memory.

While at first Milner thought H.M.'s ability to learn on a long-term basis was totally destroyed, further experimentation revealed he could learn tacitly new abilities that he could not explicitly express. "He learned to trace the outline of a star in a mirror and his skill at tracing improved from day to day, just as it would in a person without brain damage. Yet even though his performance improved at the beginning of each day's test, H.M. could never remember having performed the task on an earlier day" (131). This and other experiments revealed a difference between explicit memory, whether short-term (which H.M retained) or long-term (which H.M. lost), and the implicit memory (which H.M. retained in both short- and long-term versions).

> What we usually think of as conscious memory we now call, following Squire and Schacter, explicit (or declarative) memory. It is the conscious recall of people, places, objects, facts, and events – the memory that H.M. lacked. Unconscious memory we now call implicit (or procedural) memory. It underlies habituation, sensitization, and classical conditi oning, as well as perceptual and motor skills such as riding a bicycle or serving a tennis ball. This is the memory H.M. retained.
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> Implicit memory is not a single memory system but a collection of processes involving

> several different brain systems that lie deep within the cerebral cortex. For example, the association of feelings (such as fear or happiness) with events involves a structure called the amygdala. The formation of new motor (and perhaps cognitive) habits requires the striatum, while learning new motor skills or coordinated activities depends on the cerebellum. . .
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> Implicit memory often has an automatic quality. It is recalled directly through performance, without any conscious effort or even awareness that we are drawing on memory. . . For example, once you learn to ride a bicycle, you simply do it. (132)

Clearly, implicit memory as described by Kandel has close affinities to what Polanyi calls tacit knowing. Kandel reviews the earlier interpretations of such unconscious processes that were offered by Helmholtz, James, Ryle, and Freud and finds useful elements in each. When he focuses on learning theory, he reaches back to the association theory of Aristotle, its elaboration by Locke, and then its formulation by Pavlov and Thorndike as stimulus-response theory.

> In the course of studying classical conditioning, Pavlov discovered two nonassociative forms of learning: habituation and sensitization. In habituation and sensitization an animal learns only about the features of a single stimulus; it does not learn to associate two stimuli with each other. In habituation the animal learns to ignore a stimulus because it is trivial, whereas in sensitization it learns to attend to a stimulus because it is important. (41)

It would appear that sensitization and habituation are basic psychological processes that underlie more complex types of learning. The primitive sort of selective process included in sensitization and habituation would seem to play a supportive role in each of the three types of tacit animal learning Polanyi discusses: trick, sign, and latent learning (see *PK* 71-77). Sensitization can be correlated with what Polanyi describes as the very deepest root of discovery and perception: an "animal's capacity to be intrigued by a situation, to pursue consistently the intimation of a hidden possibility for bringing it under control, and to discover in the pursuit of this aim an orderly context concealed behind its puzzling appearances" (*PK* 73). Kandel describes the function of habituation as follows: "The elimination of responses that fail to serve a useful purpose focuses an animal's behavior. . . Once they become habituated to such stimuli, they can focus on stimuli that are novel or associated with pleasure or danger. Habituation is therefore important in organizing perception" (168). For Polanyi, of course, the way we perceive is the model for the way we make scientific discoveries. He praises both the scientist's ability to ignore trivial stimuli (including apparent falsifying data) and the sensitivity to coherence as crucial for making contact with reality and establishing a true theory (see, for instance, *SFS* 24, 39, and 90). Habituation and sensitization are thus essential components of the scientific enterprise. This twofold ability when put to use by a scientist can be called "scientific passion;" it distinguishes "between demonstrable facts which are of scientific interest, and those which are not" (*PK* 135).

The selective function of sensitization and habituation allows for the discernment of learned associations which Kandel speaks of as classical conditioning and Polanyi speaks of as sign learning. Here is the primitive basis for the notion of causality. The spatial and temporal ordering of learned associations gives rise to the mental maps Polanyi calls latent learning.

While Kandel originally wanted to become a psychoanalyst, his experience in lab work came to convince him that real progress in understanding memory requires a reductive approach within biology. It requires learning how neurons work at the molecular level, one cell at a time. Here Kandel found himself opposed by many leading neurobiologists. They are reluctant "to apply a strictly reductionist strategy to the study of behavior because they thought it would have no relevance for human behavior" (144). But Kandel, knowing that certain elementary forms of learning, like conditioning, habituation, and sensitization, are common to all animals including human beings, stuck to his reductionist instincts. He decided to study the comparatively giant neurons in the large marine snail *Aplysia* in order to determine how they were changed by learning.

Polanyi's thought is often appreciated because he takes such a firm stand against reductionism. It might then be thought that he would disapprove of Kandel's approach to learning theory. But there are different sorts of reductionism. One is the "nothing but" school that sees higher level phenomena as epiphenomena of what alone is real, the actions of the lower level of a comprehensive entity. Both Polanyi and Kandel would reject such a species of reductionism. Polanyi, however, would likely affirm the type of reductionism proposed by Kandel, as is evident especially in his evolutionary account of "the rise of man" in Part Four of *PK*. Human capabilities are built upon a series of increasingly complex animal capabilities. Explanation within Polanyi's hierarchical vision of reality would in fact require that the processes at each emergent level be understood. Kandel's reductive passion targeted the level of cell biology. But he makes it clear that he understands there are higher levels of functioning that his reductive analysis merely sets the stage for and does not determine. His comprehensive, level-sensitive vision (both he and Polanyi would likely affirm Ursula Goodenough's account of emergence as "something more from nothing but") is, for instance, indicated by his approach to mental disease. Rather than promoting simply a pharmaceutical regime for curing mental problems, which a "nothing but" biochemical reductionist would tend to do, he states, "many patients do better when some form of psychotherapy is combined with drugs, while a surprising number of patients do reasonably well with psychotherapy alone" (372).

In the nineteenth century, several important discoveries were made that indicated something about how the brain works at the level of language. Paul Broca examined a man who had suffered a stroke and "had lost the ability to speak fluently, although he indicated with facial expressions and actions that he understood the spoken language quite well" (122). In the postmortem examination of the man's brain, a lesion was discovered in what is now called Broca's area of the left cerebral hemisphere. Carl Wernicke discovered in 1879 another sort of speech defect in which people can utter words, but their order and meaning is incoherent. This disorder was found to be localized in another part of the left hemisphere. Wernicke theorized that both these two interconnected areas are each needed for the coherent expression and comprehension of language. The function of these two areas can be correlated to Polanyi's distinction between sense-giving and sense-reading (see *KB* Chapter 12). Broca's area processes sense-giving at the linguistic level; it evokes appropriate vocabulary and syntax in the construction of verbal meaning. Since a person with a damaged Broca's area can understand but not express language, sense-reading as a type of understanding occurs in another portion of the brain. That site appears to be Wernicke's area, which when damaged results in "a disruption in the comprehension of spoken or written language" (122). It is somewhat surprising to note that the ability to create meaning through language and the ability to recognize linguistic meaning are localized in different parts of the brain.

Kandel's work with *Aplysia* built upon earlier twentieth century discoveries about the functioning of neurons. Charles Sherrington, for instance, had discovered that animals possess innate reflex behaviors that are intrinsic to the spinal cord and do not require a message be sent to the brain—the equivalent of a tap on a human knee. He also found that some neurons are inhibitory while some are excitatory, and that individual neurons integrate these signals. "A motor neuron totals up all the excitatory and inhibitory signals it receives from the other neurons that converge upon it and then carries out an appropriate course of action based on that calculation" (71). Lord Adrian studied the electrical signals (the action potentials) propagated in neurons and found that they are all very much the same. "The action potential is thus a constant, all-or-none signal: once the threshold for generating the signal is reached, it is almost always the same, never smaller or larger" (77). What makes some sensory impacts feel much more intense is that the signaling neuron fires much more rapidly, not that a single firing is much stronger. Unlike electrical current in a wire, which diminishes as it travels, the electrical signal sent along an axon of a nerve cell does not decrease in strength as it travels. Rather it proceeds in wave-like chemical fashion through the intrusion or extrusion of ions. Nerve signals are thus much slower but also much more reliable than electric signals in a wire.

All of these discoveries relate in instructive ways to Polanyi's thought. For one thing, the all-or-none firing of a neuron points to the non-linear quality of thinking. The summation of inhibitory and excitatory impulses in a neuron might total .93 when 1.0 is required for a firing, and these impulses would not then be acted upon. When 1.0 is a go and .17, .54, and .93 are not (and thus are functionally equivalent), this suggests that linear mathematical and logical modeling of the brain's functioning is inappropriate with regard at least to neural processing. Polanyi's informal understanding of logic as associated with achievement and his use of integrative intuition as an explanatory tool are thus more appropriate to epistemology than the use of strict formal logic and argumentation as typically practiced in the analytical tradition of philosophy. Kandel's claim that "the fundamental task of a nerve cell is integration" (93) comports well with Polanyi's emphasis upon the integration of subsidiaries as the essential act of knowing. Moreover, the joint action of many neurons resulting in an action or thought is consistent with Polanyi's notion of a spontaneously achieved order.

Kandel's work on *Aplysia* reveals another connection to a basic Polanyian contention. Kandel studied the neural basis of habituation, which we have seen enables an animal to ignore unimportant data. It also accounts for the boredom that arises from repeated stimuli and the decrease in sexual activity with the same partner over time. He found that when he repeated an electrical stimulus to the same bundle of neurons leading to a marker cell, "the synaptic potential produced by the cell in response to the stimulus decreased progressively with repetition" (168). The change in responsiveness has to do with chemical changes produced across the synapse between cells, not with the charge within a cell. The experiments demonstrate one aspect of the plasticity of the brain—how "the flow of information in the various neural circuits of the brain could be modified by learning" (171). Habituation's function of ignoring harmless, well known signals in order to be alert to signals of greater interest shows it to be an example of that general alertness of animals that Polanyi calls "an urge to achieve intellectual control over the situations confronting it. Here at last, in the logical structure of such exploring—and of visual perception—we found prefigured that combination of the active shaping of knowledge with its acceptance as a token of reality, which we recognize as a distinctive feature of all personal knowing" (*PK* 132).

After studying *Aplysia* for years, Kandel determined that the neural architecture of each member of the species was exactly like the architecture of other individuals. That raised the question of how a behavior controlled by invariant circuitry could be changed by experience. Further experiments demonstrated that "learning leads to a change in the strength of synaptic connections—and therefore in the effectiveness of communication—between specific cells in the neural circuit that mediates behavior" (200). Kandel links his discovery to the conflict in philosophy between empiricism and Kantian rationalism. "The anatomy of the neural circuit is a simple example of Kantian *a priori* knowledge, while changes in the strength of particular connections in the neural circuit reflect the influence of experience. Moreover, consistent with Locke's notion that practice makes perfect, the persistence of such changes underlies memory" (203). Put somewhat differently, the study of the brain shows that empiricism and rationalism have complementary merit.

Further study revealed that the mechanisms of short- and long-term memory are different. Short-term memory strengthens or weakens preexisting connections, but it does so for minutes, not just for the flash of time that a stimulus is sometimes experienced. This is because there is a difference between mediating neural circuitry, which directly affects behavior by releasing a spurt of the neurotransmitter glutamate, and modulatory circuits using interneurons that release serotonin to sustain short-term memory for a period of time by regulating the strength of synaptic connections. Long-term memory is still different; it requires such anatomical changes as the growing of new or retracting of old terminals that release neurotransmitters. The anatomical changes occur through the synthesis of new proteins which act as ion channels, enzymes and receptors within neurons. These changes are initiated in the nucleus of a cell where genes reside and their regulatory activity is expressed or suppressed (241ff). At the level of genes, Polanyi's emphasis on the importance of integration is again demonstrated by this work Kandel carried out well after Polanyi's death. Kandel found

> Sherrington's discovery of the integrative action of the neuron carried to the level of the nucleus. I was amazed by the parallels: on the cellular level, excitatory and inhibitory synaptic signals converge on a nerve cell, while on the molecular level, one CREB regulatory protein facilitates gene expression and the other inhibits it. Together, the two CREB regulators integrate opposing actions. (264)

Thus it turns out that genes are not simply the masters of behavior, they are also the servants of the environment. In other words, our behavior is not simply determined by the genes we have, for many of our genes are designed to facilitate appropriate adaptation to the threats and opportunities offered by incoming receptor reports.

It can be seen that Kandel's work dramatically reveals the plasticity of the brain in its responsiveness to experience. A further element contributing to the dynamic character of the brain's amazing gelatinous machinery is that most proteins, the agents of transduction, decay within a matter of hours (272). Such dynamism reveals the fallacy of thinking of the brain as analogous to computer hardware, which is a maze of permanently fixed connections. Not only models of artificial intelligence, but many versions of supervenience are rendered otiose by the unsettled character of brain circuitry. Yet the protean nature of the circuitry has elements of stability. Memories persist, habits endure. How does Kandel's understanding of the brain account for such regularities?

One element of stability has already been noted: that in general the brain's neurons are connected one to another in the same way in each individual of a species (although the connections that are turned on or off will vary quite widely among the individuals). A young colleague of Kandel's, Kausik Si, discovered another agent of stability: a protein located at the synapse of all neurons that has the crucial characteristic of a prion, namely that it is self-perpetuating. Prions are best known for their destructive dominance over other cells as exhibited in mad cow disease and Creutzfeldt-Jakob disease. But in a benign form, a self-perpetuating prion "could explain how long-term memory is maintained in synapses indefinitely, despite constant protein degradation and turnover" (273). In Polanyian terms, by replicating themselves, prion-like proteins would maintain their ongoing identity as specific subsidiaries supporting a particular long-term memory.

In 1989, at age 60, Kandel turned his attention to explicit memory. It was known that the hippocampus is implicated in such memory, and a 1971 discovery about how rats understand and negotiate space set the stage for Kandel's further research program. John O'Keefe found

> that neurons in the hippocampus of the rat register information not about a single sensory

> modality—sight, sound, touch, or pain—but about the space surrounding the animal, a modality that depends on information from several senses. He went on to show that the hippocampus of rats contains a representation—a map—of external space and that the units of that map are the pyramidal cells of the hippocampus, which process information about place. (282)

Here at the level of molecular activity is confirmation of Polanyi's stress on the importance of latent learning (a spatial mapping of relationships) as a key attribute of inarticulate (tacit) intelligence and a prerequisite for problem-solving (see *PK* 73ff).

After his revolutionary work on *Aplysia*, which focused on cells and their connections, Kandel turned his attention to genetics as essential for understanding explicit memory. Mice, which can be bred to have differing personalities and which breed rapidly, became his primary research animal. Using a method of turning genes on and off, he could study short- and long-term spatial memory. Spatial memory is exceedingly important because it underlies many forms of explicit memory (for instance, memory of people and objects). From the perspective of neurobiology, spatiality is quite different than the necessary form of empirical intuition Kant postulated; it functions like an organizational directory relating not only empirical objects but ideas and events in memory. We have no specific organ dedicated to comprehending space. It is constructed through a complex series of integrations of different modalities.

It turns out that there is a significant difference between a spatial map generated through attention to surroundings (it has evenly distributed, allocentric coordinates, that is, ones that are centered on the world) and embodied sensory maps for touch and vision (they are egocentric, largely implicit, and especially observant of those parts of the body heavily endowed with nerves [fingers, the tongue, etc.]). The correlation is not exact, but this reminds one of the difference between Polanyi's self-centered integrations—poorly named because the focus is on the objects in the world, which makes them allocentric—and self-giving integrations which are of existential (egocentric) import (see *M* 71-75; Polanyian self-giving integrations have an important cognitive dimension lacking in Kandel's embodied sensory maps).

Kandel's investigations, especially on spatial maps, suggests that Polanyi's dichotomy between tacit and explicit knowledge leaves unarticulated some distinctions of epistemological importance. (1) Some tacit knowledge is autonomic: stimulus-response machinery built into our nervous system that need have no recourse to the mediation of the brain. The leg's action when one's knee is struck is an example of a reflexive response that is dubiously regarded as knowledge. However, the mind's innate ability to integrate inputs is a highly significant autonomic biological capacity that is not mediated by the brain but is built into its functioning as a brain. While we do not learn how to perform integration itself as a mental action, acts of integrating specific contents are necessary for learning to occur. Perhaps Polanyi would not call such instinctual processes examples of "tacit knowledge," as they are built into our biological machinery rather than learned, but they are tacit and they do contribute to higher level acts of knowing. (2) Some specific acts of tacit responsiveness are mediated by the brain but remain unconscious, taking place in the limbic system alone, for instance. Insofar as they are learned, they would seem to be examples of tacit knowing. Specific processes of sensitization, habituation, and classical conditioning are examples. (3) The three forms of tacit learning Polanyi identifies (trick, sign and latent learning) all require explicit attention when being learned, although when consolidated as skills, environmental understandings, etc. they may function in a purely implicit manner as a sort of second nature. "Learning to ride a bicycle initially involves conscious attention to one's body and the bicycle, but eventually riding becomes an automatic, unconscious motor activity" (132). That is, when thoroughly indwelt through practice, type (3) may function like type (2). Note that non-human animals have both implicit and explicit memories; for Kandel the difference is based on whether selective attention and arousal is directed toward focal objects (necessary for explicit memories on both a short- and a long-term basis). In *PK*, Polanyi can be interpreted as making the distinction between the tacit and the explicit a matter of the difference between whether (4) language functions in consciousness or not (the articulate versus the inarticulate). This is tricky, because in the process of formulation there is a tacit (skillful) component to language use, whereas as expressed in speech or writing, language is explicit. In any case, making the distinction between the tacit and the explicit rest on whether or not language shapes consciousness will not do, since animals lacking language can have explicit but inarticulate knowledge. The key issue is whether or not selective attention is directed to incoming information provided by receptors. For as Kandel notes, "explicit memory requires selective attention for encoding and recall" (311). Language can function as a means of selective attention, but it is not the only means of simplifying experience and providing selective focus.

To summarize the immediately preceding discussion, in tacit knowing in its most comprehensive sense there can be found: (1) innate capacities or skills that often are necessary for higher levels of knowing even to be possible; (2) specific unconscious acts, expressions of what Kandel calls implicit memory, that expand skills and often contribute to such conscious processes as explicit learning, perceiving, and discovering; (3) relatively complex acts of learning that typically involve explicit as well as implicit attention, acts humans share with highly developed animals and which Polanyi singles out as trick, sign, and latent learning; and (4) normal human consciousness in which explicit focus is made possible by language which in turn allows for there to be reflection and rational choice.

Selective attention is a kind of filter that focuses an animal's awareness on matters of importance to the animal and ignores (perhaps based on ignorance, perhaps based on habituation) most incoming information. Some attention is involuntary and triggered by instinctively important aspects of external reality: loud noises, sudden movements, bright colors. Voluntary attention is related to conscious intention and purpose. Voluntary attention understood at the level of the brain is a modulatory process in which the neurotransmitter dopamine typically functions as an agent. Kandel compares the involuntary attention he recognized in *Aplysia* with the voluntary attention seen in a mouse:

> In implicit memory storage, the attentional signal is recruited involuntarily (reflexively), from the bottom up: the sensory neurons of the tail, activated by a shock, act directly on the cells that release serotonin. In spatial memory, dopamine appears to be recruited voluntarily, from the top down: the cerebral cortex activates the cells that release dopamine, and dopamine modulates activity in the hippocampus. (314)

At a more sophisticated cultural level, Polanyi gets at the significance of attention in several ways, including through his emphasis on focal meaning and via his pointing out the important role of existential interest in shaping such cognitive achievements as symbols, metaphor, and works of art.

The significance of attention is utilized by Kandel in another important way: in defining consciousness "as a state of perceptual awareness, or selective attention writ large" (376). "Consciousness," he goes on to say, "thus refers to our ability not simply to experience pleasure and pain but to attend to and reflect upon those experiences, and to do so in the context of our immediate lives and our life history." In mentioning reflection, he seems to introduce the role of symbols as facilitators of human consciousness, but this particular comment seems to ignore the realm of animal awareness [(3) above] which is selective and thus richer than the experience of pleasure and pain yet not as rich as symbol-based human consciousness. He sees understanding consciousness in contrast to physical reality as the biggest challenge facing science and can offer little in the way of his own research to whittle away at the challenge. Consequently in his discussion he relies on the speculations of others, agreeing with Nagel and Searle that consciousness has two crucial characteristics that challenge our explanation: unity and subjectivity. The latter is the harder problem: we lack an adequate theory of how objective phenomena like electric signals in neurons can create subjective experience. Here perhaps Polanyi's from-to theory of consciousness, his notion of an active center, and his understanding of emergence can point the way to further progress in understanding consciousness.

Toward the end of *In Search of Memory,* Kandel shows how his original interest in psychoanalysis can be reconciled with his research in neuroscience. For neuroscience has increasingly been able to illuminate the functioning of emotion-driven behavior and mental disease, two concerns psychoanalysts have traditionally dealt with. One result of greater neurological understanding of emotions is that the seemingly paradoxical James-Lange theory has been partially vindicated. William James postulated that the cognitive experience of emotion is a secondary interpretation of prior physiological responses to dramatic environmental situations. The subsequent research of Antonio Damasio indicates that the experience of emotion indeed has two components: first, an unconscious, implicit evaluation of a stimulus that acts directly on behavior and thereby bypasses the brain, and second, the analysis by the cortex of the brain of the nature of the stimulus in relation to previous, similar stimuli and in relation to one's physiological response, all summed up in a slightly delayed conscious emotional assessment (340-344). Attending to the emotional response of fear, Kandel is able to demonstrate that there are neurobiological ways of associating fear-producing stimuli with positive feelings that culminate in learned positive feelings in place of fear. Neuroscience increasingly has therapeutic implications.

Eric Kandel, in reflecting upon his life and career, expresses a deep and abiding satisfaction. He rejoices in his participation in a communal effort that has "brought biology, once a descriptive science, to a level of rigor, mechanistic understanding, and scientific excitement comparable to that of physics and chemistry" (418). And those of us who have taken a deep interest in Michael Polanyi's thought can also feel satisfaction in the way that neuroscience, taken as a whole, confirms the Polanyian vision of epistemology and ontology worked out on quite different grounds. Or to put the point another way, it is a testament to the power of Polanyi's intuitive vision, attentive to the psychology of his time, that it correlates so well with the findings of contemporary neuroscience. To be sure, the explanations of neuroscience cover only one level of the multileveled universe in which we dwell. Still, the reassuring convergence between Polanyi's philosophy and Kandel's neurobiology ought to serve as a stimulus for further ventures that take seriously Polanyi 's relevance to issues of our day.